Desert Locust Swarms and Child Health

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Abstract: This study evaluates how in-utero exposure to an insect pest invasion, particularly, the outbreak of desert locust swarms, affects early childhood health in Africa and Asia over the past three decades (1990-2018). Employing the difference-in-differences model, we find that children being prenatally exposed to the outbreak have their height-for-age, weight-for-height, and weight-for-age z-scores lower by 0.159, 0.148, and 0.155 standard deviations, respectively, compared to unexposed children. Our heterogeneity analyses show that the health setbacks disproportionately fall on children of disadvantaged backgrounds, i.e., those born to lower-educated mothers, poorer mothers, and rural mothers. To the extent that poor health in early life exerts long-lasting irreversible consequences over the life cycle, the study calls for effective measures to minimize the pernicious effects of the desert locust swarm outbreak.

Keywords: Desert Locust; Child Health; Developing Countries.

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1 Introduction

Among the most dangerous migratory pests in the world, desert locusts that have the ability to form large swarms of adults can impose a huge economic burden on societies. For example, the desert locust swarm outbreak in Ethiopia in 2020 alone destroyed 356,286 metric tons of cereal, 197,163 hectares of cropland, and 1,350,000 hectares of pasturelands, pushing one million Ethiopians into acute food insecurity (World Bank, 2020). Besides the agricultural loss, there is an added cost of the locust outbreak response and control operations which require millions of liters of pesticides along with substantial equipment and labor (Kalakkal and Singh, 2021). For example, the total cost of response and control operations during the 2003-2005 locust plague in West and North Africa amounted to 570 million USD (Kalakkal and Singh, 2021).

In this study, we investigate the extent to which in-utero exposure to the desert locust swarm outbreak influences the health outcomes of children in early childhood. By doing so, the contribution of the study is three folds. First, we evaluate the less salient impacts of an insect pest invasion, specifically the desert locust swarm outbreak, on early human health, whereas other studies tend to look at the more discernible effects at the aggregate level. Therefore, our study sheds additional light on the relationship between insect pest invasion and human wellbeing. Second, our study complements the literature on the persistent effects of in-utero conditions on later-life outcomes by examining the consequences of prenatal exposure to the desert locust swarm outbreak on child health. In other words, our paper tests the fetal origins hypothesis by focusing on a different condition experienced during the intrauterine period. Finally, our study sample does not particularly focus on one single country, but covers 39 countries in the entire regions affected by the desert locust swarm outbreak, including Africa, West Asia, and South Asia between 1990 and 2018. The wide spatial and temporal coverage could make our results meaningful to policymakers in many countries affected by desert locusts.

To quantify the impacts of prenatal exposure to the desert locust swarm outbreak on child health, we employ the Schistocerca Warning and Management System (SWARMS) databases for the information on desert locust swarms and the Demographic and Health Surveys supplemented with the Global Positioning System components (DHS-GPS) for information on children. The SWARM provides the timing and geographic location associated with each incident related to the presence of a locust swarm. The DHS-GPS supplies the child health measures and characteristics of children as well as their mothers. The GPS component provides the geographic location of the residential area the child's household falls into, which allows us to merge the child data with the locust data. Our empirical strategy is the difference-in-differences model that exploits the differences in the health outcomes of children born to mothers experiencing the desert locust swarm outbreak during pregnancy and the health outcomes of those born to mothers unexposed to such an outbreak during pregnancy within the same district, relative to the analogous differences for mothers residing in a different district.

The results of our study can be summarized as follows. First, we detect adverse impacts of in-utero exposure to the desert locust swarm outbreak on child health. In particular, children being prenatally exposed to the outbreak have their height-for-age, weight-for-height, and weight-for-age z-scores lower by 0.159, 0.148, and 0.155 standard deviations, respectively, compared to unexposed children. Second, we do not detect significantly differential impacts across trimesters. To put it differently, exposure to the outbreak across three trimesters is all harmful to early childhood health. Third, exposed children born to lower-educated mothers, poorer mothers, and rural mothers, are disproportionately affected by the desert locust swarm outbreak, which highlights the vulnerability of children of disadvantaged backgrounds. Finally, the effect of being prenatally exposed to the outbreak on child's height-for-age cannot be recovered. On the other hand, the effect on weight-for-height can be recovered in around 42.7 months. It takes a little longer (64.7 months) for the effect on weight-for-age to go away.

Our findings underscore the serious cost of an insect pest invasion, particularly the desert locust swarm outbreak, to early human health. To the extent that poor health in early life exerts long-lasting irreversible consequences over the life cycle such as increased vulnerability to diseases, fewer educational years completed, and lower earnings (Martorell, 1999; Alderman et al., 2006; Briend and Berkley, 2016), in-utero exposure to the desert locust swarm outbreak could hamper long-term human development. Therefore, the study calls for measures to mitigate the impacts of the desert locust swarm outbreak on child health. Immediate solutions may include the provision of food and financial support to affected households to help pregnant women gain access to adequate nutrition and prenatal care. Post-outbreak rehabilitation initiatives are essential to recovering household income, which may curtail the duration of disruption to pregnant women. A longer-term solution might include developing surveillance and early warning systems to assuage the threat of future outbreaks.

Our paper proceeds as follows. Section 2 discusses the study background. Section 3 describes the data. Section 4 presents the empirical methodology. Section 5 discusses the results. Section 6 concludes.

2 Study Background

2.1 Overview of Desert Locust Swarms

Locusts belong to the grasshopper family Acrididae. However, locusts differ from grasshoppers in their ability to change their color, shape, and behavior under favorable meteorological conditions (Steedman, 1990). Non-flying juvenile locusts (or hoppers) can form masses called hopper bands while the flying adult locusts can form swarms consisting of millions of individual locusts which behave as a cohesive unit.

The desert locust (Schistocerca gregaria) is a species of locust that can be found in the desert zones across Africa, West Asia, and South Asia. According to the World Meteorological Organization (WMO) and Food and Agriculture Organization (FAO) of the United Nations (2016), desert locusts behave as individuals and are innocuous when their numbers are low. Nevertheless, under suitable conditions, usually a long period of dry spells followed by heavy rains, desert locusts breed abundantly, increase rapidly in number, and behave as a single mass, leading to the formation of hopper bands and adult swarms (WMO and FAO, 2016). Desert locust swarms can cover from less than one square kilometer to over 1000 square kilometers and each square kilometer of a swarm may consist of between 40 million to 80 million adult locusts (FAO, 2020).

In addition, it is documented that desert locust swarms are especially damaging to agricultural livelihoods. Swarms can fly over great distances and eat most of the green vegetation wherever they settle. A large swarm can voraciously feed on up to 1.8 million metric tons of green vegetation, equivalent to the amount of food for 81 million people (World Bank, 2020). Desert locust swarms can multiply exponentially in size and number and spread over a large area, threatening agricultural and livestock production as well as food supply. Outbreaks usually affect a large area of Africa, West Asia, and South Asia.

