Growing taller among toilets: Evidence from changes in sanitation and child height in Cambodia, 2005-2010

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Abstract

Child height is an important indicator of human capital and human development, in large part because early life health and net nutrition shape both height and adult economic productivity and health. Recent medical evidence suggests that exposure to poor sanitation – and specifically to widespread open defecation – can pose a critical threat to child growth. Cambodia saw a significant decline in open defecation and increase in child height between its 2005 and 2010 Demographic and Health Surveys. This paper identifies an effect of open defecation on child height from within-province changes in the local area open defecation to which children are exposed. In particular, it is local open defecation that matters most for child height, underscoring the negative externalities that make reducing open defecation a policy priority where it is common. Our estimate is quantitatively robust, and corroborated by model averaging techniques. Decomposition analysis, in the spirit of Blinder-Oaxaca, further suggests that reduction in children's exposure to open defecation can statistically account for much or all of the increase in average child height between 2005 and 2010.

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1 Introduction

Child height is an important indicator of human capital and human development, in large part because of its importance for adult economic productivity and health (Currie, 2009; Vogl, 2011). This is cheifly because height is determined by health and net nutrition in the first few years of life, a critical period for cognitive development (Case and Paxson, 2008). In poor countries, the importance for height and child development of early-life health, relative to genetics, is even greater than in richer countries (Martorell et al., 1977; Spears, 2012b). Recent econometric evidence suggests that exposure to germs from open defecation is an important determinant of child height in developing countries (World Bank, 2008; Spears, 2013). It is therefore important to better understand the relationship among sanitation, the early-life disease environment, and subsequent child health and human capital outcomes, especially in countries where practicing open defecation is widespread.

We study the effect of open defecation on child height in Cambodia, where more than half of the population defecates in the open, without using a toilet or latrine. The primary contribution of this paper is to econometrically identify an effect of the local prevalence of open defecation on child height by studying changes over time within geographic areas of Cambodia. In studying Cambodia this paper makes an important contribution to the literature for two reasons. First, in Cambodia open defecation is particularly common, representing an enduring development challenge and an unusually threatening disease environment for children. Second, although the country remains far from eliminating open defecation or child stunting, Cambodia saw an improvement in child height 2005 to 2010, coupled with a decrease in open defecation, a type of natural experiment that gives us the opportunity to identify effects of a change in sanitation.[1]

The empirical analysis in this paper comes in two parts. First, we combine the two most

[1] In Cambodia, open defecation rates fell by 14 percentage points over the 5 year studied, compared with a 8 percentage point decline over the 7 years between India's two most recent DHS surveys. According to WHO-UNICEF joint monitoring program data, Cambodia's decline in open defecation over this period was in the 96th percentile of all countries.

recent Demographic and Health Surveys in Cambodia to estimate the effect on child height of the local area open defecation to which a child is exposed, using panel data methods. We find that provinces within which open defecation decreased by more saw a greater improvement in child height, on average. Our result is robust to a range of specifications and is confirmed by two model averaging techniques: Bayesian model averaging and weighted-average least squares. In this section, we document important negative externalities of open defecation in Cambodia, an important motivation for policy action.

Second, we ask how much of the increase in child height from 2005 to 2010 can be statistically accounted for by the reduction in open defecation. We apply several complementary decomposition techniques in the spirit of Blinder-Oaxaca. Although open defecation remains common in Cambodia, we find that its decline over the period studied can account for much of the increase in child height.

1.1 Open defecation and child stunting

According to joint UNICEF and WHO (2013) estimates, 15 percent of people in the world, and 18 percent of people in developing countries - about one billion people overall - defecate in the open without using a toilet or latrine. Of these one billion people, more than 8 million live in Cambodia, representing 58 percent of the country's population. Among developing countries, open defecation is particularly common in Cambodia, notably more common than in sub-Saharan Africa, and slightly moreso than in India, where about half of all people who defecate in the open live.

Research in medicine and epidemiology links open defecation to poor health through at least two mechanisms. The first, and most commonly recognized, mechanism is diarrhea from fecal-oral contamination. Checkley et al. (2008) use detailed longitudinal data to demonstrate an association between childhood diarrhea and subsequent height. A second mechanism, only recently becoming understood, is chronic "environmental enteropathy," a disorder of the intestine that reduces the body's absorption of nutrients due to an inflammatory response to continued contamination with fecal pathogens. Humphrey (2009) proposes that chronic environmental enteropathy could cause malnutrition, stunting, and cognitive defects, even without manifesting as diarrhea such that a child would appear ill. If so, diarrhea could be merely the "tip of the iceberg" of effects of open defecation on child development, resting atop a more quantitatively important threat from enteropathy. For example, recent epidemiological studies by Lin et al. (2013) and Kosek et al. (2013) document important links among sanitation, enteropathy, and child growth.

This paper joins a growing econometric literature documenting effects of open defecation on child height. Spears (2012a) studies a program that improved rural sanitation in some districts of India. Averaging over the heterogeneity of program implementation across rural India, the government program reduced infant mortality and increased children's height in the places where it reduced open defecation. In a recent field experiment in Indonesia, Cameron et al. (2013) show that a Total Sanitation and Sanitation Marketing project increased average height of children living in households without access to sanitation at baseline. Similarly, Hammer and Spears (2013) study the effects of a randomized field experiment in Maharashtra, India, in which children living in villages randomly assigned to receive sanitation motivation and subsidized latrine construction grew taller than children in control villages. Finally, Spears (2013) investigates the difference in child height between India and Africa and documents that cross-country variation in sanitation statistically explains a large fraction of international height differences.

