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Sanitation and Externalities

Evidence from Early Childhood Health in Rural India

Luis A. Andres
Bertha Briceño
Claire Chase
Juan A. Echenique

The World Bank
South Asia Region
Sustainable Development Unit
&
Sustainable Development Network
Water and Sanitation Program
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Abstract

This paper estimates two sources of benefits related to sanitation infrastructure access on early childhood health: a direct benefit a household receives when moving from open to fixed-point defecation or from unimproved sanitation to improved sanitation, and an external benefit (externality) produced by the neighborhood's access to sanitation infrastructure. The paper uses a sample of children under 48 months in rural areas of India from the Third Round of District Level Household Survey 2007–08 and finds evidence of positive and significant direct benefits and concave positive external effects for both improved sanitation and fixed-point defecation. There is a 47 percent reduction in diarrhea prevalence between children living in a household without access to improved sanitation in a village without coverage of improved sanitation and children living in a household with access to improved sanitation in a village with complete coverage. One-fourth of this benefit is due to the direct benefit leaving the rest to external gains. Finally, all the benefits from eliminating open defecation come from improved sanitation and not other sanitation solutions.

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Luis A. Andres, Bertha Briceño, Claire Chase and Juan A. Echenique

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*Andrés: Lead Economist, Sustainable Development Department for the South Asia Region of the World Bank; Briceño: Senior Monitoring and Evaluation Specialist, Water and Sanitation Program of the World Bank; Chase: Economist, Water and Sanitation Program of the World Bank; Echenique: Consultant, Sustainable Development Department for the South Asia Region of the World Bank. We are thankful to Olga Namen, Eddy Perez, Payal Jayant, and Dean Spears for the useful comments. The order of authors is alphabetical, not by senior authorship. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the view of the World Bank, its Executive Directors, or the countries they represent. The findings, interpretations, and any remaining errors in this paper are entirely those of the authors. For comments please email landres@worldbak.org

1 Introduction

This paper investigates the existence and size of benefits from access to sanitation on child health outcomes in rural India. We emphasize in particular two sources of benefit. The first is a direct benefit, which is privately enjoyed by a household whose members stop defecating in the open, and move to either fixed-point defecation or an improved sanitation facility.[1] The second benefit is an external benefit, also called externality, generated by a neighbor's access to sanitation that results in a lower probability of human contact with human excreta. In this paper we seek to answer two questions: (i) what is the private benefit of a household's access to sanitation infrastructure on early childhood health outcomes?; and (ii) what is the benefit produced through externalities of a neighbor's access to this sanitation infrastructure? These questions are motivated by the poor sanitation situation worldwide, where by the end of 2011, 2.5 billion people still lack access to improved sanitation (JMP, 2013). In India alone there are an estimated 62 percent of households without improved sanitation and 51 percent of households practice open defecation (Figure 4). This lack of access to adequate sanitation supposedly leads to diarrheal diseases in children and has been linked to child malnutrition and mortality. But the existence of evidence supporting the relationship between access to sanitation infrastructure and diarrhea prevalence is largely anecdotal, and a small proportion based on empirical evidence. Hence, there is a need to empirically quantify the benefits of sanitation infrastructure, as well as the sources of these benefits to develop more efficient policies and with higher impact.

We estimate a model for the individual production function of health for children in rural India assuming a linear-in-parameters approximation. The main inputs to the function are the household's access to sanitation and the ratio of access to sanitation (i.e. coverage) at the village level. This model is estimated using a sample of 206,414 children from households in rural villages of India from the District Level Household Survey 2007-08 (DLHS-3). One of the novel features of this model is that we have a measure for the estimation of sanitation externalities impact through use of a robust proxy for village access to sanitation facility. Using this approach we can separate the direct from the externality benefits of sanitation, and analyze how households benefit from different levels of sanitation coverage.

This paper contributes to the literature of the health impact of sanitation access in two

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[1] In this paper we refer to 'fixed-point defecation' as defecation into a pit or other containment structure, regardless of the quality of the structure or whether it is hygienically maintained (i.e. includes access to both improved and unimproved facilities). The Joint Monitoring Program defines 'improved sanitation' as, "access to a sanitation facility that hygienically separates human excreta from human contact". Open defecation is defined as, "not having access to any type of toilet" and implies 'going in the field'.

ways. First, it adds to the existing evidence on the positive relationship between better sanitation infrastructure and early childhood health outcomes (Kumar and Vollmer (2012), Bose (2009), and Gunther and Fink (2010)). The second, and most important, is clear evidence of the existence of positive externalities from access to sanitation infrastructure which previous research did not prove convincingly.

Our principal empirical findings are:

1. In a sample where the average prevalence of diarrhea among children under 48 months is 12.1 percent, we find a reduction of 10 percent (or 1.26 percentage points in probability) of diarrhea explained by gaining access to improved sanitation. We also estimate a reduction in probability of diarrhea on the last two weeks of 5 percent (or 0.63 percentage points) when moving from open defecation to fixed-point defecation.

2. We find evidence that supports a concave relationship between sanitation coverage at village level and diarrhea prevalence, whereby the positive externalities are only enjoyed after a certain level of sanitation coverage has been achieved. The potential benefits are greater at higher levels of coverage due to the reduction in the probability of contact with human excreta. The estimates indicate that there is no improvement at all until the 30 percent coverage is achieved and that half of the potential total gains are only reached when coverage is approximately 75 percent.

3. In terms of the magnitude of the effect from both sources of benefit, direct and external ones, we estimate that a child who moves from a household without improved sanitation and a low ratio of village access to a household with improved sanitation and a high ratio of village access enjoys a reduction in diarrhea prevalence of 47 percent (from 12.54 percent to 6.79 percent). For the case of fixed-point defecation the overall effect is a reduction of 26 percent (from 12.49 percent to 9.25 percent).

4. We find the external benefit is largely responsible for the health improvements when we separate the contribution of the direct and external benefit in overall reductions of diarrhea prevalence. While for improved sanitation the direct benefits account for 23 percent, fixed-point defecation the direct benefits accounts for just 19 percent of the overall gains.

5. We find no significant difference (but negative effect) in terms of health outcomes between children living in households whose members practice open defecation and those who are living in households with unimproved sanitation, which includes unimproved sanitation facilities and those who are sharing either improved or unimproved facilities with other households. The gains are only for children who live in households with access to improved sanitation as is defined by the World Health Organization/United Nations Children's Fund (WHO/UNICEF) Joint Monitoring Programme for Water Supply and Sanitation (JMP).

These results hold under several econometric specifications. We use non-experimental methods like propensity score matching and a series of falsification tests to check the robustness of our results.

The remaining sections of this paper are organized as follows: Section 2 presents the motivation for trying to understand the source of benefits of sanitation. Section 3 reviews the literature on household sanitation and its relation to children's health and welfare. Section 4 describes a theoretical model to understand the direct and external benefit of sanitation, while the empirical implementation is discussed in Section 5. Section 6 describes the data used for this paper. We then present the empirical results in Section 7, which are checked in Section 8 through a series of robustness checks. Finally, Section 9 concludes with a discussion of the implications of these results for sanitation policy.

2 Motivation

One of the principal motivations underlying this paper is the almost evident fact that the Millennium Development Goals (MDGs) for sanitation will not be met in 2015. Globally, there are still 2.5 billion people without access to sanitation and India alone is home to over 30 percent of this population. There is little debate that safe sanitation improves health. However, despite a theoretical model that demonstrates that at least a portion of these health improvements stems from community benefits to improved sanitation, household sanitation is still often perceived as only a private good. The consequence of this is that many governments have adopted policies that shift the burden of investment to households. The resulting underinvestment by households suggests they either have credit or other financial constraints that prevent investment in improved sanitation or they underestimate the private benefit to sanitation.[2]

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[2] We do not dismiss that it could be problems from the supply side where the lack of an adequate supply side that does not meet the needs of consumers.

The second motivation for studying the benefits of household sanitation has to do with the ubiquity of policies aimed to generate open defecation free (ODF) communities. These policies are based on the plausible assumption that so as long as some human excreta remains in the open, communities will continue to be at risk of fecal-borne diseases, such as diarrhea. This assumption recognizes that open defecation poses a negative externality on others. One of the most emblematic programs calling for ODF communities is the Total Sanitation Campaign (TSC) in India (see Appendix A for details), the site of this study.

'Elimination of open defecation' is now a post-2015 Millennium Development Goal (MDG), even when there is little evidence which shows that a community that has achieved 100 percent ODF is better off from a health perspective. Surprisingly, there is still no quantitative evidence that the only way to enjoy full health benefits from improved sanitation is having full coverage at the community level. Therefore, quantification of the relationship between access to sanitation both at the household and community levels, and the role of externalities as a channel for benefits can inform a debate around whether public investment or subsidies are justified for what is normally perceived as a private good. If externalities are an important channel through which households benefit, then private markets alone will fail to produce the optimal social equilibrium that maximizes the return of sanitation investements in the society.