2.2 Literature Review

Our study can be related to two strands of literature. The first strand of literature explores the impacts of in-utero events on child health. For example, Dimitrova and Bora (2020), Randell et al. (2020), and Le and Nguyen (2021) document that in-utero exposure to weather shocks can lead to poorer health in early childhood. In the context of India and Ethiopia, Dimitrova and Bora (2020) and Randell et al. (2020) show that being prenatally exposed to excessive rainfall raises the incidence of stunting among young children. Le and Nguyen (2021) provide evidence that both abnormally wet and abnormally dry conditions during the intrauterine period worsen child's anthropometric z-scores in many developing countries. Another type of adverse shock during the intrauterine period that can be harmful to the health outcomes of children is armed conflict. Particularly, fetal exposure to armed conflict reduces the weight of Ivory and Afghan children (Minoiu and Shemyakina, 2012; Oskorouchi, 2019). Furthermore, experiencing food price inflation during the intrauterine period can be devastating to child health. Woldemichael et al. (2017) show that intrauterine exposure to food price surges makes Ethiopian children more likely to be stunted and underweight. Miller (2017) detect the growth deficit among Ethiopian children if they were prenatally exposed to food scarcity. Our study contributes to this branch of literature by exploiting the desert locust swarm outbreak as an in-utero adverse event to explore the impacts on child health.

The second line of literature that our study also fits into concentrates on the effects of insect pest invasion on economic outcomes. Pratt et al. (2017) and Sharma et al. (2018) document that invasive insect pests can cause major crop loss and endanger food security in Africa and India, thus adversely affecting household income and the national economy. Focusing on arthropods, Venette and Hutchison (2021) report that such an invasive insect species can pose substantial risks to food supplies, clean water, and sustainable economies. The authors further underline the adverse effects on human health through the use of intensive pesticides. Besides these short-run impacts, the long-run effects of insect pest invasion are also documented. Banerjee et al. (2010) study the phylloxera crisis in France and show that children born during the crisis tend to have shorter stature in adulthood. The authors explain that the phylloxera crisis negatively affects incomes for households that live on wine production. In another context, Baker et al. (2020) document that boll weevil infestation raised the educational attainment for young children in the Southern U.S. The authors suggest that the conflict between child labor in agriculture and educational attainment may be the potential mechanism. Our study complements this line of literature by evaluating how insect pest invasion, particularly the desert locust swarm outbreak, influences the health outcomes of children in the Africa, West Asia, and South Asia regions.[2]

3 Data

3.1 Data on the Desert Locust Outbreak

Information on the desert locust outbreak is drawn from the Schistocerca Warning and Management System (SWARMS) database. The SWARM is managed by the Desert Locust Information Service of the United Nations' Food and Agriculture Organization to monitor, forecast, and control desert locust swarms. The SWARM is a rich source of information on locusts since 1985, including their breeding grounds, distribution, the incidence of adult locusts, and swarms, among others.

[2] Our work can also be related to studies on other factors affecting child health such as maternal education, political violence, refugee issues, wealth, and nutrition intervention programs (Duc, 2019; Galasso, 2019; Tranchant et al., 2020; Nsababera, 2020; Le and Nguyen, 2020a; Le and Nguyen, 2020b).

As we are interested in evaluating the impacts of the outbreak of desert locust swarms, we exclusively focus on the information about swarms. The SWARM provides the date and the geographic location (that can be identified with a pair of latitude-longitude coordinates) associated with each incident related to the presence of a locust swarm. Given such exact spatial information, we can identify which residential district the incidents occur.

In Figure 1, we illustrate the spatial distribution of desert locust swarm outbreaks drawn from the SWARM database. Here, each red dot indicates an incident of locust swarm. The figure also shows that the desert locust swarm outbreaks mainly occur in Africa, West Asia, and South Asia (shaded regions). Besides, Figure A1 (Appendix) further illustrates the temporal distribution of desert locust swarm outbreaks where each blue bin indicates the number of affected districts in each month. The widespread impacts of the three worst locust infestations since 1980 (the 1986-1989, 2003-2005, and 2019-2021 infestations) can also be recognized by significant increases in the number of affected districts.

Figure 1: Spatial Distribution of Desert Locust Swarm Incidents

Note: Incidents of Swarms are illustrated by red dots.

3.2 Data on Children

The data on children are retrieved from the Demographic and Health Survey (DHS). Administered in over 90 developing countries across the world, the DHS provides nationally representative data on health and population. In this study, we utilize the DHS waves for the Africa, West Asia, and South Asia regions because they are the ones affected heavily by the desert locust outbreak. We mainly draw from the Woman's Questionnaire of the DHS that targets women of reproductive ages (15-49) and collects information on their background characteristics (education, current age, age at birth, etc.), the characteristics of their children (month-year of birth, gender, birth order, etc.), and the children's health outcomes. Child health outcomes are measured by anthropometric z-scores, including, height-for-age, weight-for-height, and weight-for-age, which are collected for children under the age of five (i.e., up to 59 months of age).

Height-for-age, weight-for-height, and weight-for-age z-scores are calculated based on WHO Child Growth Standards derived from the WHO Anthro statistical package. The z-score captures the number of standard deviations each anthropometric measure is below or above the median of the international reference population. As commonly used measures for child health, height-for-age, weight-for-height, and weight-for-age z-scores reflect the nutrition and growth status of children in both the long run and the short run (WHO, 2008). A low height-for-age can be caused by the deficiency of growth-supporting nutrients over a long period of time or recurrent illnesses, thus reflecting the long-run health condition. A low weight-for-height can be caused by serious decreases in food consumption or severe illnesses in recent times, thus indicating the short-run health condition. Weight-for-age reflects both short-run and long-run health as it is influenced by both height-for-age and weight-for-height.

In order to merge with the data on the desert locust outbreak, we need the locations of children. Therefore, we employ the DHS waves that are supplemented with the Global Positioning System (DHS-GPS) that provides geographic locations of children.[3] Specifically, in the DHS-GPS, the residential cluster the child's household belongs to can be identified with a pair of latitude and longitude.[4] Given such exact spatial information, we can identify which residential district the child resides in.

3.3 Estimation Sample

With the detailed geographic information from the DHS-GPS and the SWARM, we can identify whether the child's district of residence experienced the desert locust outbreak or not. Given that the timing of the outbreak is available from the SWARM and the child's birth month-year is present in the DHS-GPS, we can calculate whether a child was prenatally exposed to the desert locust swarm outbreak. Our main explanatory variable, Affected by Desert Locust, is an indicator that takes the value of one if the mother experienced the locust outbreak in her residential district during pregnancy. For instance, a child born in September 2010 was prenatally exposed to the desert locust swarm outbreak (Affected by Desert Locust = 1) if the outbreak happened in his/her residential district any time between January and September 2010. If the outbreak occurred and ended in his/her district prior to January 2010 or after September 2010, then the child was unexposed to the outbreak during the in-utero period (Affected by Desert Locust = 0).

[3] The list of 39 countries in the focused region with DHS-GPS available includes: Angola, Bangladesh, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo Democratic Republic, Cote d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Guinea, India, Jordan, Kenya, Liberia, Madagascar, Malawi, Mali, Morocco, Mozambique, Namibia, Nepal, Niger, Nigeria, Pakistan, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

[4] It is worth noting that the coordinates are randomly displaced by a very small distance (2-5 km) to reduce disclosure risk. The process is completely randomized and computerized, thus omitted variable bias is unlikely.