1.2 Sanitation in Cambodia

Cambodia is a Southeast Asian country of 14 million people bordering Thailand, Vietnam and Laos. Three-fourths of the population – and 90 percent of Cambodia's poor – live in rural places (World Bank, forthcoming). The country has a moderate population density of about 75 people per square kilometer, which is about one-fifth of India's population density. Over the five year period we study from 2005 to 2010, the fraction of the population living on less than \$1.25 a day fell from around 35 percent to under 20 percent, according to World Bank World Development Indicator statistics.

Open defecation has historically been high in Cambodia. We study change over the period from 2005 to 2010, when the average exposure to local open defecation of children under five fell by about 14 percentage points, starting from about three-fourths of the average child's neighbors. Sanitation coverage also varies substantially within Cambodia over geographic areas (Robinson, 2007), another dimension of heterogeneity that this paper exploits. Unsurprisingly given Cambodia's high rates of open defecation relative to its region, the sanitation sector has been an important part of development activity in Cambodia, with attention from the government, NGOs, and other partners. In the period 2005-2010 a number of sanitation programs were active in Cambodia, mostly following a supply-driven approach towards sanitation. Unlike in, for example, India, where open defecation is also extremely widespread but most new rural latrines are subsidized by the government (Alok, 2010), in Cambodia the private sector has historically been playing a significant role in the provision of the majority of latrines, accounting for almost 80 percent of all latrines built in the country (Rosenboom et al, 2011, p. 23). Although there has been some diversity of approach and method across NGO and other programs and over time during this period, much of the improvement in sanitation that this paper studies reflects new latrines that were largely invested by households themselves, complemented by some subsidized provision through development projects.

2 Empirical strategy

Demographic and Health Surveys (DHS) are large, nationally representative surveys conducted in poor and middle-income countries. We use data on the heights of children under 5 years old in the two most recent DHS surveys in Cambodia, conducted in 2005 and 2010. Our central dependent variable is child height-for-age, which is a z-score of a child's distance in standard deviations from the average height of healthy children in a reference population of the same sex and age in months. We compute z-scores using the WHO's 2006 international reference population, and follow their recommendation of omitting children beyond 6 standard deviations from the mean.

Our key independent variable is local area open defecation. Each household is classified as defecating in the open or not according to its report of where members "usually" defecate in the DHS questionnaire. However, infectious diseases often involve negative externalities (Gersovitz and Hammer, 2004), and intestinal disease resulting from open defecation is no exception: children are exposed to fecal pathogens from neighboring households. Therefore, we compute, as a measure of "local open defecation," the fraction of households in a child's survey Primary Sampling Unit (PSU) who defecate in the open, a continuous variable from 0 to 1. For comparison as a placebo independent variable and as a control, we similarly compute the fraction of households in a PSU with electrification, an alternative measure of local living standards and infrastructure development. Because all households potentially contribute feces to the environment but not all households have children under 5 years old, we compute these PSU averages from the DHS household recode. All other variables are also taken from the DHS, except measures of province mean consumption are from Knowles (2012) and population density is computed from Cambodian census data.

2.1 Fixed effects identification strategy

Our identification strategy asks whether geographic areas which experienced a decrease over time in local area open defecation also experienced an increase in child height. Thus, we apply panel data methods to a pooled dataset of repeated cross sections (Deaton, 1985).

The regression we estimate is:

$$\begin{aligned} z_{i\ell pt} = \; & \beta_1 local\ open\ defecation_{\ell pt} + \beta_2 household\ open\ defecation_{i\ell pt} + \\ & \beta_3 local\ electrification_{\ell pt} + \beta_4 mother\text{'}s\ height_{i\ell pt} + \beta_5 mother\text{'}s\ BMI_{i\ell pt} + \\ & E_{i\ell pt}\theta + D_{i\ell pt}\vartheta + H_{i\ell pt}\phi + A_{i\ell pt} + \alpha_p + \delta_t + \varepsilon_{i\ell pt}. \end{aligned} \tag{1}$$

where i indexes individual children, ℓ is local areas (survey PSUs), p are 38 rural or urban parts of provinces,[2] and t is time. Fixed effects α_p and δ_t are included for geographic and secular time variation.

The dependent variable z is a child's height-for-age z score. Local open defecation and local electrification are fractions 0 to 1 and household open defecation is an indicator, 0 or 1. Mother's height and BMI are included to control for heterogeneity in maternal nutrition and to account for any possible direct effect of mother's size (Ounsted et al., 1986). Standard errors are clustered by survey PSU, the level of heterogeneity in the key independent variable; 610 are more than enough for asymptotic clustered standard errors (Cameron et al., 2008).

The fixed effects identification strategy differences out any fixed heterogeneity across provinces within Cambodia, as well as the secular trend in child height. Controlling for local electrification serves as both a placebo alternative independent variable and an alternative control for PSU welfare and infrastructure. We include three further sets of control variables in stages, in order to demonstrate robustness of our regression specification:

- $E_{i\ell pt}$ Household socio-economic controls: household electrification; indicators for owning a radio, TV, and refrigerator; 10 indicators for floor material (an important indicator of disease exposure); 19 indicators for household size; indicators for level of literacy of the child's mother; indicators for cooking fuel type; and province-level measures of average consumption and population density.

