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RESEARCH ARTICLE

Lasting impact on health from natural disasters, potential mechanisms and mitigating effects

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Abstract
Exposure to extreme shocks in early life is found to have a lasting impact in adulthood. Exploiting the variation in exposure measured by age and intensity of an earthquake, we evaluate the impact of a 7.7 M_W earthquake in Gujarat, India, on the health stock of children who were in utero or below three years. Using the India Human Development Survey data from 2004–05 and earthquake intensity data, we find an affected girl child to be shorter by at least 2.5 cm at the age of 3–6 years. The earthquake seems to have destroyed the household infrastructures and health facilities, affecting the expecting mothers and newborn children. The households using services to meet nutritional needs of children and pregnant women seem to be least affected. Our findings recommend faster reconstruction activities and highlight the importance of universal healthcare and nutritional delivery services to mitigate the impacts of early-life shocks.

Keywords: child health; earthquake; height; India; shock; ZHFA

JEL classification: I1; I3; J1; O2

1. Introduction

According to the estimates of the United Nations (ACC/SCN, 2000), every year approximately 30 million infants in developing countries are observed to have symptoms of impaired growth at the time of birth due to inadequate nutrition during fetal life. Children who are unable to meet their nutritional requirements in the initial 'critical' and 'sensitive' period (Knudsen, 2004) of life remain malnourished in later life. Studies have established that lack of nourishment and poor health in early childhood results in worse human capital outcomes not only in the short run but also in the long run (Morgane *et al.*, 1993; Victora *et al.*, 2008). Poor infant health increases the risk of being prone to infectious diseases or sustained bad health in childhood (Oreopoulos *et al.*, 2008) as well as in adulthood (Blackwell *et al.*, 2001; Haas, 2007).

A large number of studies have used the variation in shocks such as drought (Jensen, 2000; Hoddinott and Kinsey, 2001; Maccini and Yang, 2009; Dinkelman, 2017), famine

(Chen and Zhou, 2007; Gorgens *et al.*, 2012; Dercon and Porter, 2014), flood (Del Ninno and Lundberg, 2005), epidemic (Almond and Mazumder, 2005; Almond, 2006; Kelly, 2011; Lin and Liu, 2014), and war (Alderman *et al.*, 2006) to evaluate the impact on heath due to in-utero or early childhood exposure to shocks. In recent time, researchers have used an earthquake as a shock which brings an exogenous source of variation in terms of its exposure (Fukuda *et al.*, 1998; Finlay, 2009; Tan *et al.*, 2009; Tempesta *et al.*, 2013; Caruso and Miller, 2015; Nobles *et al.*, 2015; Gignoux and Menéndez, 2016; Nandi *et al.*, 2017; Thamarapani, 2021). Negligible likelihood of prediction of such an event creates a unique opportunity to evaluate its impact on the health outcomes of the children who are in-utero or in early childhood at the time of the earthquake.

Among the immediate term impacts, the comparison of neonates born before and after the 2008 Wenchuan earthquake reveals significantly lower birthweight and Apgar scores,[1] a high ratio of low birthweight children and high rate of premature births for the post-earthquake cohort (Tan *et al.*, 2009). In a series of papers, authors have found increased incidence of metabolic syndrome and disruptive nocturnal behaviors and deteriorated sleep quality in the individuals affected by the 2009 L'Aquila earthquake (Tempesta *et al.*, 2013). Using the National Family Health Survey (NFHS) data of India, Datar *et al.* (2013) estimated the immediate impact of shocks arising from a few small and moderate natural disasters and found evidence of stunting, wasting along with deficits in immunization coverage immediately after the disasters.

Several studies have established mixed impacts of earthquakes on fertility affecting through the channel of mortality shocks (Finlay (2009) in three different countries, specifically Gujarat, India in 2001, the North-West Frontier of Pakistan in 2005 and Izmit, Turkey in 1999; Fukuda *et al.* (1998) for the 1995 Kobe earthquake; Nandi *et al.* (2017) for the Gujarat earthquake in 2001; Nobles *et al.* (2015) for the 2004 Indian Ocean tsunami in Indonesia). However, literature analyzing the impact of early life shock from an earthquake or tsunami on later life health (Andrabi *et al.*, 2021; Thamarapani, 2021), education (Caruso and Miller, 2015), crime (Hombrados, 2020), and welfare (Gignoux and Menéndez, 2016) is nascent.

Andrabi *et al.* (2021) find that the children of Pakistan have accumulated a large height deficit, when they faced an earthquake shock under age 3, and have accumulated deficits in academic tests when they faced the shock at age 3–11. They also find evidence of mother's education working as a mitigating factor. We add on to this strand of literature by estimating the impact of the 2001 Gujarat (India) earthquake on long-run health outcomes of children measured by their stature. However, our primary contribution is the investigation of the potential mechanisms followed by recommendations for public policies, while the latter is substantiated through potential channels of mitigation.