Our final estimation sample consists of 559,275 under-five children. Descriptive statistics for the outcome and explanatory variables are reported in Panels A and B of Table 1, respectively. As shown in Panel A, the average height-for-age, weight-for-height, and weight-for-age z-scores are -1.409, -0.504, and -1.162 standard deviations, respectively. Because our sample consists of mostly poor countries, the mean values of the anthropometric z-scores are negative, indicating that the health measures of children in our sample are lower than the median of the reference population which also includes children from richer countries.

Table 1: Summary Statistics (N = 559,275 for all variables)

	Mean (1)	SD (2)
Panel A: Dependent Variables		
Height-for-age Z-score	-1.409	1.701
Weight-for-height Z-score	-0.504	1.445
Weight-for-age Z-score	-1.162	1.288
Panel B: Independent Variables		
Affected by Desert Locus	0.006	0.071
Mother's Age	28.34	6.288
Mother's Age at Birth	26.39	6.148
Mother's Education	5.120	5.001
Residing in Urban Areas	0.273	0.446
Wealth Index	-0.212	1.993
Male Child	0.508	0.500
Child's Age in Months	28.87	17.10
Child's Birth Order	3.097	2.163
Being a Plural Birth	0.012	0.107
Rainfall	0.004	0.208

Evident from Panel B, approximately 0.6% of children were prenatally exposed to the desert locust swarm outbreak. On average, mothers are 28.3 years old at the time of the survey and 26.4 years old at birth. The mean educational years of mothers are 5.1. Roughly 27.3% of mothers live in urban areas and the average wealth index (a continuous scale of relative wealth based on ownership of selected assets) is -0.21. Around 50.8% of the children are male. The mean age of children is

28.9 months. The average birth order is 3.1. Approximately 1.2% of the births are plural births. Here, we also have rainfall as an independent variable to rule out the possibility that the impacts of being prenatally exposed to the outbreak might have picked up the impacts of rainfall. Our rainfall measure, which is calculated as the average of log deviation of annual rainfall from the long-run local norm prior to the outbreaks, takes the mean value of 0.004.[5]

4 Empirical Methodology

To quantify the relationship between in-utero exposure to the desert locust swarm outbreak and child health outcomes, we estimate the following regression equation,

$$Y_{ijts} = \beta_0 + \beta_1 ADL_{jt} + \delta_j + \theta_t + \lambda_s + X'_{ijts}\Omega + \epsilon_{ijts} \quad (1)$$

where the subscripts i, j, t, and s corresponds to child, district, month-year of birth, and survey month-year, respectively. The variable Y_{ijts} represents child health outcomes measured by the three anthropometric z-scores, including, height-for-age, weight-for-height, and weight-for-age. Our explanatory variable, ADL_{jt}, takes the value of one if the child was prenatally exposed to the desert locust outbreak, and zero otherwise. We also denote by δ_j, θ_t, and λ_s district, birth month-year, and survey month-year fixed effects, respectively. The vector X'_{ijts} is a covariate of child's characteristics (age in months, age in months squared, gender, birth order, plural birth indicator) and mother's characteristics (age, age squared, age at birth, age at birth squared, rainfall, education, wealth index, and if the household lives in urban areas). Finally, ϵ_{ijts} is the error term. Standard errors throughout the paper are clustered at the district level.

[5] Following Maccini and Yang (2009), rainfall is measured as the average of log deviation of rainfall from the long-run local average of rainfall (1990-2020) in the residential cluster. Rainfall data are drawn from the latest version of the Climatic Research Unit Time Series (version 4.03) produced by the United Kingdom's National Center for Atmospheric Science at the University of East Anglia's Climatic Research Unit.

The coefficient of interest is β_1 that captures the impacts of fetal exposure to the desert locust swarm outbreak on child health. In this difference-in-differences (DiD) setup, we compare the health outcomes of children born to mothers experiencing the locust outbreak during pregnancy with those born to mothers unexposed to such an outbreak during pregnancy within the same district, relative to the analogous differences for mothers residing in a different district. The identifying assumption underlying the DiD framework is that the timing of the desert locust swarm outbreak is unrelated to within district unobserved factors that could potentially affect child health.

5 Results

5.1 Main Results

The estimated impacts of in-utero exposure to desert locust swarm invasion on child's height-for-age, weight-for-height, and weight-for-age are provided in Tables 2, 3, and 4, respectively. In these tables, Column 1 displays the estimate from the most parsimonious specification where we only control for our main explanatory variable, the indicator Affected by Desert Locust. In Column 2, we add birth month-year, survey month-year, and district fixed effects to the most parsimonious specification. In Column 3, we further control for mother characteristics (mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas). Finally, Column 4 represents our most extensive specification where we account for child characteristics (child's age in months, squared-age in months, gender, birth order, and whether the child is plural birth), in addition to the fixed effects and mother characteristics.

Height-for-age – The impacts of fetal exposure to the outbreak of desert locust swarms on child's height-for-age are displayed in Table 2. According to Column 1, children being prenatally exposed to the incident have 0.196 standard deviations lower height-for-age z-scores compared to unexposed children. However, the estimate from the most parsimonious specification only reflects the correlation between desert locust swarm outbreak exposure and child health as important factors that could jointly affect exposure status and health are not accounted for. In Column 2, with the inclusion of birth month-year, survey month-year, and district fixed effects, the estimate becomes larger in magnitude and more statistically significant. Specifically, in-utero exposure to the desert locust swarm outbreak lowers in height-for-age z-scores in early childhood by 0.244 standard deviation. Further controlling for mother's characteristics leaves the estimate virtually unchanged (Column 3). Finally, according to our most extensive specification in Column 4, children prenatally exposed to desert locust swarm invasion tend to be 0.159 standard deviations shorter for their age.

Table 2: Desert Locust Swarm Outbreak and Child's Height-for-age

	Y = Height-for-age Z-score			
	(1)	(2)	(3)	(4)
Affected by Desert Locust	-0.196***	-0.244***	-0.241***	-0.159***
	(0.073)	(0.065)	(0.065)	(0.050)
Observations	559,275	559,266	559,266	558,595
Child Characteristics	.	.	.	X
Mother Characteristics	.	.	X	X
Fixed Effects	.	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The dependent variable is height-for-age z-score. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

Weight-for-height – The estimated impacts of in-utero exposure to the desert locust swarm outbreak on child's weight-for-height z-score are displayed in Table 3. The most parsimonious specification produces the negative and statistically significant estimate of -0.216 (Column 1). The estimate does not adequately reflect the relationship between locust outbreak exposure during the prenatal period and child's weight-for-height z-score because important factors affecting child health have not been controlled for. For instance, children living in areas where higher quality health facilities are present may be equipped with better resources to counteract the adverse consequences of the locust outbreak. Even when children live in the same district, being born at different times of the year means they might have been exposed to different environments that could be particularly beneficial or unfavorable to their health. We deal with these issues by introducing a series of time and location fixed effects (Column 2). Controlling for birth month-year, survey month-year, and district fixed effects, desert locust outbreak exposure during the prenatal period is linked to a 0.145 decrease in weight-for-height z-score in early childhood.