[2] Thus, provinces with both rural and urban data in the DHS have two index numbers within p and these parts each have their own separate fixed effect; provinces with only rural or urban members have one fixed effect.

- $D_{i\ell pt}$ Child birth demography controls: 13 indicators for birth order and 11 indicators for birth month (Doblhammer and Vaupel, 2001).

- $H_{i\ell pt}$ Health and healthcare: an indicator for the child having a health and vaccination card; an indicator for having had an institutional delivery; and indicators for being breastfed immediately and within the first day.[3]

Additionally, all specifications include 120 age-in-months times sex dummies $A_{i\ell pt}$ to non-parametrically account for any average difference between Cambodian children and the international reference norms (Cummins, 2013).

2.2 Averaging over model uncertainty

We include a wide range of control variables to rule out omitted variable bias as a plausible explanation for our results. However, many of these controls' coefficients will not be statistically significantly different from zero, and it is unclear whether they belong in a properly specified regression. Therefore, after presenting the results from the fully specified equation (1), we will apply two model averaging techniques (*cf.* De Luca and Magnus, 2011) which compute a weighted average over possible models – in this case, models including various subsets of the auxiliary control variables. In particular, we use Bayesian model averaging (Leamer, 1978; Raftery et al., 1997), a standard technique in empirical growth economics, and weighted-average least squares, recently proposed by Magnus et al. (2010).

2.3 Decomposition of change between 2005 and 2010

If open defecation causes child stunting, and if open defecation became less common between 2005 and 2010, then how much of the increase in child height can be statistically accounted

[3]The DHS does not have a consumption module and detailed information about food consumption is not available. Moreover, in the particular case of the 2005 to 2010 Cambodian DHS, infant and young child feeding indicators are not directly comparable across survey rounds, however, according the the official report for the 2010 Cambodian DHS, this is unlikely to threaten any bias for our results, because "There has not been much improvement in complementary feeding practices since 2005" (ICF Macro, 2011, p. 160).

for by the decline in open defecation? In a separate analysis from the fixed effects estimates of the effect of open defecation, we approach this question with three complementary decomposition methods in section 5. First, in the course of the regression analysis, we will see that controlling for open defecation eliminates the statistical importance of an indicator for survey year. Second, we will implement a standard linear Blinder-Oaxaca decomposition. Third, will conduct a non-parametric decomposition by computing a counterfactual average height for children in the 2005 DHS survey, reweighted to match the 2010 distribution of open defecation.

3 Summary statistics

Children in our sample are almost two standard deviations shorter than the healthy international reference population, and they live in households that are poor, but standards of living were detectably improving in Cambodia between 2005 and 2010. Table 1 presents sample means of the variables used in our analysis. Note that these summary statistics, like all estimates in this paper, are representative of children under 5 and not of all Cambodians. The first and second columns show averages for 2005 and 2010, and the third column reports a test that these are different. Over the period we study, the height of children under 5 significantly increased relative to the international reference population while the rates of open defecation in the locality and by individual households significantly decreased.

3.1 Height is associated with open defecation: Non-parametric descriptive regressions

Figure 1 presents non-parametric local regressions that document that child height is associated with local open defecation. Panel (a) plots child height as a function of age in months, replicating the well-known fact that most stunting occurs in the first two years of life, with height-for-age generally flat thereafter. These curves are plotted separately for children who live in local areas where they are exposed to no open defecation (6 percent of children), where everybody surveyed in their local area defecates in the open (19 percent of children), and the rest, living in areas with an intermediate sanitation profile. Children in all three groups are a little more than half of a height-for-age standard deviation too short at birth, but the lines separate as stunting unfolds over the first two years. Children exposed to the most open defecation are almost a standard deviation shorter than children exposed to no open defecation, on average. However, open defecation is not the only cause of child growth defects: even children exposed to no open defecation are more than a standard deviation shorter than the reference population.

One reason why children exposed to better sanitation are taller is that they are also richer; people in poorer households are more likely to defecate in the open. However, open defecation imposes negative externalities on people who live nearby, and fecal pathogens in the environment transmit disease to neighboring children. Panel (b) plots average child height-for-age of children under 5 as a function of local area (PSU) open defecation. Households that do and do not defecate in the open are plotted separately. Unsurprisingly, children who live in households that dispose of feces safely are taller, on average, than children who do not. The key feature of the graph, however, is that the line slopes down for both groups. Whether or not a child's own household defecates in the open, she is shorter, on average, if more of her neighbors do. Of course, neither of these curves represents a well-identified estimate of a causal effect; therefore, the next section proceeds to regression estimates.

4 Changes within provinces: Regression evidence

Did parts of Cambodian provinces where open defecation declined by more from 2005 to 2010 also see the greatest increases in average child height? Figure 2 presents two depictions of the change over time in sanitation and stunting. Panel (a) plots the association between height and local area open defecation within each of the two years. The vertical nearness of the two lines suggests that the change in open defecation can statistically account for much of the change in height, a possibility which will be further explored in section 5.