Therefore, our objective in this study is three-fold. First, we begin with evaluating the long-run impact of this major shock on the health stock of the surviving children who were in utero or under the age of three years at the time of the earthquake. Second, we investigate the potential mechanisms through which the earthquake leaves behind a persistent negative impact. We are able to produce supportive evidence that both the destruction of public infrastructures on a large scale, as well as nutritional deficiencies of the mothers during the crucial period, are the potential reasons behind long-term negative impacts. Third, we follow up our suggested mechanisms to check if access to

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[1] The Apgar score, reported at one and five minutes post birth, is a criterion used to evaluate the health of a newborn child based on five indexes – color, heart rate, reflex irritability, muscle tone and respiratory effort (American Academy of Pediatrics *et al.*, 2006).

the related essential services could work as mitigating channels. Hence, we explore if the households using the Integrated Child Development Scheme (ICDS) are able to mitigate the impact of the disaster. ICDS is a multi-dimensional scheme, accessible nationwide, which intends to provide a combination of six services such as supplementary nutrition, pre-school education, immunization, health check-up, nutrition and health education, and referral services for children aged 0–6-year-olds, adolescent girls, pregnant women and nursing mothers (MoWCD, 2017). Dhamija and Sen (2020) find that having access to the ICDS during the early years of life has been able to produce a strong positive impact on the health stock of children in their later life.

Among the existing studies that analyzed the impact of such a disaster on the health stocks of the surviving children in later lives,[2] our contribution is a detailed analysis of the potential mechanisms and establishing the channels for mitigation. The work closest to ours is that of Andrabi *et al.* (2021), which suggests mother's education as a channel for mitigation. While parents' education cannot be targeted as a corrective action in the immediate term, the access to healthcare infrastructures is a more viable recourse as found in our work. Taking care of nutrition needs through village health care centers like ICDS is found to mitigate the impact and that should be of interest to policy makers in the immediate term.

We particularly focus on stature as an outcome, as child height is considered to be an important indicator of nutritional status. It has been found that long-run implications of poor childhood health can be best captured by an indicator such as height (Strauss and Thomas, 1998). Height being the output of various inputs, a combination of both genotype and phenotype influences play a significant role in the nutritional health in-utero, at the time of birth or infancy (Martorell and Habicht, 1986). It has the potential of depicting the state of overall growth in the health of the child. Moreover, nutritional insults in terms of shorter height delays school enrollment, reduces cognitive ability in the young as well as at a later age, and lowers schooling attainment and lifetime earnings (Strauss and Thomas, 1998; Case and Paxson, 2008*a*, 2008*b*; Vogl, 2014; Bossavie *et al.*, 2021).

In terms of the destruction caused due to an earthquake, one cannot claim that the damages caused to households are limited to any specific criterion. It is possible that households located near the epicenter of the earthquake face more destruction than the others. This generates another source of variation in terms of intensity of exposure, which also helps us to estimate the impact based on intensity. On average, we find that an increase in earthquake intensity by one unit (measured by Modified Mercalli Intensities or MMI, as explained later) seems to cause 2.54 cm lower height and 0.47 standard deviations lower ZHFA (Z score for height for age) among the affected girls. In other words, an increase in earthquake intensity by one standard deviation (measured by MMI) seems to cause 0.07 standard deviations lower height and 0.39 standard deviations lower ZHFA among the affected girls. Additionally, a girl child belonging to a younger cohort in a severely-affected region seems to be shorter by about 0.11 standard deviations (or 3 cm) than her unaffected counterparts. Our estimates are robust to different specifications.

In order to understand the potential mechanisms, we investigate the impact of earthquakes on antenatal investments, household infrastructures and village-level health infrastructures. Specifically, we find that women who gave birth post-earthquake and

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[2] See Almond and Currie (2011) for a detailed analysis of the literature closest to our work, that is, the impact of early life or in-utero shock on later life outcomes.

belong to a severely-affected region had 5.8 per cent lower likelihood of receiving any antenatal health worker visit, 0.38 lesser number of antenatal visits, and 6.7 per cent lower likelihood of receiving iron and folic tablets during the last pregnancy as compared to their counterparts. In addition to this, the likelihood of individuals having a drinking water facility at home post-earthquake is 0.15 per cent lower as compared to their unaffected counterparts. Moreover, village-level regression analysis indicates that a one-unit increase in earthquake intensity is associated with a reduction in the number of trained and untrained *dai*[3] in the village by 0.61 and 0.36 respectively. The households using services targeted to meet nutritional needs of children and pregnant women seem to be the least affected. These findings highlight the importance of universal healthcare and nutritional delivery services in developing countries that can help to mitigate the long-term impact of shocks caused by natural disasters.