Table 3: Desert Locust Swarm Outbreak and Child's Weight-for-height

	Y = Weight-for-height Z-score			
	(1)	(2)	(3)	(4)
Affected by Desert Locust	-0.216***	-0.145***	-0.142***	-0.148***
	(0.063)	(0.045)	(0.045)	(0.044)
Observations	559,275	559,266	559,266	558,595
Child Characteristics	.	.	.	X
Mother Characteristics	.	.	X	X
Fixed Effects	.	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The dependent variable is weight-for-height z-score. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

In Column 3, we add mother characteristics to the specification in Column 2. The estimate is relatively unchanged compared to the one in Column 2. Specifically, children being prenatally exposed to the outbreak of desert locust swarms tends to be 0.142 standard deviations thinner for their height. Finally, in the most extensive specification, affected children have weight-for-height z-scores 0.148 standard deviations lower than unexposed children (Column 4).

Weight-for-age – The estimated impacts of fetal exposure to the desert locust swarm outbreak on child's weight-for-age z-score are displayed in Table 4. The most parsimonious specification in Column 1 shows a negative correlation between outbreak exposure during gestation and weight-for-age z-score. With the inclusion of birth month-year, survey month-year, and district fixed effects, we still find that the desert locust swarm outbreak adversely affects child's weight-for-age z-score in early childhood (Column 2). Controlling for child's characteristics, Column 3 suggests that children prenatally exposed to the outbreak tend to be 0.183 standard deviations thinner for their age. The most extensive specification in Column 4 also points to the negative effects of the incident on child's weight-for-age. Specifically, prenatally exposed children have weight-for-age z-scores 0.155 standard deviations lower than unexposed children.

Table 4: Desert Locust Swarm Outbreak and Child's Weight-for-age

	Y = Weight-for-age Z-score			
	(1)	(2)	(3)	(4)
Affected by Desert Locust	-0.199***	-0.185***	-0.183***	-0.155***
	(0.065)	(0.040)	(0.039)	(0.037)
Observations	559,275	559,266	559,266	558,595
Child Characteristics	.	.	.	X
Mother Characteristics	.	.	X	X
Fixed Effects	.	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The dependent variable is weight-for-age z-score. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

5.2 Heterogeneity Analysis

So far we have detected adverse impacts of in-utero exposure to the desert locust swarm outbreak on child health. In this section, we proceed to explore the heterogeneous impacts along the lines of maternal education, maternal wealth, and mother's locational status. The estimating results are displayed in Table 5. In Table 5, for each panel, each column represents a separate regression and the panel name indicates the dimension of heterogeneity. The estimates come from our most extensive specifications (similar to Column 4 in Tables 2 through 4).

First, we examine if children born to mothers with different levels of educational attainment are differentially affected by the desert locust outbreak. To do so, we add an interaction term between the exposure status and mother's years of education (Affected by Desert Locust x Education). This interaction term measures the degree to which the impacts of the desert locust swarm outbreak are higher or lower for mothers with higher levels of educational attainment. Evident from Panel A, the impacts of the outbreak are larger for children born to mothers with low educational attainment. Particularly, being prenatally exposed to the desert locust outbreak makes children of uneducated mothers 0.221, 0.180, and 0.206 standard deviations shorter for their age, thinner for their height, and thinner for their age, respectively (Education is zero, thus Affected by Desert Locust x Education is also zero). Then, for each additional year of education, these impacts become smaller by 0.030, 0.016, and 0.025 standard deviations, respectively. The results highlight the vulnerability of children born to mothers with low educational attainment. To put it differently, maternal education can be a cushion against adverse shocks such as the desert locust invasion.

Second, we test if children born to mothers with different levels of wealth are differentially affected by the desert locust outbreak. Thus, we add an interaction term between the exposure status and mother's wealth index (Affected by Desert Locust x Wealth) to examine the extent to which the impacts are higher or lower for mothers with higher levels of wealth. As shown in Panel B, we find that the impacts of the outbreak are larger for children born to mothers with low levels of wealth. Particularly, being prenatally exposed to the desert locust outbreak makes children of mothers having wealth index of zero (Wealth is zero) 0.136, 0.128, and 0.130 standard deviations shorter for their age, thinner for their height, and thinner for their age, respectively. Then, for each additional increase/decrease in the standardized wealth index, these impacts become smaller/larger by 0.136, 0.121, and 0.154 standard deviations, respectively. Thus, it is possible that wealthier mothers have better resources to protect their children from the adverse consequences of the desert locust invasion.

Finally, we explore the heterogeneous impacts of the desert locust swarm outbreak by mother's locational status by adding an interaction term between the exposure status and an indicator for whether the mother resides in the urban area (Affected by Desert Locust x Urban). As reported in Panel C, children born to mothers residing in rural areas bear more serious health setbacks due to the outbreak than those born to mothers residing in urban areas. Specifically, if children born to rural mothers were affected by the locust outbreak during gestation, they tend to have 0.225, 0.191, and 0.218 standard deviations lower height-for-age, weight-for-height, and weight-for-age z-scores in early childhood, respectively (Urban is zero, thus Affected by Desert Locust x Urban is also zero). However, the corresponding impacts are 0.260, 0.171, and 0.245 smaller in magnitude among children born to urban mothers. It is possible that the desert locust invasion tends to hit rural life where agriculture is the primary occupation harder than it does to urban life, leaving more harmful impacts on children born to rural mothers.

Table 5: Desert Locust Swarm Outbreak and Child Health - Heterogeneity Analysis

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
Panel A: Education			
Affected by Desert Locust	-0.221***	-0.180***	-0.206***
	(0.060)	(0.047)	(0.042)
Affected by Desert Locust x Education	0.030***	0.016**	0.025***
	(0.009)	(0.007)	(0.006)
Observations	558,595	558,595	558,595
Panel B: Wealth			
Affected by Desert Locust	-0.136***	-0.128***	-0.130***
	(0.050)	(0.042)	(0.036)
Affected by Desert Locust x Wealth	0.136***	0.121***	0.154***
	(0.043)	(0.033)	(0.034)
Observations	558,595	558,595	558,595
Panel C: Location			
Affected by Desert Locust	-0.225***	-0.191***	-0.218***
	(0.059)	(0.044)	(0.043)
Affected by Desert Locust x Urban	0.260***	0.171***	0.245***
	(0.081)	(0.066)	(0.064)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

5.3 Trimester Analysis

Our main results show that prenatal exposure to the desert locust swarm outbreak is detrimental to the health outcomes of children in early childhood. In this section, we further explore the relative importance of exposure timing. Specifically, we want to know exposure to the incident in which trimester exerts the largest impacts on child health. To do so, we replace the single indicator

Affected by Desert Locust in the main model in equation (1) with three indicators namely, 1st Trimester Exposure, 2nd Trimester Exposure, and 3rd Trimester Exposure, which indicates whether the child was prenatally exposed to the desert locust outbreak in the first, second, and third trimester, respectively. The estimating results are reported in Table 6. All presenting estimates come from our most extensive specifications (similar to those in Column 4 in Tables 2 through 4).