Panel (b) presents a visual depiction of this section's fixed effects analysis. In this plot, each rural or urban region of a province is represented by one of the small lines. Each line connects one geographic area's 2005 averages of child height and rate of open defecation to its 2010 averages. Of the 38 lines, 24 slope down, indicating that the average reduction in local area open defecation an increase in child height in 24 urban and rural parts of provinces. As a preliminary non-parametric statistical significance test, a binomial distribution reports that there is only a 7 percent chance of seeing at least 24 of 38 slope down if these slopes are independent of one another and if there really were no association, so that each line were equally likely to slope up or down.

4.1 Regression results

Table 2 reports our main regression results. Panel A shows estimates from OLS regressions without province part fixed effects, while Panel B displays results from regressions with fixed effects for urban and rural province parts. The OLS regressions identify the variation both between and within urban and rural regions of provinces, while the fixed effects regressions isolate the within-region variation, indicating that the relationship is not merely driven by coincidental differences between regions. An increase from 0 to 1 in the rate of open defecation in a child's locality is linearly associated with a decrease in children's height by between 0.43 to 0.84 standard deviations, depending on the estimation strategy and model used.

Column 1 shows that child height improved from 2005 to 2010 on average using both estimation strategies. Could the reduction in open defecation account for this overall increase in average child height? Notably, when we introduce open defecation rates in the locality in column 2, the 2010 dummy variable becomes insignificant, indicating that sanitation statistically explains the average change over time. As we progress from column 3 to column

7, progressively more controls are added.[4]

Two conclusions emerge from the table. The first is that the point estimate for open defecation in the child's locality stays quite stable as controls are added.[5] The stability of the coefficient on local open defecation despite the wide range of controls suggests that it is unlikely to be due to omitted variable bias. Measures of maternal anthropometry also do not diminish the apparent role of sanitation, although measures of maternal size and nutrition are unsurprisingly themselves robust predictors of child size.[6] The clear similarity between coefficients obtained from the OLS and fixed effects regressions suggests that the results from the OLS regressions are not a spurious artifact of heterogeneity across regions.[7]

Second, an important result for policy is that the coefficient on *household* open defecation loses statistical significance and falls to zero when other household socio-economic controls are included in column 4. This is unsurprising for two reasons: richer households are less likely to defecate in the open, and open defecation – like other sources of infectious disease – involves important negative externalities.[8] This result corroborates this role of negative

[4]We further tested the stability of the effect of the sanitation environment by including a rough measure of province-level averages of calories consumed per person per day obtained from the Cambodia Socio-Economic Surveys in 2004 and 2009. Inclusion of this control variable does not materially affect the magnitude or direction of the open defecation effect. We elected not to include this result due to the geographic coarseness of the calorie measure.

[5]The estimate is also consistently highly statistically significant. If instead at clustering at the PSU level we cluster at the more conservative level of 38 rural/urban province parts, then the t-statistic on open defecation in the most controlled specification, column 7 of Panel B, becomes -3.7, although this may be too few clusters for asymptotic results (Cameron et al., 2008).

[6]The DHS does not include measures of food or calorie consumption, but overall household food availability would likely be at least partially reflected in mothers's BMI, controlling for which does not change our result.

[7]Fixed effects are well-known to risk attenuation bias, although this appears to be unlikely in this case due to the small differences between corresponding parts of Panel A and Panel B. Nevertheless, attenuation bias may also result from the fact that local area open defecation rates are themselves estimates (computed sample means), and therefore contain measurement error (Deaton, 1985). To respond to this concern, we instrument for the same PSU-level local open defecation independent variable with another measure of the local disease environment: *district*-level open defecation. The time and place fixed effects estimate in column 2 of Panel B rises in absolute value from -0.77 without instrumenting to -1.12 (s.e. = 0.32) with instrumenting, or an intermediate point estimate of -0.91 with instrumenting and all of the controls in column 7 of Panel B. Thus, if attenuation bias is indeed a problem here, the true effect of open defecation on child height may be greater than we have estimated.

[8]This finding is also econometrically important as a reminder that statistical approaches which study the "effects" of a child's own household's open defecation are likely to both importantly overlook these external effects and conflate heterogeneity in wealth. For example, in a recent analysis of child height in Cambodia

externalities in the effect of open defecation on child stunting. Because such externalities are a classic economic rationale for public action, they point to the importance of a policy response to open defecation.

4.2 Averaging over model uncertainty

After controls are added to the regressions in Table 2, estimates vary from a range of about 0.4 to 0.6 standard deviations linearly associated with a change from 0% to 100% open defecation. The coefficients appear robust, but many of the included controls are not statistically significant, and it is unclear which estimate is most "correct." Table 3 presents results from two approaches to averaging estimates over model uncertainty: Bayesian model averaging and weighted-average least squares. It would be computationally intractable to include the full range of controls, so eight representative auxiliary controls are used, creating a space of 512 models over which these algorithms search. The resulting effect estimates are quantitatively similar to those in Table 2, suggesting we can be confident in the robustness of these results.

4.3 A mechanism check: Steeper slope in urban places

The importance of local open defecation, rather than a household's own open defecation, indicates a key role for externalities of disease. If so, then because children are more exposed to others' fecal pathogens where people live nearer together, we would further expect that open defecation should have a steeper association with child height in urban areas where population density is particularly high (Bateman et al., 1993; Bateman and Smith, 1991). We test this by introducing an interaction between prevalence of open defecation in the locality and an urban dummy to the specification in column 2 of table 2.