The rest of the paper is organized as follows. Section 2 discusses the severity of the Gujarat earthquake. Section 3 elaborates the data used in the work. Section 4 explains the identification mechanism. Section 5 discusses the findings, potential mechanisms, and the mitigating effects of the ICDS. Section 6 concludes the discussion.

2. The Gujarat earthquake

In 2001, the morning of 26th January brought an unfortunate disaster for the state of Gujarat when an extremely powerful earthquake measuring 7.7 M_W, based on the US Geological Survey's estimate, shook the whole state at 8:46 A.M., local time. Its epicenter was traced to the Chaubari located in the north of Bhachau, about 250 km west of Ahmedabad and a depth of 25 km (GSDMA, 2002). More than 500 aftershocks of smaller magnitudes were felt after the main shock wave (Negishi *et al.*, 2002).

According to government data, approximately 28 million individuals were affected by the destruction, not only due to loss of physical capital but also due to loss of human capital in 21 out of 25 districts in Gujarat (Mishra, 2004). Out of these 21 affected districts, six districts, namely Kutch, Jamnagar, Surendranagar, Rajkot, Patan and Ahmedabad, were severely affected (Lahiri *et al.*, 2001; GSDMA, 2002). Most of the health infrastructures were badly damaged which further escalated the severity of the problem especially on the vulnerable groups such as women and children (GSDMA, 2002). Around 442 villages from these severely-affected districts had more than 70 per cent of the houses destroyed due to the earthquake (Mishra, 2004). Approximately 1.2 million houses were damaged or destroyed due to the earthquake (GSDMA, 2002), while more than 20,000 individuals died and 166,800 were injured. More than 50 per cent of the individuals who died were of working age. Analysis based on the loss to medium- and small-scale industries and other labor market opportunities led to an estimated unemployment of approximately 488 thousand persons. The 'Memorandum on the Earthquake Damage in Gujarat'[4] estimated a loss of about Rs144.54 billion (equivalent to US$1.94 billion approximately) (Lahiri *et al.*, 2001). In addition to this, economic loss of around US$1.3 billion was estimated by the Government of India (Hough *et al.*, 2002). The teams responsible for assessment of the loss were more worried about the social costs of being homeless, mental trauma, poor physical health and reduced earning opportunities that are more difficult to recover from. Recovery and reconstruction of the public and private assets were estimated to cost around US$1.1 million (GSDMA, 2002).

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[3] *Dai* is a form of skilled healthcare worker in the villages or a midwife.

[4] Submitted to the Government of India on February 17, 2001.

3. Data

We use the first round of the India Human Development Survey (IHDS-1, 2005) data collected by joint research exercise of the University of Maryland and the National Council of Applied Economic Research, New Delhi in 2004–05. It is a multi-topic panel survey which covered 41,554 households spread over 1,503 villages and 971 urban blocks in 385 districts, across 33 states and union territories in India. This wide coverage makes this data set representative at the national, state and district level. This survey captures information related to health, education, employment, economic status, marriage, fertility, gender relations, and social capital for every household. It collects anthropometric information such as height and weight data of children under age 6, 8–11 years old, and ever-married women aged 15–49 years old at the time of survey.[5] We calculate the Z score for height for age (ZHFA) using the British 1990 Growth Charts. It allows us to find standardized values of height for a cohort of children aged 0–23 years old.[6]

In order to explore potential mechanisms behind the long-run negative impact, we also use the District Level Household Surveys (DLHS) data of India. The Government of India started the DLHS to assess the reproductive and child health indicators at the district level. The research exercise to carry out these surveys was delegated to the International Institute for Population Sciences. To date, periodic exercise of DLHS cross-sectional surveys have been completed four times (DLHS-1 in 1998–99, DLHS-2 in 2002–04, DLHS-3 in 2007–08 and DLHS-4 in 2012–13). In order to assess the impact of the Gujarat earthquake on the prenatal investments, we specifically use the first two cross sectional rounds of DLHS. Household surveys in DLHS-1 (1998-99) and DLHS-2 (2002-2003) are taken from 5,29,817 households (in 504 districts) and 6,20,107 households (in 593 districts) respectively.

The fieldwork for both DLHS-1 and DLHS-2 were done in two phases. The first phase of DLHS-1 was conducted in 1998 and the second phase was conducted in 1999 (IIPS, 2001). In DLHS-2, the first phase was carried out in 2002 except for some districts of Bihar and Jharkhand, where the field work was extended to 2003. The second phase was carried out in 2004, except for some districts of Bihar and Jharkhand, that were covered in 2005 (IIPS, 2006). We do not use the second phase of DLHS-2 as there was a gap of three years between the earthquake (in 2001) and the second phase of DLHS-2 (in 2004). It helps us to avoid the possibility of the reconstruction of the health facilities three years post-earthquake as this may contaminate our results. We aim to cover those surveyed women who gave birth in the last two years. Therefore, for the study of the potential mechanisms, we restrict the sample for those women who reported giving birth from 1997 to 1999 in DLHS-1, and from 2001 to 2002 in DLHS-2.