Table 6: Desert Locust Swarm Outbreak and Child Health - Trimester Analysis

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
1st Trimester Exposure	-0.085	-0.160***	-0.136***
	(0.058)	(0.047)	(0.043)
2nd Trimester Exposure	-0.175**	-0.138**	-0.163***
	(0.079)	(0.057)	(0.060)
3rd Trimester Exposure	-0.162***	-0.027	-0.075**
	(0.055)	(0.052)	(0.039)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

Regarding height-for-age, Column 1 shows that exposure to the desert locust swarm outbreak during the first, second, and third trimester leads to the 0.085, 0.175, and 0.162 standard deviation decreases in height-for-age z-scores, respectively. As for weight-for-height, exposure during the first, second, and third trimesters make children 0.160, 0.138, and 0.027 standard deviations thinner for their height, respectively (Column 2). About weight-for-age, exposure to the outbreak during the first, second, and third trimesters makes children 0.136, 0.163, and 0.075 standard deviations thinner for their age, respectively (Column 3). Overall, there are no heterogeneous impacts of exposure across trimesters, i.e. exposure to the desert locust swarm outbreak in all three trimesters are all harmful to children's health outcomes in early childhood.[6]

5.4 Persistence Analysis

The main analyses suggest that being prenatally exposed to the desert locust outbreak makes children shorter for their age, thinner for their height, and thinner for their age. However, it is worth noting that these relationships are not only about height and weight, but also about the extent to which the effects of being prenatally exposed to the outbreak persist over time. In particular, a low height-for-age can be caused by the deficiency of growth-supporting nutrients affecting the long-run health condition. A low weight-for-height can be caused by serious decreases in food consumption indicating the short-run health condition. Weight-for-age reflects both short-run and long-run health as it is influenced by both height-for-age and weight-for-height.

Therefore, it is also important to look at the temporal dimension of the impacts of interest, thus addressing questions such as whether the impacts persist or diminish over time. To do so, we introduce an interaction term between the exposure status and child's age in month (Affected by Desert Locust x Age (in month)). This interaction term measures the extent to which the impacts of the desert locust swarm outbreak become smaller as children get older. The estimating results

[6] Instead of examining the impacts of each trimester separately, we also investigate the accumulation impacts of exposure. To do so, we construct three explanatories, namely: (i) 1st Trimester Exposure indicates whether the child was prenatally exposed to the outbreak in the first trimester only, (ii) 1st & 2nd Trimester Exposure indicates whether the child was prenatally exposed in both first and second trimesters, and (iii) All Trimester Exposure indicates whether the child was prenatally exposed in all three trimesters. We re-run our most extensive specifications using these explanatories and report the estimates in Table A1 (Appendix). We find that the impacts of being prenatally exposed to the outbreak can be accumulated. The impacts of exposure in all three trimesters are more than triple the impacts of being exposed in any of the three trimester.

are reported in Table 7. Here, each column represents a separate regression. The estimates come from our most extensive specifications (similar to Column 4 in Tables 2 through 4).

Regarding height-for-age, Column 1 of Table 7 shows that exposure to the desert locust swarm outbreak during pregnancy lowers height-for-age z-score by 0.158 standard deviation. More importantly, the interaction term is close to zero and statistically insignificant, which means the effect of being prenatally exposed to the outbreak on child's height-for-age is permanent and cannot be recovered.

Table 7: Desert Locust Swarm Outbreak and Child Health - Persistence Analysis

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
Affected by Desert Locust	-0.158**	-0.342***	-0.259***
	(0.070)	(0.059)	(0.051)
Affected by Desert Locust x Age (in month)	0.000	0.008***	0.004**
	(0.003)	(0.002)	(0.002)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

As for weight-for-height and weight-for-age, exposure during pregnancy makes children 0.342 and 0.259 standard deviations thinner for their height and thinner for their age, respectively (Columns 2 and 3). The interaction term is statistically significant and takes a value of 0.008 in Column 2 as well as 0.004 in Column 3. This means that the effects of being prenatally exposed to the outbreak on child's weight-for-height and weight-for-age diminish over time at a rate of

0.008 and 0.004 standard deviations per month, respectively. Hence, on average, it takes around 42.7 and 64.7 months for children to fully recover from low weight-for-height and weight-for-age due to being exposed to the outbreak during pregnancy.

Overall, our persistence analysis suggests that the effect of being prenatally exposed to the outbreak on child's height-for-age cannot be recovered. On the other hand, the effect on weight-for-height can be recovered in around 42.7 months. It takes a little longer (64.7 months) for the effect on weight-for-age to go away.

5.5 Other Specifications

Recall that our main DiD model compares the health outcomes of children born to mothers experiencing the desert locust swarm outbreak during pregnancy with those born to mothers unexposed to such an incident during pregnancy within the same district, relative to the analogous differences for mothers residing in a different district. In this section, we adopt different specifications to test for the sensitivity of our results.

First, we use the household fixed effects model where the health outcomes of children prenatally exposed to the desert locust invasion are compared with the health outcomes of unexposed children from the same household. The within-household comparison will account for common characteristics among children from the same household that could be correlated with both the exposure status and health outcomes. The estimating results in Table 8 point to the negative impacts of fetal exposure to the desert locust swarm outbreak on child health. In particular, children prenatally exposed to such an incident tend to be 0.303, 0.158, and 0.249 standard deviations shorter for their age, thinner for their height, and thinner for their age, respectively. The estimates are statistically significant and slightly larger in magnitude than those in our main DiD model

(Column 4 in Tables 2 through 4). Overall, employing the household fixed effects model leaves our conclusion unchanged.

Table 8: Desert Locust Swarm and Child Health - Other Specification 1

	Household Fixed Effects		
	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (3)
Affected by Desert Locust	-0.303***	-0.158***	-0.249***
	(0.085)	(0.058)	(0.045)
Observations	300,116	300,116	300,116
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects (Household)	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects (Household) include birth month-year, survey month-year, and household fixed effects.

Table 9: Desert Locust Swarm and Child Health - Other Specification 2

	Mother Fixed Effects		
	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (3)
Affected by Desert Locust	-0.310***	-0.141**	-0.251***
	(0.083)	(0.058)	(0.047)
Observations	261,944	261,944	261,944
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects (Mother)	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects (Mother) include birth month-year, survey month-year, and mother fixed effects.

Second, we use the mother fixed effects model to estimate the impacts of interest. Within this empirical setup, we compare the health outcomes of siblings in which one was exposed to the desert locust swarm outbreak during the in-utero period while the other sibling was unexposed. The mother fixed effects model exploits the variation in exposure status of children born to the same mother, which could better control for unobserved heterogeneity in family endowments compared with the household fixed effects model that exploits the variation in exposure status of children from the same household.[7] The results reported in Table 9 suggest that experiencing the desert locust swarm outbreak during the in-utero period is harmful to child health. Children prenatally exposed to such an incident have height-for-age, weight-for-height, and weight-for-age z-scores 0.310, 0.141, and 0.251 standard deviations lower compared to their unexposed siblings. The mother fixed effects estimates are slightly larger in magnitude than the DiD estimates and the statistical significance level remains unchanged.

Here, we should take careful note of the use of the household and mother fixed effects models. In particular, these models reduce the sample size significantly since households or mothers with only one under-five child when being surveyed are omitted from the sample. Consequently, the estimates from these models may be biased, thus undesirable.