3 Literature Review

It is estimated that the risk of fecal-oral diseases resulting from poor water, sanitation and hygiene (WSH) contributes to 5.7 percent of the global disease burden (Prüss et al. (2002)). Diarrhea is the most common fecal-oral disease associated with poor WSH, accounting for nearly 0.8 million child (under five years) deaths each year worldwide (Liu et al. (2012)), and 11 percent of all deaths of children under 5 in 2010 (UNICEF et al. (2012)). Open defecation, practiced by an estimated 626 million people in India (JMP (2012)), is pointed as a major contributing factor to diarrheal disease. Evidence therefore suggests that stopping open defecation and safely containing feces with improved household sanitation can effectively break down the fecal-oral transmission of disease, thereby improving health. Many studies have attempted to quantify the effect of this transition from widespread open defecation to improved sanitation on health outcomes. However, to date, few rigorous studies have been conducted and most have taken place alongside complementary water and hygiene interventions, making separating the effect of safe feces containment difficult[3] (Andres et al. (2013)). A widely cited meta-analysis estimates the impact of sanitation on diarrheal disease to be 32 percent (Fewtrell et al. (2005)), but this estimate is based on just two studies. More recently, communities who were randomly assigned to receive a community led total sanitation and sanitation marketing (TSSM) intervention reported reductions in 2-day prevalence of diarrhea in children under 5 of 45 percent (Cameron and Shah (2013)). It is critically recognized that the consequences of poor sanitation extend beyond the burden of diarrhea. Exposure to fecal contamination in the environment and chronic diarrhea decreases the ability to absorb essential nutrients, leading to malnutrition (Checkley et al. (2008)).[4] Poor sanitation is increasingly recognized as a distal cause of underweight and stunting in children (Humphrey et al. (2009)). Malnourishment during childhood is associated with severe long-term consequences. These long-term consequences include poor cognitive development, lower school attendance, reduced human capital attainment, and potentially a higher risk of chronic disease in adulthood (Victora et al. (2008)).

There is strong evidence that the individual benefit to having improved sanitation is potentially very large, but to what extreme is this benefit actually driven through a community benefit, or externality to private sanitation, is less well understood. It has been suggested that even a few remaining open defecators in a community risk bringing fecal matter back into the environment resulting in continued contamination of soil and water, and potentially infecting others in the community who practice safe sanitation. In other words, even if my household has chosen to practice safe sanitation, if others in my community continue to defecate in the open, what are the consequences for the welfare of my household?

Observational and quasi-experimental studies have looked at the impact of improved sanitation on child health outcomes including diarrhea, infant mortality, and stunting. However, most of these studies have focused on the effects at the household level and have not considered the importance, or additional effects, that may be present when an entire community has access to sanitation. The most relevant for the current study is a recent paper that used propensity score matching to estimate the effect of access to improved sanitation on diarrhea in children under five using the District Level Household Survey (DLHS-3) (Ku-

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[3] Indeed, some have suggested there is too little evidence on the complementary effects of WSH interventions and that too much attention has been focused on understanding the epidemiology of single transmission pathways (see Eisenberg (2007 and 2012)).

[4] This effect also goes the other way, with poor nutritional status associated with increased risk of diarrhea (see for example Chen et al. (1981)).

mar & Vollmer, 2011). The authors find access to improved sanitation reduces diarrhea by 2.2 percentage points (pp) corresponding to a 17 percent drop in prevalence. Another study (Bose, 2009) using similar methods from Nepal looks at access to sanitation using a 2006 Demographic and Health Survey (DHS) finding reductions of 5 percent from mean prevalence of 8 percent, a substantially larger relative reduction. A third study, Spears (2013), estimates the effect of open defecation in anthropometric measures between and within countries, where it finds positive benefits from externalities and direct effects of eliminating open defecation. Finally, Gunther and Fink (2010) analyze data from 172 DHS surveys and find that households having flush toilets have 13 percent lower odds of diarrhea than households without - in line with the estimates from Kumar and Vollmer (2012) but much less than estimates from meta-analyses. Moreover the study finds the benefits at the cluster level[5] are twice as large as those at the household level, suggesting there may be positive externalities to improved sanitation.

4 Model

In this paper we seek to answer two questions: (i) what is the private benefit of a household's access to sanitation infrastructure on early childhood health outcomes?; and (ii) what is the benefit produced through an external effect, or externalities, of a neighbor's access to this sanitation infrastructure? In this paper we define external effect or externality as the change in final utility, in this case health status, originated from the access to sanitation infrastructure by others in the surroundings.[6] We define this surrounding as a village, which we assume ensures a minimum level of isolation from other surroundings. In order to answer these important questions, especially the role of externalities of sanitation access, we propose a theoretical model presented in Equation (1) where a health outcome D_{ijk} of a child i of the household j that is in the village k is a function of household sanitation access S_{jk}, an externality R_k produced by his neighbor's sanitation access, and a vector X_{ijk} of child and household characteristics.

$$D_{ijk} = V(S_{jk}, R_k, X_{ijk}) \tag{1}$$

We define the externality R_k as the ratio of households in the village with access to sanitation $S_{jk} \in (0, 1)$. The rationale behind this definition is that lack of full sanitation coverage could cause inter-household contamination (as described in Section 3). So it is natural to

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[5] A cluster in the DHS is typically a village for rural areas and district for urban areas.

[6] This follows the classical defitinition of externality in economics as a change in the utility level produced by other actions.

think that if this is the case, then sanitation externalities depend on both the individual's S_{jk} and his neighbor's access $S_{j'k}$, or $R_k(S_{jk}, S_{j'k})$. In order to separate the direct benefit from the external benefit, we assume that a household's access has no effect on the village ratio, $\frac{\partial R_k}{\partial S_{jk}} \approx 0$[7] , resulting in $R_k(S_{j'k})$.

$$\text{Positive Direct Benefits:} \qquad \frac{\partial D_{ijk}}{\partial S_{jk}} < 0 \tag{2}$$

$$\text{Positive Concave Externality Benefits:} \qquad \frac{\partial D_{ijk}}{\partial R_k} < 0 \quad , \quad \frac{\partial^2 D_{ijk}}{\partial R_k^2} < 0 \tag{3}$$

With this in mind we can rewrite our hypothesis from Equation (1). In Equation (2) we assume that a child's health improves when he gains access to sanitation (the direct benefit). Furthermore, in Equation (3) we assume that as the proportion of neighbors with access to sanitation increases there are improvements to a child's health (externality). And the size of the phenomenon grows at higher rates of access that could be described as a 'positive concave externality effect'.

5 Empirical Implementation

We test the hypothesis presented in Equations (2) and (3) for different types (in terms of quality) of access to sanitation infrastructure, namely access to improved sanitation facilities, access to fixed-point defecation, and open defecation, based on the theory that as quality of sanitation improves so does health. These levels are defined from the 'Sanitation Ladder' (Figure 1). The rungs on the ladder represent an improvement in sanitation infrastructure, which correlates with gains in health outcomes. We define access to sanitation according to the definitions used by the JMP[8], which tracks country progress towards achieving the MDGs related to water and sanitation. The JMP uses two key characteristics to classify access to sanitation: (a) degree to which infrastructure safely isolates excreta

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[7] If one thinks of the share that one household has over the ratio of access of a village, an irrelevant share for the analysis would be 5 percent. For this we need a minimum of 20 households in a village. In the data that we are using 90 percent of the households surveyed are in villages with at least 20 households.

[8] World Health Organization/United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation website http://www.wssinfo.org

from the environment, and (b) ownership of the structure. Table 1 shows how each type of sanitation is classified following JMP's criteria.

In terms of isolation of excreta from the environment there are three levels. The lowest level is open defecation in the bush, fields, or surface water. The second includes unimproved facilities, such as a pit latrine without a slab, a hanging toilet or latrine over a pond or other surface water, or a flush toilet that does not properly dispose of waste. These types of sanitation do not hygienically separate human excreta from the environment. Finally, improved facilities, including septic or piped sewage, pit latrines with slab, and composting toilets, hygienically separate human excreta from the environment. In terms of ownership, the JMP classifies any shared latrine as unimproved sanitation due to the constraints placed on households having to share facilities. From the improved facilities definition, and using the ownership structure, we can define four groups that do not practice open defecation: (a) shared unimproved facilities, (b) private unimproved facilities,(c) improved shared facilities, and (d) improved sanitation.

We define a child's access to sanitation S^v_{jk} as a dichotomous variable in Equation (4), which takes value 1 if the child's household j from village k has access to sanitation, and zero if otherwise. We define this for two types of access to sanitation $v = \{1$ (Fixed-Point Defecation), 2 (Improved Sanitation) $\}$ according to the JMP's classification.

$$S^v_{jk} = \begin{cases} 1 & \text{if household } j \text{ of village } k \text{ has access to sanitation } v \\ 0 & \text{if household } j \text{ of village } k \text{ does not have access to sanitation } v \end{cases} \tag{4}$$

Using our child's household access to sanitation variable S^v_{jk} we define R^v_k in Equation (5) as the proportion of households in the village j that have access to the sanitation infrastructure v. So, variable R^v_k measures the externality through the level of decontamination at the village level. The distribution of the ratio in our sample is presented in Figure 2.

$$R^v_k = \frac{\sum_j S^v_{jk}}{\sum_j 1} \tag{5}$$

In order to test the hypotheses presented in Equations (2) and (3) we use a parametric model assuming a linear-in-parameters approximation of Equation (1). We impose a quadratic linear relation between our measure of externality and our outcome of interest based on an exploratory data analysis using a local polynomial regression estimator (Nadaraya (1964) and Watson (1964)) between ratio of access to sanitation and our health outcome measure, diarrhea prevalence.