4. Conceptual framework and identification strategy

Out of 25 districts in Gujarat in the year 2001,[7] six were severely affected by the earthquake. According to Mishra (2004), more than 99 per cent of the death toll was reported in the six severely-affected districts (figure A1, online appendix). Fifteen other districts faced some damages of a milder manner. The remaining four districts were not reported

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[5] Online appendix section I explains the reasons behind our choice of IHDS data in more detail.

[6] While the reason behind using the British Growth Chart instead of the more common WHO growth chart is explained in online appendix section II, table A19 presents estimates using the WHO growth chart (with much smaller sample) as well, and our findings do not change.

[7] Some districts bifurcated later, making a current total of 33 districts in Gujarat in the year 2021.

to be affected. However, IHDS-1 surveyed all six severely-affected districts, only ten out of the 15 marginally-affected districts and only one out of four unaffected districts in Gujarat. Therefore, our final sample of Gujarat gets restricted to a total of 17 districts.

4.1 Identification using difference in difference

Our initial plan is to restrict the treatment group to six severely-affected districts, and to compare them with the ten marginally-affected districts, with the premise that severely-affected districts should face worse health outcomes as compared to the marginally-affected ones. In order to distinguish these ten districts from the only one unaffected Narmada district, we call the former 'marginally-affected' districts in figure A1. However, in order to increase the sample size of the control group and to make it stronger with a 'true' control who were not affected by the earthquake, we also include the other surveyed districts of the neighboring states of Maharashtra, Rajasthan and Madhya Pradesh in the control group, along with the unaffected Narmada district of Gujarat. The first level of difference is, therefore, calculated across space, that is, among same age-cohorts belonging to six districts of Gujarat, with the ten marginally-affected districts and one unaffected district of Gujarat, plus all surveyed districts of Maharashtra, Rajasthan and Madhya Pradesh as listed in online appendix table A1.

Since lack of nourishment for children in-utero or in the age group of 0–3-years can bring disastrous outcomes in later life, we aim to restrict our treated group to the children born from 1998 to 2001, aged 3–6 years during 2004–05. The data collection for IHDS-1 was done from November 2004 to October 2005, with most of it being done in 2005. We restrict our treated group to those children whose age is reported as 4 or 5 in the survey year 2005 and whose age is reported as 3–5 in the survey year 2004.[8] With an objective of restricting our treated group to the children born in 2001 or before, we include only those children in the sample who report being 4 or 5 years old in survey year 2005.[9] However, our results are robust to inclusion of children whose age is reported as 3 in the survey year 2005.[10] Moreover, to ensure that all individuals from our treated group have been truly exposed to the earthquake, we limit the sample to females in households, who have been in the same place at least for the last ten years.[11] Figure 1 explains the construction of the treatment and control cohorts.

One may wonder why we choose to study two cohorts, knowing that *ex ante*, one expects not to observe a difference between young adults in treated and control regions as they are in the last stage of physical development. However, our double difference

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[8] Anthropometric information for 6-year-old children was not collected in the survey, due to which inclusion of the 6 year old cohort in the analysis is not possible.

[9] In order to understand the logic behind this selection, let us take an example: If the child is born in January 2001 then her completed age in survey year 2004 is reported as 3. In survey year 2005, it is reported as 4 if the date of survey is on or after the birth date or else it is reported as 3. In such a scenario we should also include children whose age is reported as 3 in the survey year 2005. But inclusion of these cases will bring the possibility of children being included in the sample whose age is reported as 3 in July 2005 and born in June 2002.

[10] Results are not presented in this paper, but available from the authors on request.

[11] Our findings do not change if we relax this sample restriction of residing in the same place for the last ten years. See online appendix tables A3 and A4.