Ikeda et al. (2013) include an indicator for household sanitation as an independent variable, but they omit any measure of local or otherwise geographic sanitation. Unsurprisingly, they find, as we do, that household open defecation is not a particularly important predictor of child height after including other measures of household wealth.

Does open defecation indeed havea a steeper association with child height in urban parts of Cambodia than in rural parts? The fraction of open defecation in the PSU interacts with an indicator for an urban place, with and without fixed effects: when the rate of open defecation increases from 0 to 1, the decrease in average child height is between 0.32 and 0.41 standard deviations greater in urban areas than in rural areas. This effect is statistically significant at the two-sided 10 percent level.[9] This finding is consistent with both Spears (2012a), who finds a greater effect of a widespread government sanitation program in districts with higher population density, and with Spears (2013) who finds that internationally, open defecation has a steeper association with child height in urban places and where population density is greater.

5 Decomposition of the 2005-2010 increase in child height

How much of the increase in child height between 2005 and 2010 in Cambodia can be explained by the decrease in local open defecation to which the average child was exposed? Econometric decompositions ask how much of the difference in an outcome variable across two groups can be accounted for by observable differences in input variables (Fortin et al., 2011). Although the canonical use of decomposition in labor economics is to analyze differences in economic outcomes (such as wages) between two groups of people (such as black and white people in the U.S.), here we will be asking how much of the difference in child height in Cambodia between 2005 and 2010 can be accounted for by the difference in the level of open defecation in a child's locality. In general, econometric decompositions of observational data are tools of statistical accounting that may or may not have a causal interpretation depending on the details of the data and the source of heterogeneity studied. Although we have already offered evidence of a quantitatively robust effect of sanitation on child height

[9] The p-value in the OLS regression is 0.062 and the p-value in the fixed effects regression is 0.078.

in section 4, this section interprets decomposition results conservatively as accounting for differences.

Various methods of econometric decomposition are available, and we study three. The first and simplest was already presented in the difference between columns 1 and 2 of Table 2. Adding a linear control for local area open defecation (as before, collapsed PSU mean) eliminated a statistically significant difference in child height between the two DHS survey rounds (see decomposition results in Table 4). This section will also consider a Blinder (1973) – Oaxaca (1973) decomposition, and will apply a non-parametric reweighting technique.

Panel (a) of figure 2 can be interpreted as a visual depiction of the extent to which the change in open defecation can explain the change in child height. Within each of the two years, local polynomial regression lines plot average child height-for-age against local area open defecation rates. The lines are relatively close to one another and quite nearly pass through both of the overall year average points. Note that this is not mechanically determined: although each year's average point must be on or near its own line, the two lines could be vertically far apart. If the lines were vertically separated, this would indicate differences in average height between the two years even at the same level of open defecation. However, the fact that the points are on the similar lines indicates that the within-year association between height and sanitation appears to statistically account for the between-years change in height.

5.1 Blinder-Oaxaca decomposition

Reimers (1983) and Jann (2008) recommend a Blinder-Oaxaca decomposition in which the estimate of the overall effect of the explanatory variable is constructed by assigning equal weight to estimates of the effect computed separately from each of the two sub-samples. In this case, two regressions would separately estimate $\hat{\beta}_1^{2005}$ and $\hat{\beta}_1^{2010}$ and then average them to create a counterfactual within-year height sanitation slope. Then, the Blinder-Oaxaca estimate of the portion of the change in height that can be attributed to reduced open defecation would be:

$$explained\,change = \left(0.5\hat{\beta}_1^{2005} + 0.5\hat{\beta}_1^{2010}\right) \times \left(\overline{PSU\,open\,defecation}^{2010} - \overline{PSU\,open\,defecation}^{2010}\right). \tag{2}$$

As table 4 shows, this approach finds that the reduction in local area open defecation to which the average child was exposed can linearly explain 0.128 of the 0.129 standard deviation increase in child height. Thus, 98 percent of the difference in height can be accounted for by the difference in sanitation..

5.2 Non-parametric re-weighting decomposition

A final, most flexible, decomposition method is non-parametric reweighting.[10] This method creates a counterfactual avreage of 2005 children's height, reweighted to match the 2010 distribution of open defecation. In particular, the sample is split into 12 bins of PSU open defecation levels: 10 deciles with extra categories for 0 open defecation and for 1 open defecation. These are crossed with an indicator for own household open defecation to create 22 overall open defecation bins (22 instead of 24 because there are no children in households that openly defecate who also live in PSUs where nobody sampled openly defecates, and vice versa). Then, within each of the 22 bins, the total sample weight is computed separately for 2010 and 2005. Finally, a set of new weights is computed for children in 2005 by multiplying their sampling weight by the ratio of their bin's 2010 total sampling weight to their bin's 2005 total sampling weight.

The result is compared with the other decomposition methods in table 4. The true sample mean height-for-age was -1.77 in 2005 and was -1.64 in 2010. When the 2005 sample is reweighted to match the 2010 sanitation distribution, the counterfactual mean height-for-

[10] Spears (2013) uses this method to estimate the fraction of the India-Africa average height gap that is attributable to open defecation, and Geruso (2012) employs it to estimate the extent to which socio-economic status can account for the difference in life expectancy between blacks and whites in the U.S.

age is -1.62, essentially the same as the true 2010 average (this difference is not statistically significant $t = 0.41$).