Then, we evidence a nonlinear relationship between the two variables (Figures 3(a) and 3(b)). After which, we estimate the parametric model presented in Equation (6) with a probit model.

$$\begin{aligned} D_{ijk} = \quad & \alpha + \theta S_{ij}^{v} + \delta^{00}(R_k^v) + \delta^{01}(R_k^v)^2 + \delta^{10}(R_k^v) * S_{ij}^{v} \\ & + \delta^{11}(R_k^v)^2 * S_{ij}^{v} + \beta X_{ijk} + \epsilon_{ijk} \quad \text{for} \quad v = 1, 2 \end{aligned} \tag{6}$$

We assume different benefits from externalities to children that live in households with and without access to sanitation infrastructure. We include X_{ijk}, a vector of controls including years of schooling, sex and caste of household head, age in months of the child, and sex of the child. Because we use a variable that is measured on a higher level than the dependent variable, we will estimate our model using clustered errors[9] at the village level to obtain robust errors that do not affect our inference.

Using this model to test the hypothesis presented in Equations (2) and (3), our relevant parameters will be: the marginal effects on the probability of diarrhea of access to fixed-point defecation (S_{ik}^1) and of access to improved sanitation (S_{ik}^2). The first order derivative of the ratio of access over the probability of diarrhea gives us the change in diarrhea benefit from externalities, and the second order derivative of the ratio of access over the probability of diarrhea gives us the rate of change of the benefit from externalities. The expressions for each one these parameters are:

- Change in diarrhea from direct benefit:

$$\frac{\partial Pr_{ijk}(D_{ijk} = 1)}{\partial S_{jk}^{v}} = \phi(x\beta) * \theta \tag{7}$$

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[9] For further discussion see Moulton (1990) and Bertrand et al. (2004).

- Change in diarrhea from external effect for children with access:

$$\left.\frac{\partial Pr_{ijk}(D_{ijk}=1)}{\partial R_k^v}\right|_{S_{jk}^v=1} = \phi(x\beta) * [\delta^{00} + \delta^{01} + 2R_k(\delta^{11} + \delta^{10})] \tag{8}$$

- Rate of change from external effect for children with access:

$$\left.\frac{\partial^2 Pr_{ijk}(D_{ijk}=1)}{\partial R_k^{v2}}\right|_{S_{jk}^v=1} = \phi(x\beta) * -(x\beta) * [2(\delta^{11} + \delta^{10})] \tag{9}$$

- Change in diarrhea from external effect for children without access:

$$\left.\frac{\partial Pr_{ijk}(D_{ijk}=1)}{\partial R_k^v}\right|_{S_{jk}^v=0} = \phi(x\beta) * [\delta^{00} + 2R_k\delta^{10}] \tag{10}$$

- Rate of change from external effect the children without access:

$$\left.\frac{\partial^2 Pr_{ijk}(D_{ijk}=1)}{\partial R_k^{v2}}\right|_{S_{jk}^v=0} = \phi(x\beta) * -(x\beta) * [2\delta^{10}] \tag{11}$$

These parameters allow us to simulate the predicted probability of diarrhea for the different combinations of ratio of access and household access to sanitation technology.

6 Data

We use a subsample of 209,762 children between 0 to 48 months of age that live in rural areas from the Third Round of the District Level Household Survey (DLHS-3). The DLHS is a nationwide survey with district level representation of India's households, which collects information on family planning, maternal and child health, reproductive health of ever married women and adolescent girls, and utilization of maternal and child healthcare services.

As described previously, an important feature of this paper is the explicit identification of the external benefit of sanitation, or externality, as measured through the ratio of access to sanitation at the village level. In this paper, we use the ratio of access to sanitation at the primary sampling unit (PSU) level as a proxy for the ratio at the village level. The sample design of the DLHS-3 survey makes this measure possible since in rural areas the DLHS-3 uses census villages as PSU (International Institute for Population Sciences (2010)). This gives us a plausible measure of access to sanitation infrastructure at the village level. However, because PSU's for urban areas are not clearly isolated (so neighbors are not clearly defined), we restrict the sample to rural areas only. In our sample, the ratio of access to sanitation ranges from 0 to 100 percent. Our main health outcome measure is a binary variable (Equation (12)) that takes value 1 if a mother reports that her child, "*has had diarrhea in the last two weeks*," and 0 if otherwise.

$$D_{ijk} = \begin{cases} 1 & \text{if has had diarrhea in the last two weeks} \\ 0 & \text{if has not had diarrhea in the last two weeks} \end{cases} \tag{12}$$

When we analyze the differences between those who have access to improved sanitation and fixed-point defecation, the differences in diarrhea prevalence emerge. While the limitations of caregiver-reported diarrhea have been noted in the literature (Das et al., 2012), we chose this outcome in order to make the findings more comparable to previous studies on the health benefits of sanitation.

Figure 4 shows the distribution of type of sanitation for this sample. We find that 18 percent of children under 48 months live in households with improved sanitation, 9 percent have unimproved facilities which include shared improved facilities, and 72 percent live in households which lack access to any type of sanitation facility and thus defecate in the open. These ratios are reasonably comparable with the estimations of JMP for rural areas in India. Table 2 presents the summary statistics of these variables for the 209,762 observations in our sample, cross-tabulated by type of access to sanitation. In our sample we observe that the average prevalence of diarrhea is 12.1 percent.

7 Empirical Estimates

In this section, we discuss our empirical findings: First for direct benefits on childhood prevalence of diarrhea resulting from access to sanitation, and second the benefits resulting from externalities.

7.1 Direct Benefits

Table 5 presents the marginal effect on diarrhea prevalence of moving from open defecation to fixed-point defecation (S^1_{ijk}), and of moving from unimproved sanitation (which includes open defecation) to improved sanitation (S^2_{ijk}), estimated from the model 4 in Table 3 and 4 which correspond to Equation (7). Similar to other studies, we find a direct benefit to children living in households that stopped defecating in the open: both households that moved to fixed-point defecation or to improved sanitation.

The magnitude of the effect is a 0.62 percentage points (pp) reduction in diarrhea prevalence for a child in a household that goes from open defecation to fixed-point defecation (unimproved or improved facilities). For the same children, a move directly from unimproved sanitation or open defecation to a sanitation facility classified as improved sanitation provides a greater benefit of 1.26 percentage points reduction in diarrhea prevalence. Given that diarrhea prevalence in the sample is 12.1 percent, this implies relative reductions of between 5.1 percent and 10.4 percent for fixed-point defecation and improved sanitation, respectively. We should analyze these results carefully because access to fixed-point defecation and access to improved sanitation are not mutually exclusive: improved sanitation is a subset of fixed-point defecation.

Does the benefit from fixed-point defecation stem from the isolation of excreta itself (type of sanitation infrastructure), the ownership (sanitation facility is shared with other households or used only by household members) or a combination of these (improved sanitation)? To test the contribution of these factors for the direct benefits on diarrhea, we run our parametric model for the marginal effect on diarrhea prevalence of each ownership and infrastructure type against open defecation. We use S^*_{jk}, defined in Equation (13), and control for household coverage of each type. The results are shown in Figure 5.

$$S_{jk}^{*} = \begin{cases} 0 & \text{if household } j \text{ of village } k \text{ does not have access to any facility} \\ 1 & \text{if household } j \text{ of village } k \text{ has access to shared unimproved sanitation} \\ 2 & \text{if household } j \text{ of village } k \text{ has access to private unimproved sanitation} \\ 3 & \text{if household } j \text{ of village } k \text{ has access to shared improved sanitation} \\ 4 & \text{if household } j \text{ of village } k \text{ has access to improved sanitation} \end{cases} \tag{13}$$

The graph illustrates that there is no significant benefit (or detriment) in terms of reduction of diarrhea for any unimproved sanitation, as classified by the JMP. In other words, in a context where externalities are included as a source of benefit, the categories of unimproved/private, unimproved/shared, and improved/shared are no better than open defecation. The DLHS-3 data do not provide details on the number of households that share the latrines reported, whether the shared latrine belongs to the household or another household. These details could help us understand the intensive margin of the effect. This evidence is relevant for the Total Sanitation Campaign, where the goal is eliminating open defecation, where it is evident that which fixed-point defecation solution is offered matters. If the way to achieve the goal is building a fixed-open defecation infrastructure different from improved sanitation, this investment would have a negative rate of return because it is not producing any visible impact.