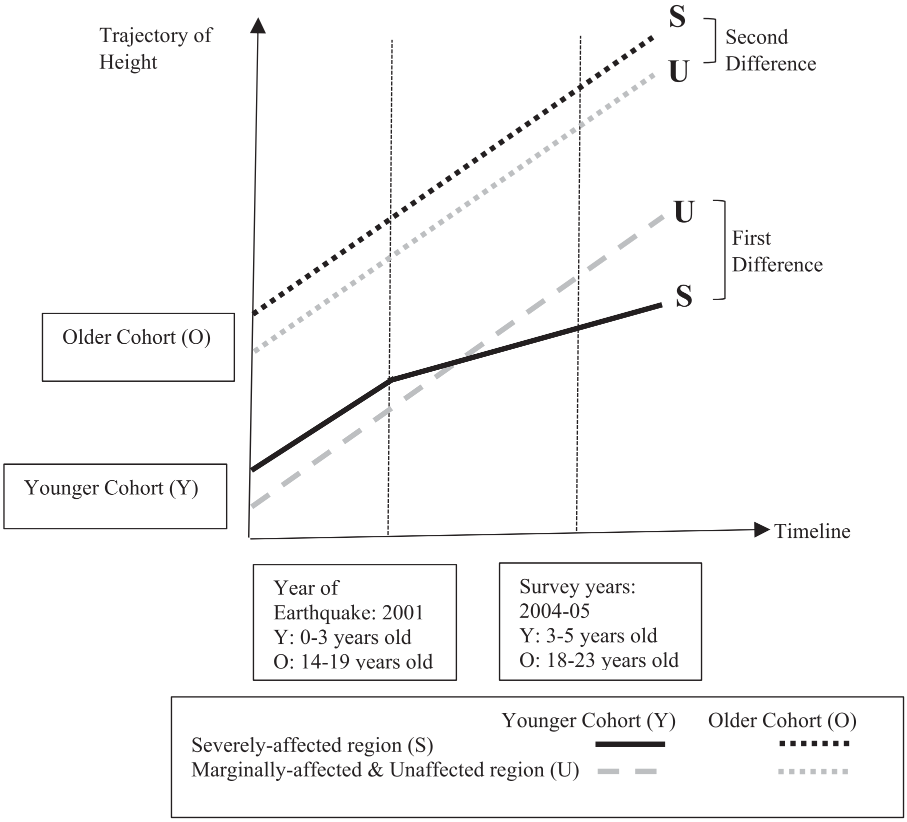

Figure 1. Timeline projecting treatment and trajectory of height.

strategy helps to alleviate the concerns related to pre-treatment differences in health outcomes of children in the severely-affected region and other region.[12] In order to control for pre-treatment differences between the earthquake-affected and unaffected regions, we need a counterfactual group who are unlikely to be affected by the earthquake in a way the outcomes of the treated cohort should be. Therefore, the second level of difference across time includes cohorts aged 18 to 23 years at the time of the survey. By choosing this as the counterfactual cohort we ensure that the youngest child in this cohort could be 14 years old at the time of the earthquake. It is important to note that this cohort has already passed the crucial age where malnutrition due to shock was expected to reduce growth. Moreover, the fact that puberty in females is complete by the age of 17 (Marcell, 2007), encourages us to choose 18 as the lowest age for the counterfactual cohort. So,

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[12] We also provide the estimates following the most straightforward approach by focusing only on children that are between 0–3 years old and compare the outcomes between affected and non-affected regions. Online appendix table A16 provides the magnitude of the effect of the earthquake on the 0–3 years male cohort. However, our preferred specification is not this one, as we believe the difference in difference estimation strategy can potentially address the concerns related to pre-treatment differences in health outcomes of children in the severely-affected region and other region.

we assume that this cohort is unlikely to be affected by the earthquake and will help in differencing out pre-treatment differences in the affected and unaffected regions.

Since anthropometric information for the elder group is collected only from the ever-married women, our analysis is restricted to female cohort for height and ZHFA. However, ZHFA could not be calculated for the individuals older than 23 years due to unavailable reference data. Therefore, in all our primary specifications, our counterfactual cohort gets restricted to 18–23 years old in the survey year. However, the information on heights being available for the cohort up to 49 years, as we check the specification with 18–36 being the counterfactual, our estimates for height remain similar in magnitude.[13] For the analysis using the double difference strategy, and for the robustness checks, we restrict our sample to the individuals surveyed in four states – Gujarat, Maharashtra, Rajasthan and Madhya Pradesh – as listed in online appendix table A1. For falsification tests, we also include the districts of the Bihar, Chhattisgarh and Uttar Pradesh in the analysis.[14]

This identification strategy is based on the comparisons of both the height and ZHFA outcomes of females belonging to the same cohort in severely-affected versus other districts. We try to elaborate this in table 1, which has the unconditional means of health outcomes of different cohorts in different regions. In *Actual Experiment*, we compare the health outcomes of the *Older Cohort* females (14 to 19 years old at the time of the earthquake) unlikely to be affected by the earthquake of 2001, to the *Younger Cohort* females directly affected, being in-utero or under the age of 3 years during the earthquake. These comparisons are also made in both the *treated* and *control* regions.

We find that older cohort females belonging to the severely-affected (*treated)* region may have both higher height and lower negative ZHFA as compared to those who belong to the *control* region. This may indicate better health outcomes for the older cohort in the severely-affected region as compared to marginally-affected and unaffected regions. But the younger cohort that is expected to be affected due to the earthquake has marginally lower height, indicating poor health outcomes among them in the severely-affected regions. Under the assumption that health outcomes in the absence of the earthquake would have been systematically indifferent in both the regions, we can interpret the difference in these differences as the effect of the earthquake on the health outcomes. Table 1 indicates that the unconditional average height seem to be 5.21 cm lower for the younger cohort in the severely-affected region, but we do not get a statistically significant difference in ZHFA.