In the third specification, we add the sampling weights to our DiD regression. Doing so does not largely change our main results. Table 10 suggests that children prenatally exposed to the desert locust swarm outbreak are 0.188, 0.152, and 0.161 standard deviations shorter for their age, thinner for their height, and thinner for their age, respectively. In other words, our results are robust to the inclusion of sampling weights. We also note carefully that the use of sampling weights in

[7] It is worth noting that children living in the same household can still be born to different mothers because household size tends to be large in developing countries.

regressions might not be desirable because weighting can lower efficiency and statistical power (Winship and Radbill, 1994; Gelman, 2007; Solon et al., 2015).

Table 10: Desert Locust Swarm and Child Health - Other Specification 3

	Weighted Regressions		
	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (3)
Affected by Desert Locust	-0.188***	-0.152***	-0.161***
	(0.070)	(0.050)	(0.050)
Observations	555,736	555,736	555,736
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects. Sampling weight is applied for regressions in Column 1, 2, and 3.

Table 11: Desert Locust Swarm and Child Health - Other Specification 4

	Excluding Teen Mothers		
	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (3)
Affected by Desert Locust	-0.213***	-0.168***	-0.197***
	(0.055)	(0.049)	(0.042)
Observations	493,955	493,955	493,955
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects. Birth cases by teen mothers (age at birth<20) are excluded from regressions in Column 1, 2, and 3.

In the fourth exercise, we exclude teen mothers from our sample. It is because early age at childbirth such as teen pregnancy could result in poor birth outcomes, thus child health (Chen et al., 2007; Gibbs et al., 2012). One may be concerned that the estimated impacts of the desert locust outbreak are driven by teenage mothers. Therefore, we only include mothers aged 20 and above at childbirth in our sample. The results in Table 11 show that the exclusion of teenage mothers does not largely change our main results. Particularly, in-utero exposure to the desert locust swarm outbreak is associated with the 0.213, 0.168, and 0.197 standard deviation decreases in height-for-age, weight-for-height, and weight-for-age z-scores in early childhood, respectively.

Another concern is that misclassification bias could potentially be an issue to our analysis. Because of mismeasured birth dates, some children would be classified as exposed to the shock while they were not, and vice versa. Therefore, we conduct another robustness check where we only consider a child being exposed to the outbreak if he/she was exposed to the outbreak from the 2nd to the 8th month of pregnancy (instead of the 1st – 9th). Excluding the first and the last month of pregnancy allows us to avoid the potential misclassification bias for up to one month. The results are reported in Table A2 (Appendix). We continue to observe the statistically significant impacts of prenatal exposure to the locust outbreaks. Thus, the significant estimates in our main analysis are unlikely to be driven by misclassification bias.[8]

[8] We also have a robustness test for the Persistence Analysis (Section 5.4) where we regress the district's birth cohort mortality rates (the numbers of child deaths per 1,000 children of the same cohort in a given district) on the indicator for whether locust outbreak occurs. The estimating results are presented in Table A3. We find that the number of child deaths due to the outbreaks is the largest in the first 12 months after the outbreak (0.758 deaths per 1,000), and gradually decrease to the insignificant level at the period of 49-60 months after the outbreak. The finding here is consistent with our analysis in Section 5.4 where we find that the effects on child weight measures can be recovered in around 42.7 to 64.7 months.

5.6 Other Measures

In this section, we employ alternative measures of child health to test for the robustness of our results. In Table 12, percentile measures are utilized in place of the z-score measures. Height-for-age, weight-for-height, and weight-for-age percentiles indicate the ranking of the child's anthropometric measures among the reference population. We still detect the adverse relationship between in-utero exposure to the desert locust swarm outbreak and child health. Specifically, children prenatally exposed to such an incident have their rankings in height-for-age, weight-for-height, and weight-for-age lower by 5.359, 3.863, and 5.104 percentiles, respectively.

Table 12: Desert Locust Swarm Outbreak and Child Health - Other Health Measures 1

	Percentile Measures		
	Height-for-age Percentile (1)	Weight-for-height Percentile (2)	Weight-for-age Percentile (2)
Affected by Desert Locust	-5.359***	-3.863***	-5.104***
	(0.972)	(0.961)	(0.884)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

Next, we construct three nutrition indicators from the three anthropometric z-scores. Specifically, stunting, wasting, and underweight are dummy variables taking the value of one if height-for-age, weight-for-height, and weight-for-age z-scores are less than -2, respectively. The -2 threshold is established by WHO (2010). According to Table 13, children prenatally exposed to the desert locust swarm outbreak are 3.4, 3.2, and 5.5 percentage points more likely to be stunted, wasted, and underweight, compared to unexposed children.

Table 13: Desert Locust Swarm Outbreak and Child Health - Other Health Measures 2

	Indicator Measures		
	Stunting (1)	Wasting (2)	Underweight (2)
Affected by Desert Locust	0.034**	0.032***	0.055***
	(0.015)	(0.010)	(0.012)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficient in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects.

We also have a robustness check on the measure of our main explanatory (Affected by Desert Locust). Instead of using the indicator for exposure status, we construct a continuous variable to measure the intensity of exposure by counting the number of months affected by the outbreak during pregnancy. The estimating results are reported in Table A4 (Appendix) suggesting that an additional month exposed to the desert locust swarm outbreak lowers child's height-for-age, weight-for-height, and weight-for-age z-scores by 0.126, 0.082, and 0.105 standard deviations, respectively.

Taken together, our conclusion on the adverse relationship between in-utero exposure to the outbreak of desert locust swarms and early childhood health remains unchanged when employing other commonly used measures of child health.

5.7 Discussion

Collectively, we have presented compelling evidence for the detrimental impacts of in-utero exposure to the desert locust swarm outbreak on early childhood health. Specifically, children prenatally exposed to the outbreak have height-for-age, weight-for-height, and weight-for-age z-scores 0.159, 0.148, and 0.155 standard deviations lower compared to unexposed children. Exploring the heterogeneity in the impacts of the locust outbreak, we find that the incident disproportionately hit children of disadvantaged backgrounds such as those born to lower-educated mothers, those born to poorer mothers, and those born to rural mothers. Our trimester analysis shows that exposure to the desert locust swarm outbreak in all three trimesters of pregnancy is harmful to child health. Our persistence analysis suggests that the effect of being prenatally exposed to the outbreak on child's height-for-age cannot be recovered. On the other hand, the effects on weight-for-height and weight-for-age can be recovered in around 42.7 and 64.7 months, respectively. Employing different model specifications and different measures of outcome variables leaves our conclusions unchanged.

Our results are consistent with the fetal origins hypothesis, which proposes that the period of gestation has significant impacts on future health outcomes. The central point of the hypothesis is that changes in the maternal environment can cause three main forms of fetal programming (i.e. developmental changes, genetic changes, and epigenetic changes) that can affect later health outcomes. Within our context, the desert locust swarm outbreak can alter the maternal environment leading to fetal programming, thus child health, through three pathways.