7.2 Externalities

Taking into consideration the effect of externalities estimated through Equation (7), we find there is a positive and significant relationship between the level of access to sanitation in a village and the prevalence of diarrhea (Table 5). Moreover, we corroborate our hypothesis that this relation follows a concave function, where at low levels of village access there are limited positive externalities, but as access to sanitation increases, these externalities begin to accrue at a faster rate. Again, the findings are similar for fixed-point defecation and for improved sanitation. An interesting finding is the difference between the children that already have access and the ones who do not. We observe that the change in diarrhea prevalence caused by the external effect is larger for children living in households without access. But the rate of change of this effect is larger on children living in households with access.

In Figures 6(a) and 6(b) we illustrate the predicted probability of diarrhea in the past two weeks from Equations (7), (8), (9), (10), and (11) conditional on a household's provate access to sanitation and the ratio of access to sanitation at the village level, for both fixed-point defecation and improved sanitation, respectively. In both cases, we confirm our hypothesis that there is a negative relationship between the ratio of access and diarrhea, and more importantly, that the benefit from externalities to sanitation follows a concave function. The rationale behind these results is that a sufficient number of households must have access to improved sanitation in order to decontaminate the village to a level where everyone benefits. This convergence in probability shows that children living in households without access to sanitation enjoy nearly the same benefit from lower levels of open defecation as those who have sanitation facilities.

This finding bolsters the policy argument for high coverage as a goal. The benefits that a child would receive when he goes from a state of no sanitation coverage ($S^2_{jk} = 0$) in a village where no one has access to improved sanitation ($R^2_k = 0$) to a state of access to improved sanitation ($S^2_{jk} = 1$) and full coverage at the village level ($R^2_k = 100$) is estimated from our simulations to yield a decrease in the prevalence of diarrhea of 5.7 percentage points, which is a 47.5 percent reduction in the prevalence of diarrhea. This final result shows that 23 percent of the combined health benefits of improved sanitation are explained by the direct benefit (i.e. vertical distance between the two curves in Figure 6(b)) and 77 percent are explained by the indirect or externality benefit (i.e. horizontal distance between 0 percent and 100 percent ratio of access in Figure 6(b)). The estimates indicate that there is no improvement at all until 30 percent of improved sanitation coverage is achieved and that half the potential total gains are only reached when coverage is 75 percent.

Taking into consideration the fact that our estimates show a smaller direct impact of sanitation on child health than found in previous research, we conclude that direct benefits have previously been overestimated because they include a portion of the external benefit. In addition, by not accounting for externalities, previous research may have underestimated the overall benefit.

8 Robustness Checks

In our analysis we control for a set of household and child characteristics that are correlated with our main outcome of diarrhea prevalence and the household's probability of having access to sanitation. However, we are unable to control for characteristics that are unobservable, like risk aversion, that vary systematically between households, leading some households to invest in sanitation at higher rates while simultaneously taking precautions to lower diarrhea risk in children. These unobserved characteristics could bias our results.

To test the robustness of the results presented in Section 7, we run four separate checks: (i) difference in health outcomes between children in households at either extreme of the distribution of ratio of access, (ii) difference between households with and without access to sanitation at similar levels of village ratio of access, (iii) estimate our model using a placebo treatment and outcome as falsification test, and finally (iv) a counterfactual model.

8.1 Testing Effects at the Extremes of Ratio of Access

The first exercise to check the robustness of our results is based on the capacity that we have to compare children that live in villages in which almost everyone declares that they defecate in the open with children living in villages that are almost or completely ODF. If the children are not comparable the difference in diarrhea that we observe would be biased and not explained completely by the access to sanitation. Assuming the existence of a non-random selection between groups, we estimate the treatment parameters (average treatment effect (ATE), average treatment on the treated (ATT), and average treatment on the untreated (ATU) using a nearest neighbors matching estimator (Leuven and Sianesi (2012)) between children that live in villages with a ratio of access lower than 10 percent and children that live in villages with a ratio of access higher than 90 percent, defined in Equation (14).

$$R_k^v = \begin{cases} 0 & \text{if } R_k^v < 10\% \\ 1 & \text{if } R_k^v > 90\% \end{cases} \tag{14}$$

The covariates used for the matching estimator are the same that we use as control variables in our parametric model (X_{ijk}) and 15 matches for each observation of the treatment group. From Figure 7 we show that the differences in diarrhea prevalence between children on the extremes of ratio of access distribution are negative (positive effects), with an ATE of -2.65 pp for fixed-point defecation and -6.32 pp for improved sanitation. This is consistent with the differences presented in our parametric model for moving from a state of open defecation ($R_k^v \approx 0$) in a village where everyone practices open defecation ($R_k^v \approx 100$) to a state of fixed-point defecation/improved sanitation in an open defecation free village.

A second result from these figures is the difference between the effect for the ones that are in the top part of the distribution of access (ATT) and the effect for the ones at the bottom of the distribution (ATU). In a context of complete randomness of the treatment we could expect that the treatment parameters would be the same. But in Figure 7 we observe that the benefits from externalities are being obtained from those who benefit the most. Nevertheless, the benefit from moving a child that lives in a village with very low access is not small.

8.2 Testing Effects Within Ratio of Access

At each ratio of access in which a household resides we only observe health outcomes for households with and without access to sanitation and cannot observe the counterfactual of the direct benefit for this same household residing in a village with a different ratio. To address this problem we implement a nearest neighborhood matching estimator for households at each village ratio of access (Equation (16)). Where $R_k^{v*} \in r^* = [10, 80]$ as ±5 on each tens of ratio of access.

$$\left.\frac{\partial D_i jk}{\partial S_{ij}^v}\right|_{R_k^{v*}=(r^*,r^*+10)} = E[D_{ijk}|S_{ij}^v = 1, R_k^{v*} = (r^*, r^*+10)] - E[D_{ijk}|S_{ij}^v = 0, R_k^{v*} = (r^*, r^*+10)] \tag{15}$$

The graph in Figure 8 demonstrates that holding the ratio of access constant the within-direct benefit of moving from no sanitation to improved sanitation (or fixed-point sanitation) is similar to the direct benefit that is predicted in Figures 6(a) and 6(b). Finding that the direct benefit of improved sanitation reduces when we move to a complete coverage and for fixed-point sanitation we evidence a greater direct benefit around the ratio of access of 30 percent and 40 percent.

8.3 Falsification Tests

The third potential problem we encounter is that our measure of the external benefit of improved sanitation could be explained by a factor correlated with both access to sanitation and assets for a healthier environment and healthier parenting behavior, but is unobservable in this data set. If this is the case, the difference in diarrhea prevalence estimated in our parametric model would be partially or fully explained by differences in household income. To test the hypothesis that income is driving our result we estimate a locally weighted polynomial regression over an outcome that would be similarly affected by household income but which is not correlated with access to sanitation. A natural candidate is a non-hydric disease, which should be correlated with the level of income but not with the access to sanitation. The measure used was the prevalence of cough reported by the mother. Using a local polynomial regression we estimate the curves in Figures 9(a) and 9(b). We observe that there is no relationship between ratio of access to fixed-point defecation or improved sanitation, and the prevalence of cough.

A second way to test if there is an income factor explaining the ratio of access to sanitation is using the rate of access to another infrastructure. We used the ratio of access to electricity, which is measured as the proportion of households who claim to own electricity. If we look at Figure 10 we can see that there is a flat relation when we estimate a local polynomial regression between the prevalence of diarrhea and the ratio of electricity.

8.4 Counterfactual Model

Finally, we carry out a non-parametric matching of ratios of access to sanitation. We use as a baseline benchmark $D_{ijk}(S_{ij}^{v} = 0, R_{k}^{v} = 0)$ for each node of distribution of $D_{ijk}(S_{ij}^{v} = s, R_{k}^{*v} = r)$ where $s \in [0, 1]$ and $r \in [0.1, 0.9]$. For each node, we estimate an average treatment effect (ATE) estimator of Equation (16) through matching estimators.

$$\frac{\partial D_{i}jk}{\partial(S_{ij}^{v}, R_{k}^{v})} = E[D_{ijk}(S_{ij}^{v} = s, R_{k}^{v} = (r, r+10))] - E[D_{ijk}(S_{ij}^{v} = 0, R_{k}^{v} = 0)] \tag{16}$$

We estimate each of these nodes $(S_{ij}^{v} = s, R_{k}^{v} = (r, r+10))$ using a nearest neighborhood matching estimator with 2 matches (used as control group) for observation in the treatment group. The results of these estimations are presented in Figures 11(a) and 11(b) for fixed-point defecation and improved sanitation respectively. The graph demonstrates results similar to those estimated with our parametric model (Figures 6(a) and 6(b)) with an average direct benefit of 1 pp for access to fixed-point defecation and 1.5 pp for access to improved sanitation. When we look at the combined effect of going from a household without sanitation in a village without coverage to a household with fixed-point defecation in a village with complete coverage we find a benefit equivalent to a reduction in diarrhea prevalence of 3 pp. This is analogous to the difference in Figure 6(a) where the predicted probability of diarrhea for $E[D_{ijk}(S_{ij}^{0} = 0, R_{k} = 0)]$ is 12.5 percent and $E[D_{ijk}(S_{ij}^{1} = 1, R_{k} = (80, 90))]$ is 1.0 pp, a reduction of 2.5 pp.