Therefore, all three approaches to decomposing the change over time in child height reach similar conclusions. Using simple pooled regression, a Blinder-Oaxaca decomposition, or non-parametric re-weighting, the decline in exposure to open defecation can statistically account for almost all of the approximately 0.13 standard deviation increase in height-for-age.

6 Conclusion

Child height is an important economic variable predicting adult human capital, cognitive achievement, and health. The average child under 5 in Cambodia was 0.13 standard deviations taller in 2010 than in 2005. This is an important difference: Spears' (2012b) estimates of the height-cognitive achievement gradient for Indian children suggest that a 0.13 standard deviation increase in child height would be associated with a 1 to 4 percentage point increase in the probability of being able to read words or paragraphs among 8 to 11 year-olds. Reductions in the amount of open defecation to which the average child exposed are able to account for much of this difference; increasing open defecation predicts a large and quantitatively robust decline in Cambodian children's height.

These results indicate that widespread open defecation could be a critical constraint for human development. Moreover, we have seen various indicators of the role of negative externalities in propagating fecal pathogens. Open defecation has decreased, and child height has increased, but open defecation is still common in Cambodia and the mean child was still 1.6 standard deviations below a healthy height distribution. In any country where this is the case, spillovers of poor sanitation indicate that reducing open defecation must be a policy priority.

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(a) stunting unfolds in the first two years of life, depending on the disease environment

(b) negative externalities:
neighbors' open defecation matters for households with and without sanitation

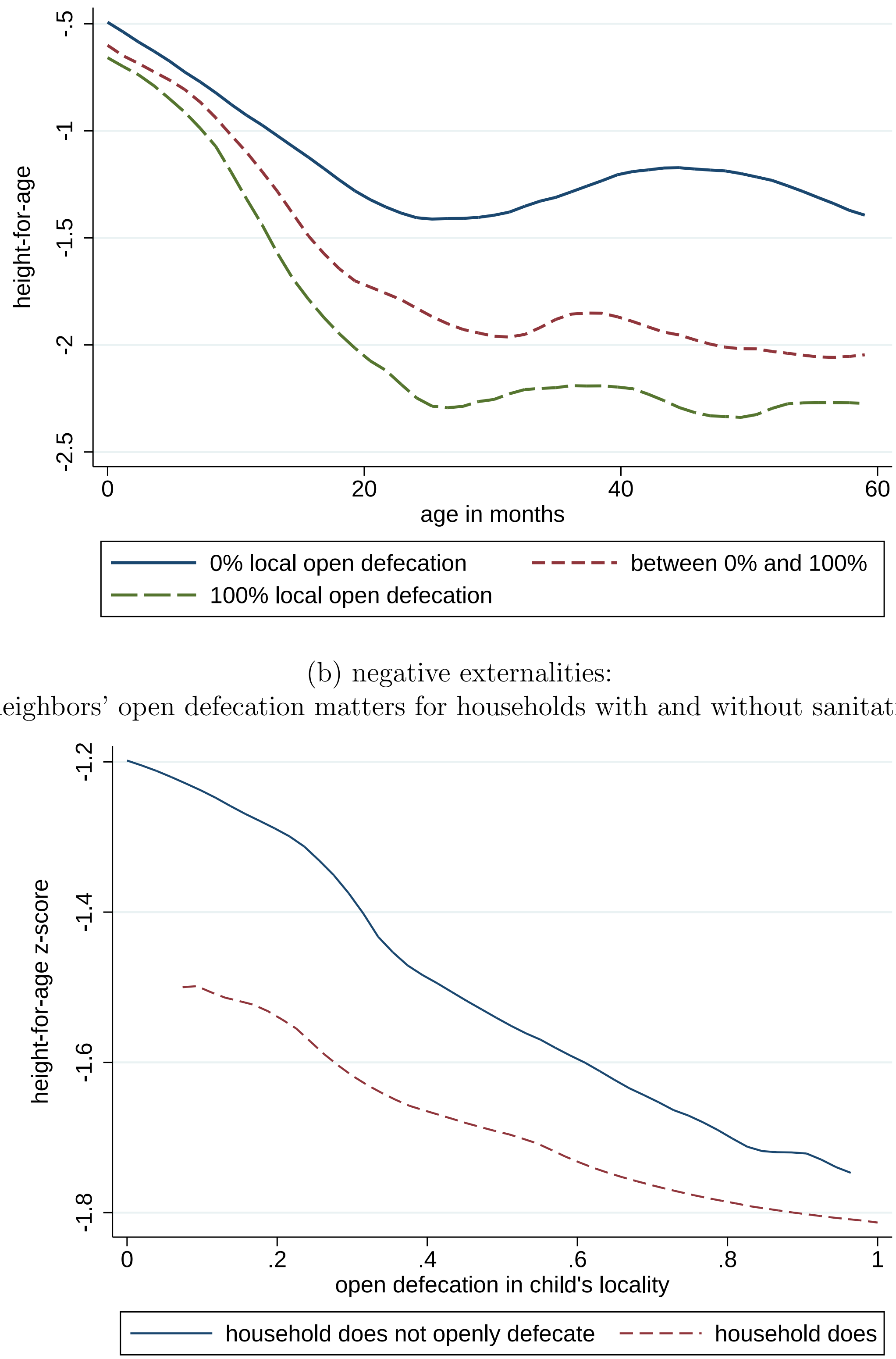
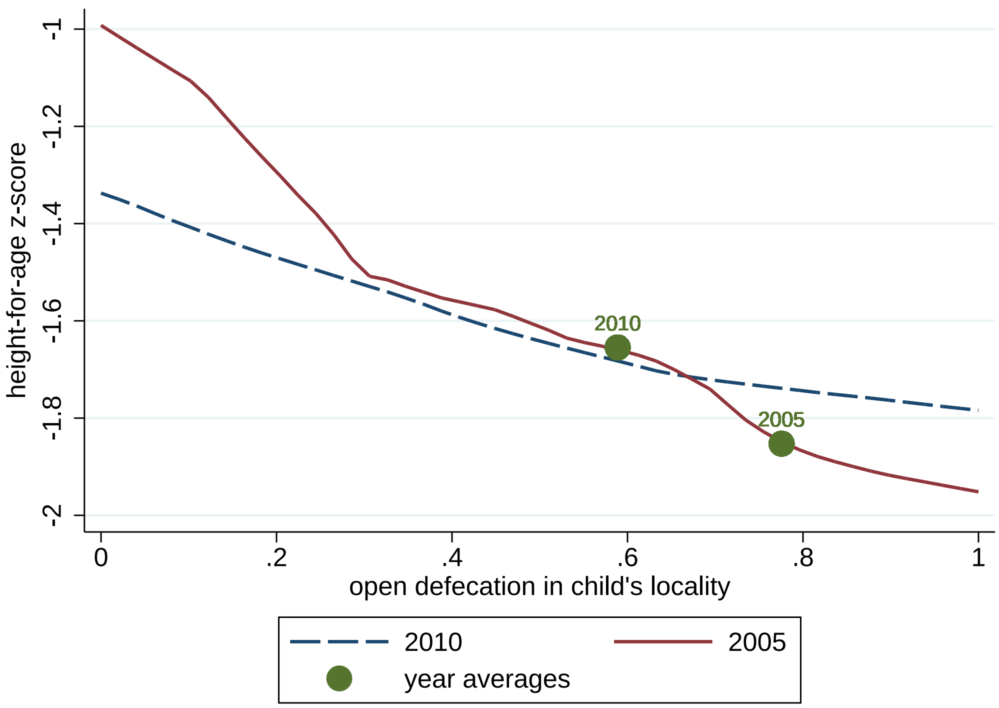