In order to test the implications of our assumption, we conduct a controlled experiment for height by comparing the means of health outcomes of two cohorts whom we expect to remain unaffected by the earthquake. We choose 18 to 23 and 24 to 49 year old women for this purpose (who were 14 to 19 and 20 to 45 years old respectively at the time of earthquake in 2001). In column (3), we find that the unconditional double difference of mean height is not significant. This result provides supportive evidence that our estimates are not influenced by any systematic differences in the two regions. Under the assumption that, conditional on a host of observables and district-specific or time variant unobservables, differences across different cohorts in each of the outcomes would be similar between severely-affected - *treated* districts and unaffected or marginally-affected - *control* districts in the absence of the earthquake, we estimate the

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[13] Estimates are available from the authors on request.

[14] See online appendix figure A2 for the map of neighboring states used in one specification of control group, and the other state used for the falsification exercise.

Table 1. Unconditional means of health outcomes by cohort and regions

	Actual experiment		Controlled experiment
Variables	(1) Height (in cm)	(2) ZHFA in (−6,6)	(3) Height (in cm)
Diff-in-diff (Y-O)	−5.21 (2.79)	−0.35 (0.33)	−0.99 (1.25)
Observations	2,146	2,057	8,205
R^2	0.90	0.03	0.02
Older cohort (O)			
Marginally-affected & Unaffected region (U)	151.10	−2.07	151.12
Severely-affected region (S)	153.97	−1.54	154.99
Diff (S – U)	2.87 (1.18)	0.53 (0.17)	3.87 (0.43)
Younger cohort (Y)			
Marginally-affected & Unaffected region (U)	95.53	−1.60	151.09
Severely-affected region (S)	93.19	−1.41	153.97
Diff (S – U)	−2.34 (2.53)	0.19 (0.28)	2.88 (1.18)

Notes: Full sample of 98 districts including control district of neighboring states.
Robust standard errors are clustered at the district-age level.
In the actual experiment, younger cohort consists of females who were in-utero or under the age of 3 in 2001. Older cohort consists of females aged 14–19 years old at the time of the earthquake in 2001. In the controlled experiment, younger cohort consists of 14–19 years old females, and older cohort consists of 20–45 years old females.
Data source: IHDS-1.

following equation in our first specification:

$$H_{ihjt} = \beta(\text{Younger Cohort}_i \times \text{Severely Affected Region}_j) \\ + \delta_t + \alpha_{jt} + \gamma_{sy} + \mu X_h + \varepsilon_{ihjt}, \qquad (1)$$

where H_{ihjt} is the health outcomes measured by height (or ZHFA in alternative specification) for the individual i who belongs to household h in district j and birth year t.[15] $\textit{Younger Cohort}_i$ is a dummy variable indicating whether the individual was in-utero or under age of three at the time of the earthquake (=1). $\text{Severely Affected Region}_j$ is a dummy variable indicating the individual belonging to one of the six severely-affected districts. We include birth-year fixed effects δ_t to account for unobservable time-variant changes that might have happened in both regions, which could also affect the health outcomes. α_{jt}, capturing the time-trend across districts, controls for the unobserved time-variant differences among districts which could cause differential developmental outcomes irrespective of the earthquake. All our estimates include survey-year fixed effects denoted by γ_{sy}. $\boldsymbol{X}_h$ controls for other household-specific covariates such as ethnicity, religion, and residence status, which may also affect the health outcomes of the

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[15] Throughout the analysis, age in years is used as a proxy for birth year due to the large number of missing observations in the latter.

children.[16] ε_{ihjt} is the error term with the usual assumptions. Descriptive statistics about the background characteristics of individuals disaggregated by the region are provided in online appendix table A8.

Since inference based on the clustered standard errors may be misleading if the number of clusters is less (Roodman *et al.*, 2019), throughout all our regression estimates, we cluster the standard errors at the district-age level. However, our results remain qualitatively unchanged even after clustering the standard errors at the district level.[17]

4.2 Identification using earthquake intensity as primary evidence

The above-mentioned identification strategy may suffer from a few potential concerns. First, it is possible that some other shocks with the potential of affecting health outcomes may have occurred in one of the regions during the same time, causing treated and control districts to have different health outcomes irrespective of the earthquake. This is difficult to address in the above difference in difference framework using cross-section data. Second, the limited sample on unaffected districts (counterfactuals) persuades us to consider the moderately-affected districts as counterfactuals as well. This has the potential of generating bias in our estimates. Even though we try to address that concern using districts from other neighboring states as counterfactuals as well, it is difficult to establish that those would be true controls. Hence the Difference in Difference strategy explained earlier requires validity of much stronger assumptions. Third, the above strategy treats all the districts in the severely-affected region uniformly. However, the intensity of the earthquake is higher closer to the epicenter and reduces with the distance away from the epicenter.