Similarly, the results for improved sanitation show a direct benefit that ranges from $[0.5, 2]$, which on average is consistent with the 1.4 percentage points reduction in diarrhea prevalence that we find in our parametric model. When we look at the difference between

$E[D_{ijk}(S_{ij}^1 = 0, R_k = 0)] = 12.5$ and $E[D_{ijk}(S_{ij}^1 = 1, R_k = (80, 90))] = 5.1$ is consistent with the parameter estimated with our counterfactual model for the node $(80, 1)$ which is a reduction in diarrhea prevalence of 5.1 pp.

9 Conclusions

This paper investigates the sources of health benefits to improved sanitation infrastructure access and elimination of open defecation. We hypothesize that there are two sources of benefit, a direct benefit on intra-household child health when moving from open defecation to accessing sanitation, and an externality benefit driven by the ratio of access to sanitation at the village level. We estimate our parametric model of the treatment effect of access to sanitation on child health outcomes to test for both the marginal effect on the probability of diarrhea of sanitation access (direct benefit), as well as the change and the rate of change in diarrhea resulting from externalities to sanitation access. Consistent with other studies on this topic, we find evidence of positive direct benefits for both access to fixed-point defecation and improved sanitation. On average, moving of a child from a household practicing open defecation or using an unimproved sanitation facility to a household with improved sanitation results in a direct benefit of of 10 percent (1.26 percentage points) reduction in diarrhea prevalence. However, we find that the external benefit from community coverage is more than three times the individual benefit, an additional 37 percent (4.5 percentage points) reduction in diarrhea prevalence. These results hold under several specifications and robustness tests.

The magnitude of direct benefits is smaller than shown in previous studies, but this is consistent with our hypothesis that positive externalities to improved sanitation access drive much of the benefit of sanitation. More importantly, we find that the benefits from externalities follow a concave function in that benefits begin to accrue as higher level of community coverage is met, and these benefits accrue at a faster rate as coverage increases. This suggests that the goal of open defecation free communities as proposed by the post-2015 MDG working group on sanitation goals is socially optimal. For the full benefit of sanitation infrastructure to be realized efforts should focus on achieving community wide coverage of improved sanitation and elimination of open defecation.

These results make two important contributions to the economics literature on health outcomes in early childhood as an indicator of long-term human capital attainment, and the public policies that address inequalities in these outcomes. The first is that the results of this study position household sanitation as a public good with public benefits, rather than a private good with only private benefits. The existence of externalities to sanitation suggests that households will underinvest in sanitation and that private markets alone fail to produce optimal outcomes. The second contribution is to demonstrate a potential role for public sector intervention, either by easing budget constraints or increasing access to information about the benefits of sanitation. Indeed, 77 percent of our sample of rural households lacks access to improved sanitation, suggesting that the potential health benefits from increasing access to sanitation are huge.

We can see from our sample that a great proportion of the rural population lives in villages with low sanitation coverage. But our results show that most of the benefits from sanitation, especially their externalities, appear at upper levels of coverage, giving us a feeling that the best is yet to come.

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Appendix A - The Total Sanitation Campaign

The Total Sanitation Campaign (TSC) was launched in 1999 with the goal to completely eliminate open defecation worldwide by the year 2012.[1] The TSC aims to do this through a combination of community-led approaches to generate demand for sanitation, financial incentives aimed at below poverty line (BPL) households, and financial assistance to local governments to construct community and institutional toilets. To achieve its objective of open defecation free communities, the Government of India (GOI) rewards community outcomes through the Nirmal Gram Puraskar (NGP) award given to villages, blocks, and districts that achieve 100 percent open defecation free status. Despite a 9 percent increase in access to sanitation in the span of 10 years (as of the 2011 census), an estimated 69 percent of households in India still do not have a sanitation facility in their household (Government of India, 2011). These figures highlight the enormous difficulty India faces of simultaneously reaching all households while keeping pace with population growth, which grew by 21 percent over the same period.

The aim of open defection free communities is a prominent water and sanitation sector objective and is attractive from several perspectives. At its core, water and sanitation related diarrheal diseases are caused by enteric pathogens in fecal matter. The popular F-diagram demonstrates the pathways through which human and animal feces can come into contact with humans causing them to be sick (Kawata, 1978). Therefore, if all feces are safely contained these pathways, flies, fluids or floors/fields are cut off, fecal contamination should not occur (aside from poor hand washing habits). Elimination of open defecation by ensuring that all households have access to sanitation may also be attractive from an equity perspective. The poorest and most marginalized are the most likely to not have access and thus suffer the majority of the disease burden. Finally, advocating for 100 percent of no open defecation is seen by many in the sanitation sector as a more salient objective than targets that aim for lower coverage, despite these being more feasible to reach.[2] Still, reaching the last mile has several disadvantages. It is often not cost-effective to reach remote locations and there may be unique obstacles to changing behavior of those who continue to practice open defecation. Monitoring adherence to 100 percent ODF can also be very costly, since a larger sample size is required to measure small deviations from universal coverage.

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[1] In 2012 the Total Sanitation Campaign was rebranded the Nirmal Bharat Abhiyan (NBA) under Rural Development Minister Jairam Ramesh, and a new target to eliminate open defecation by 2017 was announced.

[2] Interestingly, the UN General Assembly sets a less ambitious goal for child immunization at 90 percent coverage nationally and 80 percent sub nationally by 2010.

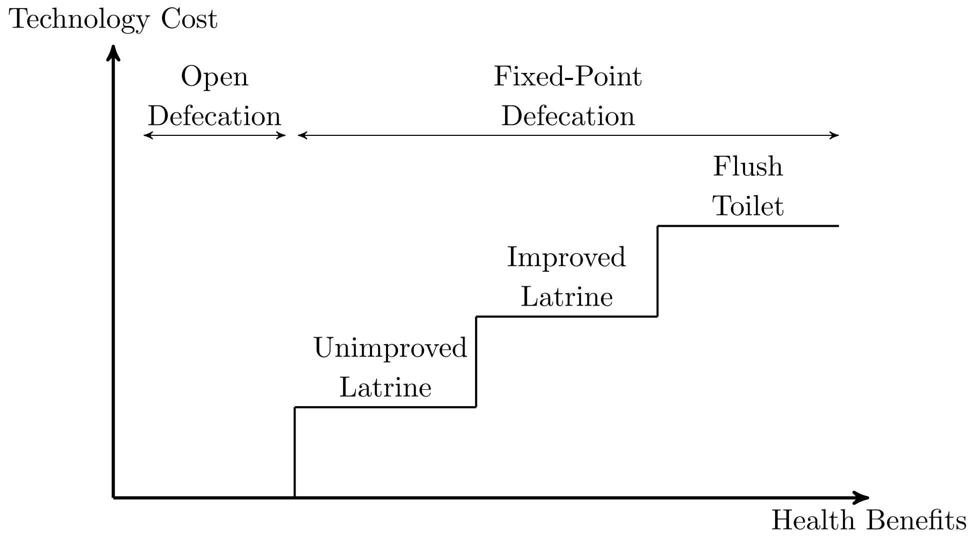


Figure 1: The Sanitation Ladder

Open Defecation	Fixed-Point Defecation	
	Improved Sanitation	**Unimproved Sanitation**
No facilities, bush or field	Private Flush Toilet	Shared Flush Toilet
	Private Piped sewer system	Shared Piped sewer system
	Private Septic tank	Shared Septic tank
	Private Flush/pour flush to pit latrine	Shared Flush/pour flush to pit latrine
	Private Ventilated improved pit latrine (VIP)	Shared Ventilated improved pit latrine (VIP)
	Private Pit latrine with slab	Shared Pit latrine with slab
	Private Composting toilet	Shared Composting toilet
		Flush/pour flush to elsewhere, private or shared
		Pit latrine without slab, private or shared
		Hanging toilet or hanging latrine, private or shared

Table 1: Classification of Sanitation Infrastructure Access

Note: This classification is based on the definitions created by the WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation for the Millennium Development Goals monitoring. An improved sanitation infrastructure is one that hygienically separates human excreta from human contact and is for private use of the household.