The first pathway is nutritional deprivation. As desert locust swarms can voraciously feed on crops, trees, and grass, the locust outbreak can cause substantial destruction to agriculture and livestock production. For example, a small swarm of locusts (approximately 80 million locusts) can consume the amount of green vegetation that can feed 35,000 people while the amount that a large swarm consumes can feed up to 81 million people (World Bank, 2020). In other words, the desert locust swarm outbreak can disrupt the agricultural economy and threaten food security, potentially leading to famine and starvation. It is possible that pregnant women experiencing the outbreak do not have adequate access to food and important nutrients. There is evidence that nutritional deprivation during pregnancy could restrict fetal growth and raise the risk of the baby being born at a low birth weight (Belkacemi et al., 2010; Ramakrishnan et al., 2012). As infants with poor health will grow up to become unhealthy children, in-utero exposure to the desert locust swarm outbreak can be devastating to child health.

The second pathway through which desert locust swarm outbreak deteriorates child health is income shock. By decimating large areas of pastures and crops, the desert locust infestation can cause an adverse agricultural production shock that could dreadfully threaten livelihoods and depress household income. Once income thus standard of living is lowered, households may not afford health inputs for pregnant women such as health supplements and prenatal care. Women receiving insufficient care during pregnancy are likely to give birth to infants with unfavorable health conditions (Tura et al., 2013; Makate and Makate, 2017). Since such infants would grow up into unhealthy children, being prenatally exposed to the desert locust swarm outbreak is injurious to early childhood health.

The third pathway to the adverse impacts of the desert locust swarm outbreak can be the psychological distress on pregnant women. The enormous damage that the desert locust infestation inflicts on crops and livestock, thus household food supply and income, might put pregnant women under acute stress. The release of stress hormones, such as norepinephrine and cortisol, can be especially harmful to infant health (Wang and Yang, 2019; Bush et al., 2021). Moreover, psychological stress may weaken the immune system of the mothers and increase their susceptibility to illnesses, which could potentially expose the fetuses to health risks (Salleh, 2008; Vitlic et al., 2014). As infants with poor health conditions would grow up to be unhealthy in early childhood, in-utero exposure to the desert locust swarm outbreak can have inimical impacts on child health.

Our findings on the adverse relationship between fetal exposure to the outbreak of desert locust swarms and child health are consistent with the literature on the detrimental impacts of adverse shocks during the in-utero period. Specifically, being prenatally exposed to weather shocks worsens child's nutritional status (Dimitrova and Bora, 2020; Randell et al., 2020; Le and Nguyen, 2021). Intrauterine exposure to armed conflict can reduce the height and weight of children (Minoiu and Shemyakina, 2012; Oskorouchi, 2019). Experiencing negative nutritional shocks during gestation could also devastate health outcomes in early childhood (Miller, 2017; Woldemichael et al, 2017). In a different vein, our findings are in line with studies on the effects of insect pest invasion on economic outcomes. Particularly, the insect pest invasion is reported to disrupt agricultural production, threaten food security, and depress household income (Pratt et al., 2017; Sharma et al., 2018; Venette and Hutchison, 2021). The insect pest invasion can adversely affect human health through the use of intensive pesticides (Venette and Hutchison, 2021). Furthermore, the insect pest invasion might leave long-lasting consequences as early-life exposure to such an event could lead to a permanent growth deficit (Banerjee et al., 2010).

Our study highlights the detrimental repercussions of an insect pest invasion, particularly, the desert locust swarm outbreak, on early human health. As poor health in early life can exert long-lasting irreversible consequences over the life cycle such as fewer educational years completed, increased vulnerability to diseases, and lower earnings (Martorell, 1999; Alderman et al., 2006;

Briend and Berkley, 2016), prenatal exposure to the desert locust swarm outbreak could be devastating to long-term human development. Therefore, the study calls for effective measures to minimize the pernicious effects of the desert locust swarm outbreak. The provision of food to affected households is of great importance to ensure nutrition for pregnant women. Cash transfers and other social protection measures should be implemented so that pregnant women can afford crucial health inputs such as prenatal care services and health supplements. Post-outbreak rehabilitation initiatives are essential to restore agricultural production and livelihood systems, which may curtail the duration of negative shocks within the pregnancy period. Extra attention should be given to pregnant women of disadvantaged backgrounds such as those with no formal education, being poor, and living in rural areas because their children tend to be the most vulnerable. Furthermore, surveillance and early warning systems need to be developed to alleviate the threat of future outbreaks. Because the behavior of desert locusts is directly affected by meteorological indicators like rainfall, temperature, and winds, it is important to acquire accurate meteorological information to understand locust outbreaks as well as to conduct control operations (WMO and FAO, 2016).

6 Conclusion

This paper contributes to the literature by evaluating the extent to which prenatal exposure to the desert locust swarm outbreak affects early childhood health for countries in Africa, West Asia, and South Asia regions. The data underlying this study come from the Demographic and Health Surveys supplemented with the Global Positioning System (DHS-GPS) and the Schistocerca Warning and Management System (SWARMS) database. The DHS-GPS offers detailed information on the health outcomes of children as well as various characteristics of children and their mothers. Moreover, the GPS component provides the geographic location of the residential area the child's household falls into, which allows us to merge the child data with the locust data. Information on desert locust swarm outbreaks, including the date and the geographic location of each incident, is drawn from the SWARMS database. In terms of identification, we employ the difference-in-differences model where the health outcomes of children born to mothers experiencing the desert locust swarm outbreak during pregnancy are compared with the health outcomes of those born to mothers unexposed to such an outbreak during pregnancy within the same district, relative to the analogous differences for mothers residing in a different district

We find that in-utero exposure to the desert locust swarm outbreak adversely affects child health. In particular, children prenatally exposed to the outbreak tend to be 0.159, 0.148, and 0.155 standard deviations shorter for their age, thinner for their height, and thinner for their age, respectively, compared to unexposed children. Moreover, we do not detect significantly differential impacts across trimesters. In other words, exposure to the desert locust swarm outbreak across three trimesters is all harmful to early childhood health. Furthermore, our heterogeneity analysis shows that children of disadvantaged backgrounds, i.e., those born to lower-educated mothers, poorer mothers, and rural mothers, are especially vulnerable to the outbreak. Our persistence analysis suggests that the effect of being prenatally exposed to the outbreak on child's height-for-age cannot be recovered. Meanwhile, the effect on weight-for-height can be recovered in around 42.7 months. It takes a little longer (64.7 months) for the effect on weight-for-age to go away. Finally, our results are robust to different model specifications and alternative measures of child health.

Our findings emphasize the damaging impacts of the desert locust swarm outbreak on early human health. Given the persistent consequences of poor health in early life such as fewer educational years completed, increased vulnerability to diseases, and lower earnings (Martorell, 1999; Alderman et al., 2006; Briend and Berkley, 2016), prenatal exposure to the desert locust swarm outbreak might impose detrimental effects on long-term human development. Therefore, our study suggests that mitigative measures to the desert locust swarm outbreak are of crucial importance to protect the future generation. The provision of food and financial support to affected households can help pregnant women have access to adequate nutrition and prenatal care, which can minimize the adverse consequences on infant and child health. Post-outbreak rehabilitation is essential to restore household income and shorten the disruption to pregnant women. Furthermore, mitigating the threat of future outbreaks requires the development of surveillance and early warning systems.

The limitation of our study is that although we uncover the detrimental consequences of in-utero exposure to the desert locust swarm outbreak on child health, we could not examine the effectiveness of possible policies to alleviate such impacts. In other words, we can only propose relevant policy recommendations based on our estimated results without quantitatively analyzing potential solutions. Future studies might want to focus on mitigative measures of the outbreak.