Figure 1: Open defecation predicts child height

Both panels present local non-parametric regressions.

(a) differences within and across years in height and sanitation



(b) decrease in open defecation and increase in height, by rural-urban province part

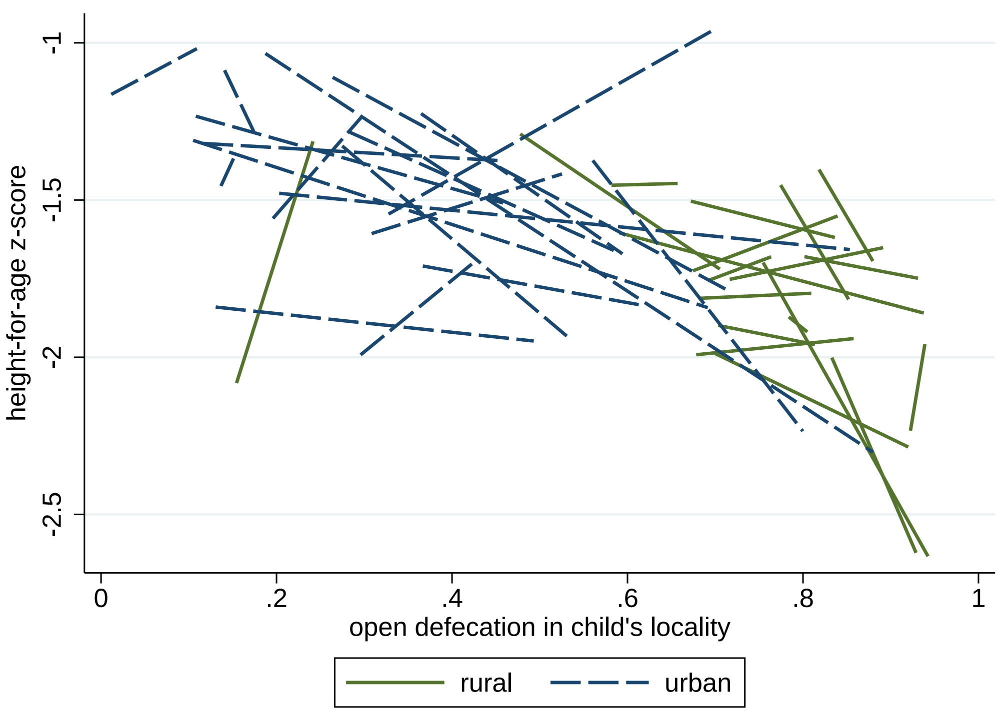


Figure 2: Change over time in open defecation and child height, 2005-2010

Panel (a) presents Cambodia-wide local non-parametric regressions by year, along with collapsed year averages. In panel (b), for each rural or urban part of a province, its 2005 (open defecation, child height) point is connected with its 2010 point, to depict change over time within provinces.