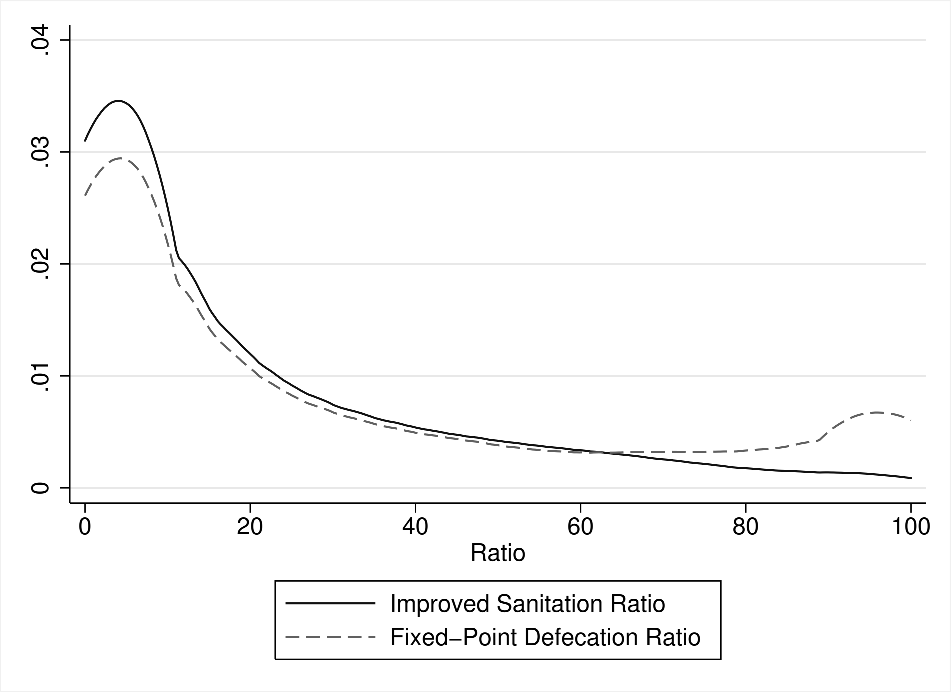
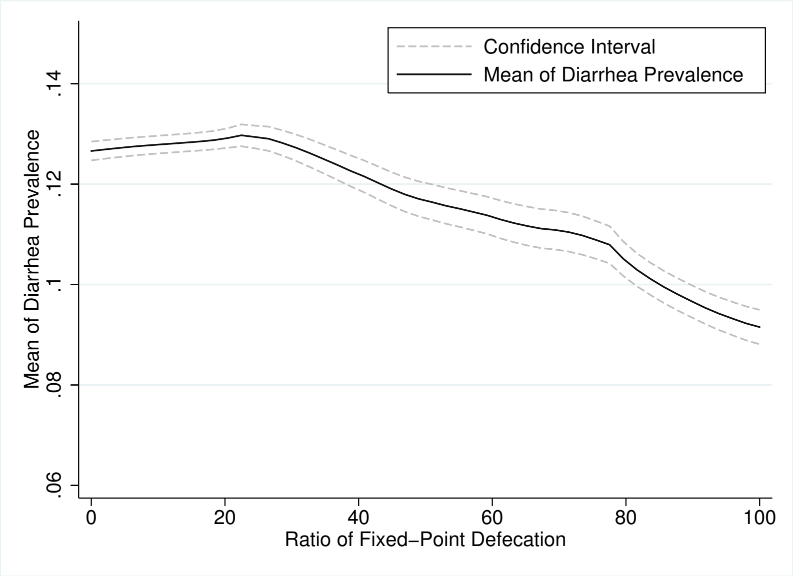
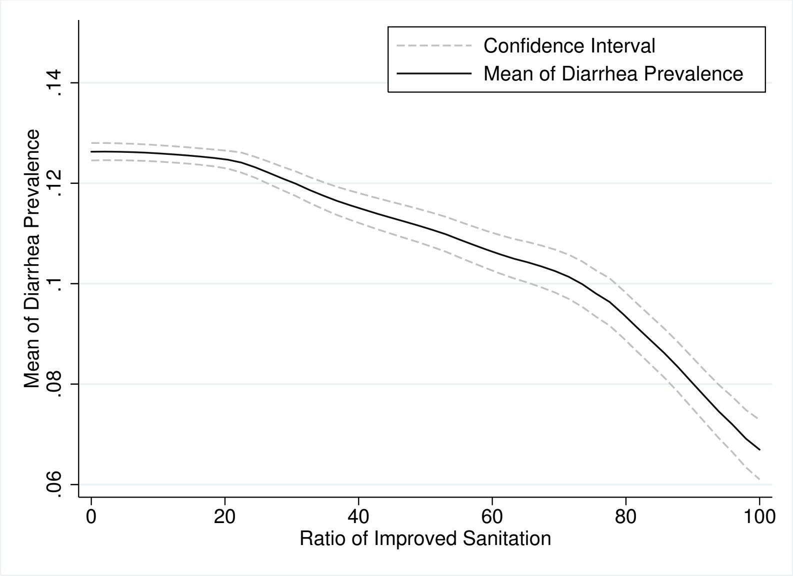


Figure 2: Distributions of Improved Sanitation Ratio

Note: The ratios of *Improved Sanitation* and *Fixed-Point Defecation* are constructed as the proportion of households in the primary sampling unit (PSU), define as village in DLHS-3, that has access to that kind of sanitation technology. The use of villages as the PSU for rural areas by DLHS gives us a random sample of households of each village, making the ratio reliable. The distribution presented on the figure was estimated using a kernel density estimation with a bandwidth of 5.



(a) Ratio of Fixed-Point Defecation



(b) Ratio of Improved Sanitation

Figure 3: Nonparametric Relation of Diarrhea and Ratio of Access to Sanitation

Note: The curve presents the local polynomial regression between the prevalence of diarrhea for each level of ratio of access to sanitation. And the pointed lines are the confidence interval is at 95 percent.

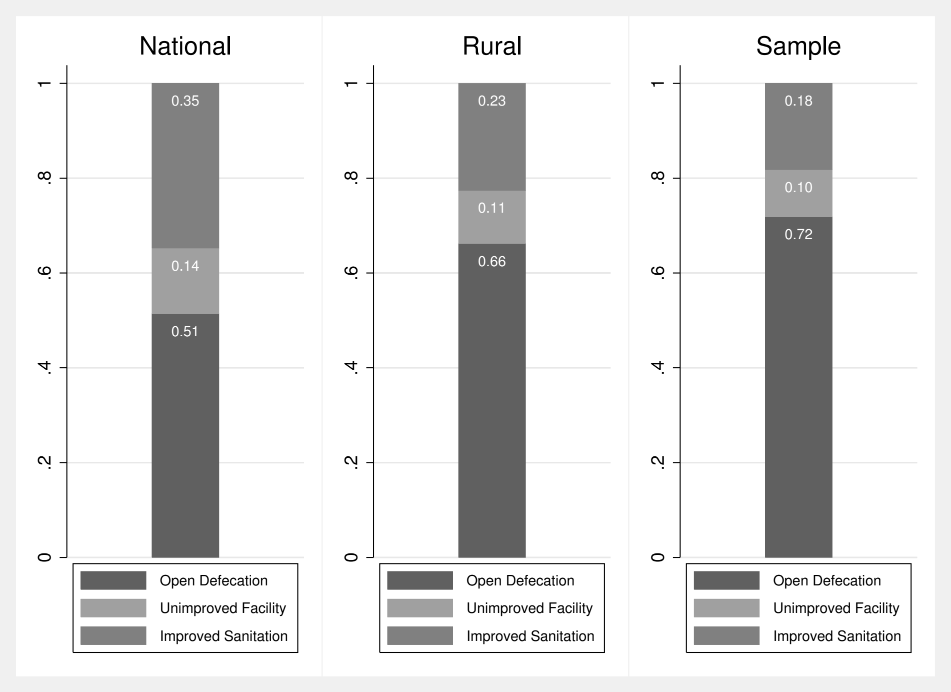


Figure 4: Distributions of Sanitations Infrastructure

Note: *Open Defecation* is defined as if the household doesn't have any access to any type of facility . The *unimproved facilities* are sanitation infrastructures that don't separate the human excreta from human contact and/or are shared with other households. *Improved sanitation* are sanitation infrastructures that separate human excreta from human contact and are private for the household. These definitions come from the WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation for the Millennium Development Goals monitoring.

This figure is constructed with the sample of children used for the estimations.

Variable	Full Sample		With Access to Improved Sanitation		With Access to Fixed-Point Defecation	
	Mean	(Std. Dev.)	Mean	(Std. Dev.)	Mean	(Std. Dev.)
Diarrhea	0.121	(0.327)	0.102	(0.303)	0.106	(0.308)
Years of Schooling of Household Head	4.452	(4.525)	6.483	(4.805)	6.116	(4.737)
Access to Fixed-Point Defecation	0.282	(0.450)	1.000	(0.000)	1.000	(0.000)
Access to Improved Sanitation	0.182	(0.386)	1.000	(0.000)	0.645	(0.478)
Access to Improved facilities are shared	0.036	(0.186)	0.000	(0.000)	0.127	(0.333)
Ratio of Access to Fixed-Point Defecation	28.39	(33.07)	60.95	(32.64)	65.66	(32.24)
Ratio of Access to Improved Sanitation	18.38	(23.31)	45.66	(28.36)	39.60	(27.74)
Gender of Household Head (Male = 1)	0.084	(0.277)	0.092	(0.289)	0.084	(0.278)
Household Head is from a low caste	0.191	(0.393)	0.133	(0.339)	0.122	(0.327)
Age of the child (in months)	22.79	(13.77)	23.04	(13.72)	23.19	(13.71)
Gender of Child (Male = 1)	0.521	(0.500)	0.528	(0.499)	0.526	(0.499)
Number of Observation	**209,762**		**37,275**		**57,311**	

Table 2: Summary Statistics

Note: Children with missing values for the variables presented are excluded from the sample. The variables: gender of the household head and gender of the child takes value 1 when it is a male and zero when it is female.