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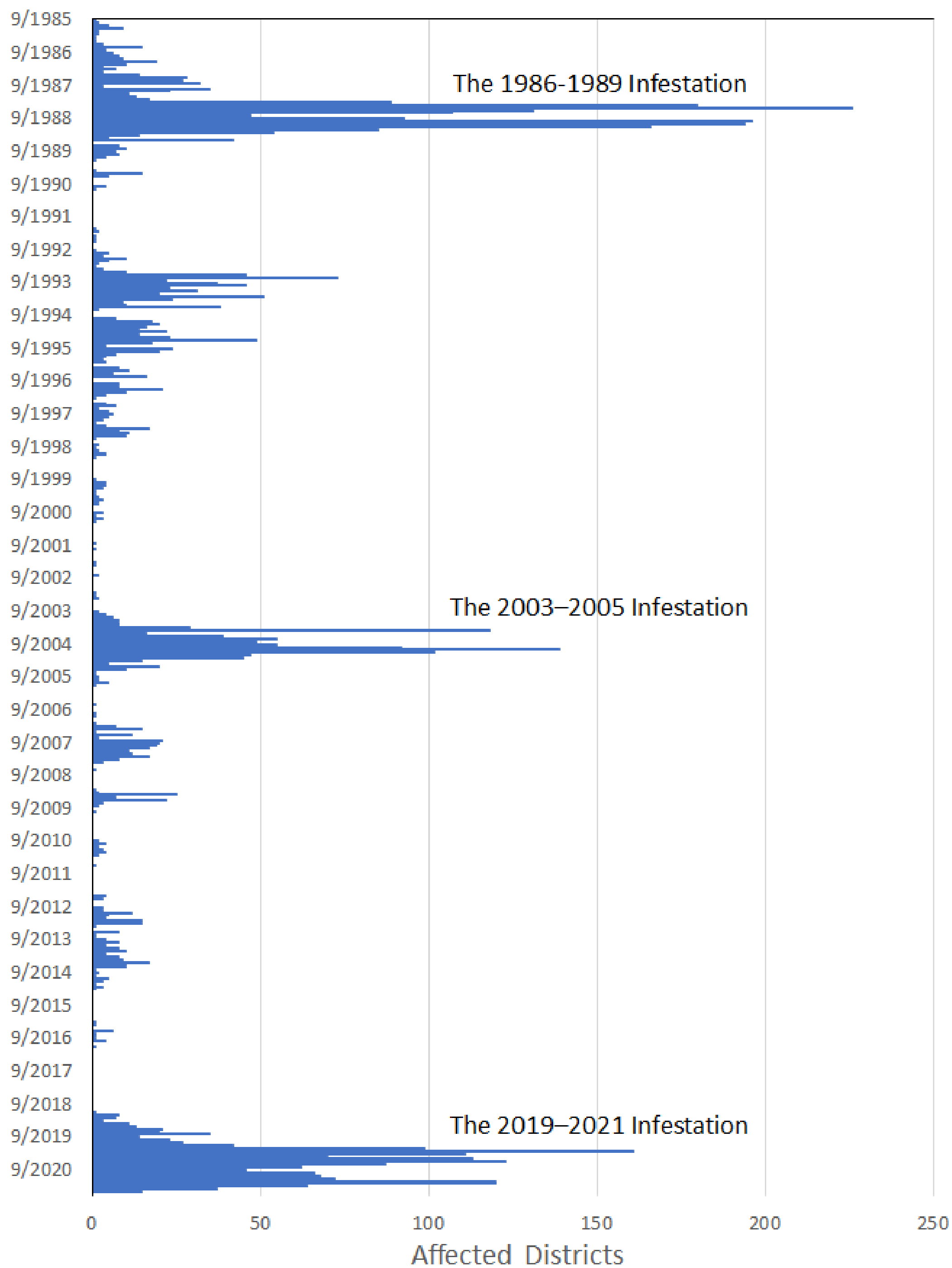
Appendix

Figure A1: Temporal Distribution of Desert Locust Swarm Incidents



Note: Each blue bin indicates the number of affected districts in each month. The figure also shows the widespread impacts of the three worst locust infestations (the 1986-1989, 2003-2005, and 2019-2021 infestations).

Table A1: Desert Locust Swarm Outbreak and Child Health - Additional Trimester Analysis

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
Panel A: Exposure in First Trimester			
1st Trimester Exposure	-0.105*	-0.174***	-0.153***
	(0.059)	(0.048)	(0.044)
Observations	558,595	558,595	558,595
Panel B: Exposure in First and Second Trimesters			
1st & 2nd Trimester Exposure	-0.203**	-0.228**	-0.233***
	(0.099)	(0.104)	(0.094)
Observations	558,595	558,595	558,595
Panel C: Exposure in All Trimesters			
All Trimester Exposure	-0.540***	-0.433**	-0.544***
	(0.081)	(0.190)	(0.097)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects. 1st Trimester Exposure indicates whether the child was prenatally exposed to the outbreak in the first trimester only. 1st & 2nd Trimester Exposure indicates whether the child was prenatally exposed in both first and second trimesters. All Trimester Exposure indicates whether the child was prenatally exposed in all three trimesters.

Table A2: Desert Locust Swarm Outbreak and Child Health - Misclassification

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
Affected by Desert Locust	-0.226***	-0.153***	-0.192***
(2nd - 8th month)	(0.055)	(0.048)	(0.039)
Observations	558595	558595	558595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects. Affected by Desert Locust (2nd - 8th month) indicates whether the child was exposed to the outbreak from the second to the eighth month of pregnancy.

Table A3: Desert Locust Swarm Outbreak and Mortality

	Y = The number of child deaths				
	1-12	13-24	25-36	37-48	49-60
	(1)	(2)	(2)	(2)	(2)
Desert Locust Outbreak	0.758***	0.337***	0.183***	0.073***	0.013
	(0.174)	(0.125)	(0.055)	(0.028)	(0.015)
Observations	14251	14251	14251	14251	14251

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The outcomes are the district's birth cohort mortality rates (the numbers of child deaths per 1000 children of the same cohort in a given district) in different time periods. The column headings indicate the periods after the outbreaks (e.g. 1-12 indicates the mortality rates from 1 to 12 months after the outbreaks).

Table A4: Desert Locust Swarm Outbreak and Child Health - Other Explanatory Measure

	Height-for-age Z-score (1)	Weight-for-height Z-score (2)	Weight-for-age Z-score (2)
Affected by Desert Locust (in months)	-0.126***	-0.082***	-0.105***
	(0.032)	(0.028)	(0.024)
Observations	558,595	558,595	558,595
Child Characteristics	X	X	X
Mother Characteristics	X	X	X
Fixed Effects	X	X	X

Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors are clustered at the district level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age, squared-age, age at birth, squared-age at birth, rainfall, years of education, wealth index, and whether the household lives in urban areas. Child Characteristics include child's age in months, squared-age in months, gender, birth order, and whether the child is a plural birth. Fixed Effects include birth month-year, survey month-year, and district fixed effects. Affected by Desert Locust (in months) refers to the number of months affected by the outbreak during pregnancy.