Therefore, in order to ensure that the observed health effects in the severely-affected regions are due to the earthquake, our primary specification is a different model, where we use another variant of treatment capturing intensity of the earthquake data from Hough *et al.* (2002). Due to scarcity of instrumental recordings of the intensity at various locations, Hough *et al.* (2002) have used the extensive news articles on print media and electronic media in the United States and India, along with internet-based sources, to assign the MMIs at various locations. Based on the severity of ground shaking and destruction, these MMIs were assigned (for details, please see Hough *et al.* (2002)). MMIs are interpreted as point data. Hough *et al.* (2002) show that these intensities were inversely related to the distance from the epicenter. We use this data on MMIs for all the severely-affected and marginally-affected districts of Gujarat. Since MMIs are reported from several locations along with their geo-coded locations within the same district, we find the average MMI for each district affected by the earthquake and surveyed in IHDS-1. We re-tabulate MMIs for all the severely- and marginally-affected districts as presented in online appendix tables A2a-A2c. Since MMIs are reported from several

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[16] For robustness check, we also include education of the household head, dependent ratio, wealth index measured by the number of assets, primary source of income, sources of drinking water, and toilet facility in an additional specification.

[17] See tables A13-A17 (online appendix) for these robustness tests. However, the presence of spatial correlation in outcome as well as the main variable of interest may increase the likelihood of Type I error if it remains unaccounted for in the regression model (Colella *et al.*, 2019). Arbitrary correlation regression based on the Stata command 'acreg' can give us the corrected standard errors after accounting for spatial correlation. But, we need the latitude, longitude, and bilateral distances between the observations to use this program. Unfortunately, IHDS data does not provide the household-level geocodes, in the absence of which, we could not use this Stata command to complete this robustness check.

locations[18] within the same district, we take an average to get a representative MMI for each district. Online appendix table A22 shows the average intensity for every district. Since the IHDS-1 data does not provide the geo-coded locations of the surveyed households, we had to use the average intensities at the district level.

Using this variable of intensity, we estimate the following equation:

$$H_{ihjt} = \beta(\text{Younger Cohort}_i \times \text{Intensity}_j) + \delta_t + \alpha_{jt} + \mu X_h + \varepsilon_{ihjt}, \tag{2}$$

where all other variable specifications remain the same as in equation (1) *Intensity*$_j$ measures the MMI of the earthquake in district *j*. This specification helps us to check if districts with higher intensities have worse health outcomes than the districts with lower intensities.

In order to check the validity of our identification strategy, we further generalize equation (2) to estimate age-specific impact. We construct seven age dummies that are a dummy for each age 4, 5, and 18 to 22, with individuals aged 23 years in 2005 being the reference category:

$$\begin{aligned} H_{ihjt} = {} & \sum_{l=4}^{l=5}(\text{age}_{il} \times \text{Intensity}_j)\gamma_{1l} + \sum_{l=18}^{l=22}(\text{age}_{il} \times \text{Intensity}_j)\gamma_{1l} + \delta_t + \alpha_{jt} \\ & + \mu X_h + \varepsilon_{ihjt}, \end{aligned} \tag{3}$$

where *age*$_{il}$ is a dummy variable indicating whether individual i is of age l in the survey year 2005. Each coefficient γ_{1l} can be interpreted as an estimate of the impact of the earthquake on a given l year cohort. Since individuals aged 18 and older in 2005 would have been at least 14 years old at the time of the earthquake in 2001, we do not expect their health outcomes measured by height and ZHFA to be affected through the channel of early-life malnutrition caused by the earthquake.

We plot the coefficients γ_{1l} in figure 2 for the outcome variables height and ZHFA. Each dot on the middle line is the coefficient of the interaction between age dummy and the intensity measure. The dashed lines above and below the solid line connect the 95-per cent confidence interval for each coefficient. Since our cohort-based analysis as mentioned in specification (2) can only capture average effect on the treated (younger) cohort, the figure 2 helps us to identify age-specific linear impact, along with presenting evidence for parallel trends (Duflo, 2004).

In figure 2, none of the coefficients for the age cohorts 18 to 22 is significantly different from zero, which supports our a priori assumption of parallel trends. As the impact of the earthquake, we expect significantly negative coefficients for both the 4 and 5 year old cohorts. However, the negative impact on height seems to be primarily driven by the effect on a 4-year old cohort, as the coefficient for age 5 is small in magnitude and not statistically significant. Individuals whom we expect to be in-utero or were less than a year old at the time of the earthquake (i.e., aged 4 years old in 2005), have significantly negative coefficients, as expected. Similarly, for the outcome variable ZHFA, none of the coefficients of the interaction terms, except for that of age 4, is significantly different from zero, which indicates the negative impact on affected children who may have been in-utero or less than a year old during the disaster.