Table 3: Fixed-Point Defecation Estimations

	Model 1	Model 2	Model 3	Model 4
Diarrhea				
Access to Fixed-Point Defecation	–.107 ***	–.0967 ***	–.0289	–.0195
Sex of Household Head		–.0161		–.017
Years of Schooling of Household Head		.000376		-.00013
Household Head is from a low caste		.0549 ***		.0509 ***
Age of the child (in months)		–.0109 ***		–.0109 ***
Gender of Child (Male = 1)		.026 ***		.0259 ***
Ratio of Fixed Point-Defecation			.00235 **	.00235 **
Ratio of Fixed Point-Defecation x Access			.00114	.000847
Square Ratio of Fixed Point-Defecation			–.0000406 ***	–.0000398 ***
Square Ratio of Fixed Point-Defecation x Access			–.0000271 **	–.0000213 *
Constant	–1.14 ***	–.932 ***	–1.15 ***	–.94 ***
No. of observations	209762	209758	209696	209692

Source: Authors estimations

Notes: The table presents the coefficients from the estimation of the parametric model through a probit model

Significance levels : * : 10% , ** : 5% and * * * : 1%

Table 4: Improved Sanitation Estimations

	Model 1	Model 2	Model 3	Model 4
Diarrhea				
Have access to improved sanitation	–.12 ***	–.115 ***	–.0679 *	–.0622 *
Gender of Household Head (Male = 1)		–.0149		–.00945
Years of Schooling of Household Head		.000271		.000265
Household Head is from a low caste		.059 ***		.0597 ***
Age of the child (in months)		–.0109 ***		–.0109 ***
Gender of Child (Male = 1)		.026 ***		.0259 ***
Ratio of Improved Sanitation			.00126	.00139
Ratio of Improved Sanitation x Access			.00145	.00138
Square Ratio of Improved Sanitation			–.0000431 **	–.0000414 **
Square Ratio of Improved Sanitation x Access			–.0000431 ***	–.0000417 **
Constant	–1.15 ***	–.938 ***	–1.15 ***	–.94 ***
No. of observations	209762	209758	209696	209692

Source: Authors estimations

Notes: The table presents the coefficients from the estimation of the parametric model through a probit model

Significance levels : * : 10% , ** : 5% and * * * : 1%

	S^1_{ijk} **Fixed-Point**	S^2_{ijk} **Improved Sanitation**
Direct Benefit		
$\frac{\partial Pr_{ijk}(D_{ijk}=1)}{\partial S^v_{jk}}$	-0.623 **	-1.26 ***
Externality Benefit, for children with access		
$\left.\frac{\partial Pr_{ijk}(D_{ijk}=1)}{\partial R^v_k}\right\rvert_{S^v_{ijk}=1}$	-0.2063***	-0.1208*
$\left.\frac{\partial^2 Pr_{ijk}(D_{ijk}=1)}{\partial R^{v2}_k}\right\rvert_{S^v_{ijk}=1}$	-0.0041***	-0.0059***
Externality Benefit, for children without access		
$\left.\frac{\partial Pr_{ijk}(D_{ijk}=1)}{\partial R_k}\right\rvert_{S^v_{ijk}=0}$	-0.1639***	-0.1087***
$\left.\frac{\partial^2 Pr_{ijk}(D_{ijk}=1)}{\partial R^{v2}_k}\right\rvert_{S^v_{ijk}=0}$	-0.0018***	-0.0018 ***

Table 5: Benefits of Sanitation from Direct and Externalities Benefits

Note: The values presented in the table are marginal effects in percentage points based on Model 4 of Table 3 and 4

The means used to estimate the marginal effects are 27.78 percent for fixed-point defecation and 18.33 percent for improved sanitation are based on the sample used for the estimates. The covariates used on the three models are the sex of the household, if the household head is from a low caste, the age of the child and the sex of the child.

Significance levels : $*$: 10% , $**$: 5% and $***$: 1%

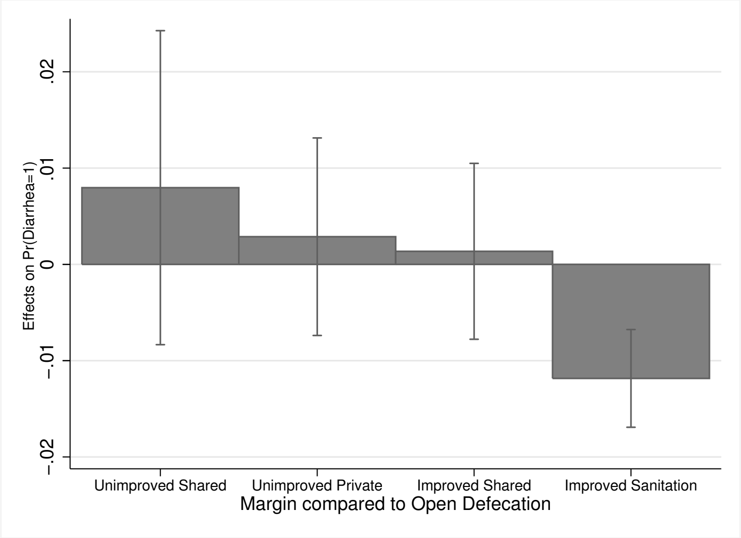
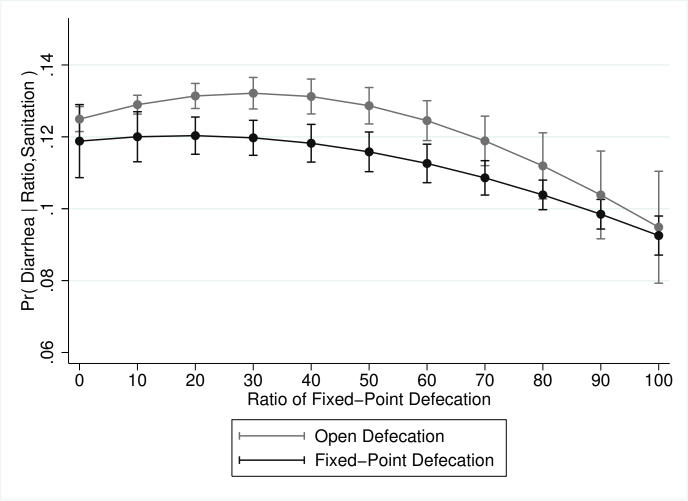


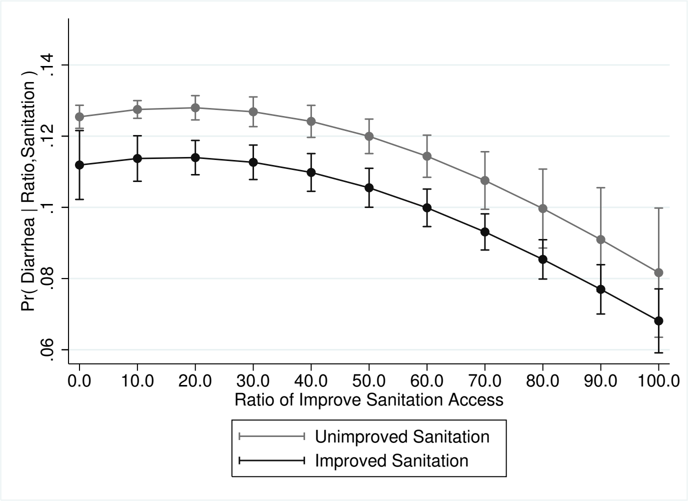
Figure 5: $\frac{\partial Pr_{ijk}(D=1)}{\partial S^*_{jk}}$

Note: The bars presented are the difference between the option j and option i of sanitation, as following $Pr(D_{ijk}|S^*_{ijk}=t) - Pr(Diarrhoea_i|S^*_{ijk}=0)$, where $S^*_{ijk}=0$ is open defecation. The categories presented are defined by the combination of two conditions, isolation of excreta from human contact and if it is for private use for the household, where improved sanitation is the JMP classification which achieve both conditions.

The confidence intervals are constructed using a 95 percent significance.



(a) Fixed-Point Defecation



(b) Improved Sanitation

Figure 6: Parametric Model Simulation

Note: Calculated as $\hat{Pr}(D_{ijk}|R^v_k, S^v_{jk})|_{R^v_k=J}$ for each value of improvement sanitation ratio, $J \in [0, 100]$. The bars at each point of estimation correspond to the confidence interval.