Table 1: Summary statistics: Improvements in height, sanitation, and living standards

	2005	2010	t-statistic 2005 = 2010
height-for-age z-score	-1.77	-1.64	2.65
	(0.04)	(0.03)	
open defecation in child's locality	0.75	0.61	-6.27
	(0.02)	(0.02)	
household open defecation	0.78	0.65	-5.65
	(0.02)	(0.02)	
urban residence	0.14	0.16	0.76
	(0.02)	(0.02)	
consumption	3756	5148	12.38
	(81)	(78)	
local electrification	0.19	0.29	3.98
	(0.02)	(0.02)	
mother's height	152.62	152.79	0.91
	(0.13)	(0.14)	
mother's BMI	20.84	20.98	1.39
	(0.07)	(0.07)	
n (children under 5)	3,587	3,699	

Table presents sample means, with standard errors in parentheses computed to reflect survey design. Note that this table is representative of children under 5 and not of all Cambodians.

Table 2: Regression results: Open defecation in the child's locality predicts child height

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Without rural and urban province part fixed effects							
open defecation		-0.838***	-0.675***	-0.578***	-0.475***	-0.500***	-0.462***
in child's locality		(0.0748)	(0.146)	(0.131)	(0.126)	(0.116)	(0.113)
year 2010	0.129***	0.0124	0.0214	0.0322	0.0721	0.0464	-0.00410
	(0.0488)	(0.0474)	(0.0471)	(0.0447)	(0.0516)	(0.0480)	(0.0490)
household open			-0.144**	-0.116**	0.00411	0.0404	0.0449
defecation			(0.0627)	(0.0582)	(0.0594)	(0.0577)	(0.0573)
electrification in			0.0199	0.0389	-0.0922	-0.0739	-0.0858
child's locality			(0.108)	(0.0988)	(0.137)	(0.129)	(0.128)
urban			0.00186	-0.000237	-0.0529	-0.0620	-0.0502
			(0.0735)	(0.0684)	(0.0653)	(0.0637)	(0.0631)
mother's height				0.0568***	0.0553***	0.0567***	0.0564***
				(0.00364)	(0.00356)	(0.00341)	(0.00341)
mother's BMI				0.0233***	0.0209**	0.0259***	0.0249***
				(0.00686)	(0.00693)	(0.00681)	(0.00686)
household controls					✓	✓	✓
child demography						✓	✓
health controls							✓
n (children under 5)	7,286	7,286	7,184	7,168	7,168	7,168	7,168
Panel B: With rural and urban province part fixed effects							
open defecation		-0.771***	-0.587***	-0.501***	-0.444***	-0.469***	-0.432***
in child's locality		(0.0973)	(0.142)	(0.128)	(0.128)	(0.120)	(0.117)
year 2010	0.118**	0.00966	0.0164	0.0287	0.291	0.232	0.159
	(0.0463)	(0.0449)	(0.0447)	(0.0432)	(0.152)	(0.145)	(0.145)
household open			-0.137**	-0.108	0.00720	0.0413	0.0458
defecation			(0.0622)	(0.0590)	(0.0590)	(0.0574)	(0.0571)
electrification in			0.0594	0.0626	-0.0788	-0.0606	-0.0743
child's locality			(0.101)	(0.0939)	(0.137)	(0.131)	(0.130)
mother's height				0.0544***	0.0537***	0.0549***	0.0547***
				(0.00355)	(0.00360)	(0.00342)	(0.00341)
mother's BMI				0.0257***	0.0227**	0.0276***	0.0264***
				(0.00692)	(0.00692)	(0.00685)	(0.00690)
household controls					✓	✓	✓
child demography						✓	✓
health controls							✓
n (children under 5)	7,286	7,286	7,184	7,168	7,168	7,168	7,168

Standard errors clustered by survey primary sampling unit in parentheses. Two-sided p values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All specifications include 120 age-in-month dummies, separately for boys and girls.

Table 3: Model averaging estimates of effect of open defecation on child height

	Model averaging technique:	
	Bayesian Model Averaging	Weighted-Average Least Squares
Without rural-urban province part fixed effects:	-0.519	-0.468
	(0.056)	(0.089)
With rural-urban province part fixed effects:	-0.478	-0.376
	(0.077)	(0.096)

Note: Estimates are of β_1, the linear association between PSU open defecation rate and child height-for-age z score also estimated in Table 2. The sample is the same 7,168 children under 5 in columns 4-7 of Table 2. Focus parameters included in every specification include, in addition to PSU open defecation, a constant, an indicator for the year 2010, and 120 age-in-months by sex dummies. Eight auxiliary regressors are PSU electrification, household electrification, household open defecation, whether the household owns a radio, whether the household owns a TV, household size, mother's height, and mother's BMI, making a search space of 512 models.

Table 4: Decomposition results: Fraction of 2005-2010 height change explained by improving sanitation

	difference between 2005 and 2010 mean heights		
decomposition method	before sanitation	after sanitation	percent explained:
regression, OLS	0.129	0.012	90
regression, fixed effects	0.118	0.010	92
Blinder-Oaxaca	0.129	0.001	98
reweighted mean	0.13	-0.02	115

"Blinder-Oaxaca" is a two-way decomposition with equal weight on within-sample slopes. "Reweighted mean" constructs a counterfactual mean 2005 height by reweighting the 2005 sample to match the sanitation distribution of the 2010 sample; the after difference is negative because the counterfactual 2005 height is slightly greater than the real 2010 height. Regression results are reinterpreted from table 2. "Before sanitation" is the simple average difference; "after sanitation" is the unexplained difference after accounting for the improvement in open defecation.