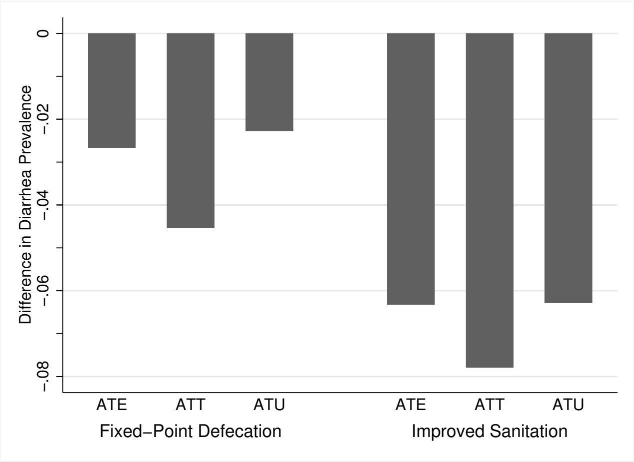


Figure 7: Matching Estimator between Extremes of Ratio of Access

Note: The estimator presented are estimated using a nearest neighborhood matching estimator, with a set of 15 matches for each observation in the treatment group. The six estimators are significant at 95 percent of confidence.

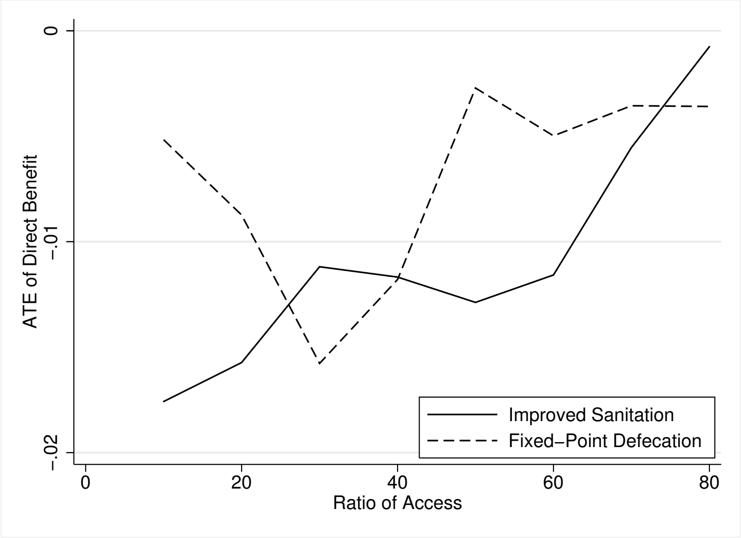
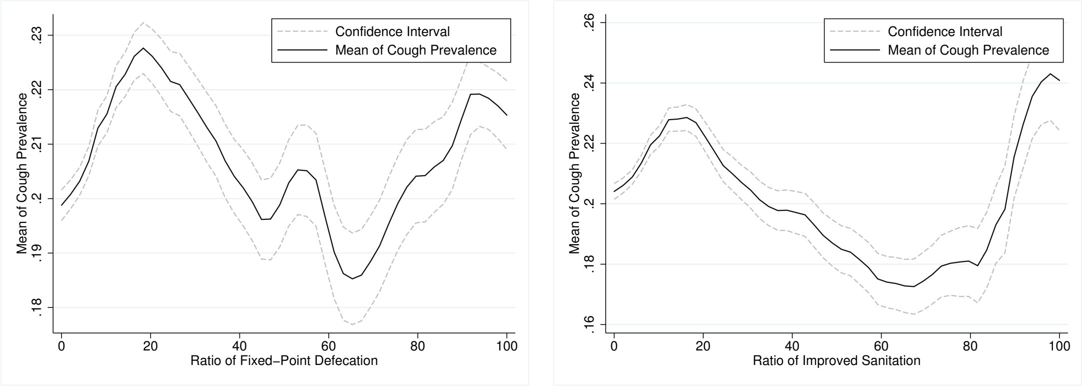


Figure 8: Direct Benefit Matching Within Level of Access



(a) Fixed-Point Defecation

(b) Improved Sanitation

Figure 9: Local Polinomial Regression Cough and Ratio of Sanitation

The curve presents the local polynomial regression between the prevalence of cough for each level of ratio of access to electricity in the village. The pointed lines are the confidence interval is at 95 percent.

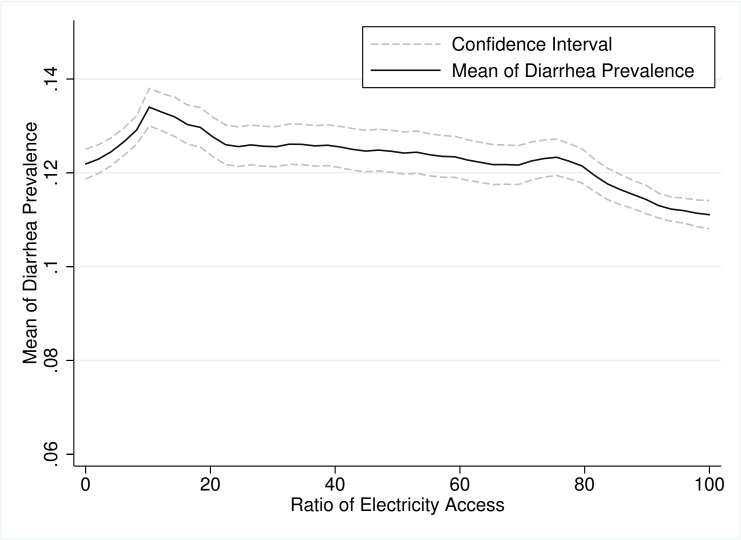
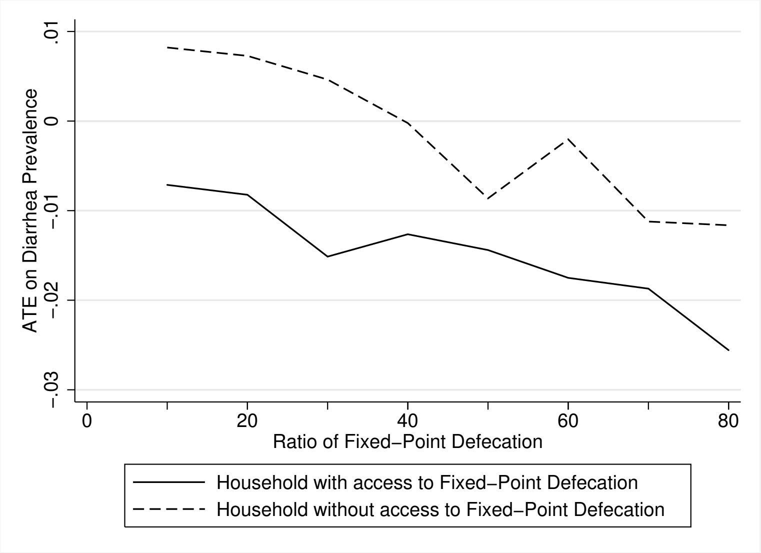
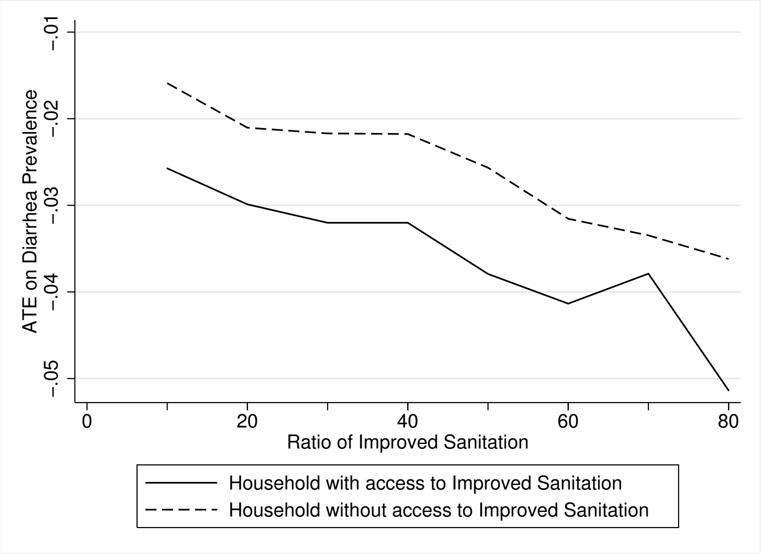


Figure 10: Local Polinomial Regression Diarrhea and Ratio of Electricity Access

The curve presents the local polynomial regression between the prevalence of diarrhea for each level of ratio of access to electricity in the village. The pointed lines are the confidence interval is at 95 percent.



(a) Fixed-Point Defecation



(b) Improved Sanitation

Figure 11: Counterfactual Model

Note: The parameters presented on the graph are calculated for each node (r, s) as $E(D_{ijk} = 1|R_k^v = (r, r+1), S_{jk}^v = s) - E(D_{ijk} = 1|R_k^v = 0, S_{jk}^v = 0)$. Where $r \in [10, 90]$, $s \in [0, 1]$. These parameters where estimated using a nearest-neighborhood propensity score matching estimator with 30 neighbors. The variables used to estimate the propensity score for the matching are sex of the household, if the household head is from a low caste, the age of the child and the sex of the child.