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[18] However, for five districts, it was reported from only one location.

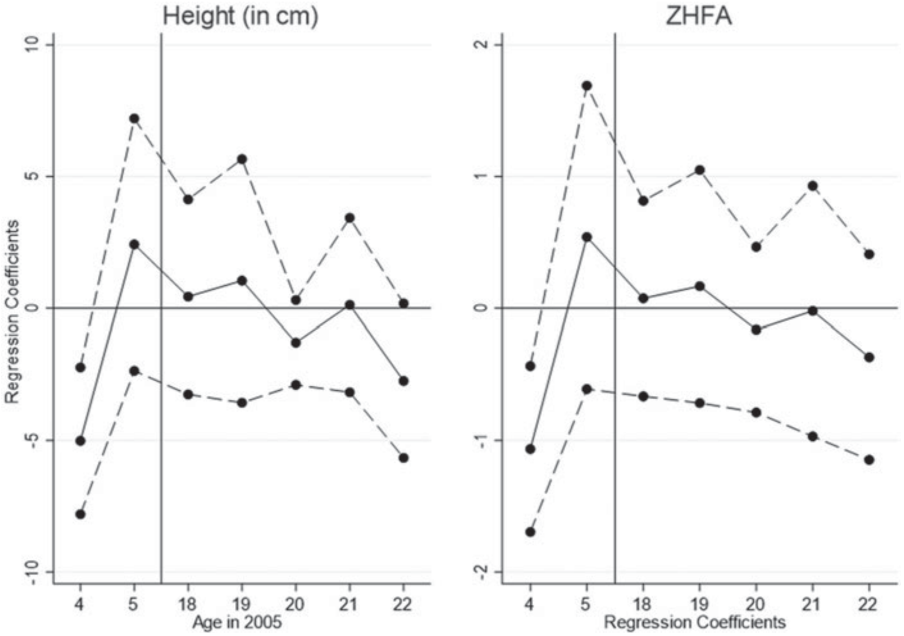

Figure 2. Coefficients of height and ZHFA on the interactions between age in 2005 and earthquake intensity in the affected districts of Gujarat.

5. Discussion of results

The impact of the earthquake intensity (in MMI scale) on height and ZHFA outcomes as estimated by equation (2) are presented in panels A and B respectively of table 2. For the earthquake-intensity-related estimates in table 2, our sample includes six severely-affected and ten marginally-affected surveyed districts. We do not use survey year fixed effects in this specification, because all the affected Gujarat districts in our sample were surveyed in the year 2005. The first columns of both panels present estimates of our full model specifications with birth year fixed effects, district-time linear trend, and household level covariates as mentioned in specification (2). The next two columns are presented for robustness checks. The second columns present estimates without household level covariates. The last columns present estimates of the full model along with nine additional household level covariates, which are suspected to be endogenous. In lieu of availability of a baseline survey, we present the last column estimates with a few additional presumably endogenous household-level variables only for the purpose of robustness checks. The additional covariates are education of the household head, dependent ratio, wealth index measured by the number of assets, primary source of income, sources of drinking water, and toilet facility, with the potential of affecting the health outcomes of the children. Although mother's health and educational characteristics are strong determinants of stunting, we could not control mother's height because this information is not available for the 18–23 year old women in the counterfactual group. However, inclusion of a few available determinants of stunting such as household head's education (which is expected to be correlated with mother's education), sources of drinking water and toilet facility are expected to improve our precision.

Table 2. OLS estimates of the earthquake: sample of 16 districts of Gujarat

Panel A: outcome is height (in cm)			
	(1)	(2)	(3)
Variables	Height	Height	Height
Younger cohort × Intensity	−2.539 (1.37)	−2.725 (1.24)	−1.667 (1.16)
Observations	297	297	297
Number of additional controls	Three	Zero	Nine
Panel B: outcome is ZHFA in (−6, 6) range			
Variables	ZHFA	ZHFA	ZHFA
Younger cohort × Intensity	−0.470 (0.23)	−0.456 (0.18)	−0.317 (0.21)
Observations	278	278	278
Number of additional controls	Three	Zero	Nine

Notes: Robust standard errors clustered at the district-age levels are in brackets.
Younger cohorts are females who were in-utero or under the age of 3, and older cohorts are females aged 14–19 years, at the time of the earthquake in 2001.
Intensity is earthquake intensities of 16 districts of Gujarat which include six severely-affected and ten marginally-affected districts.
All specifications include age fixed effects, district-specific time trends.
The first column includes three covariates, such as, ethnicity (SC, ST, OBC or others), religion (Hindu or others) and residence status (urban or rural); the second column is without additional covariates; the third column includes all nine covariates, such as education of the household head, dependent ratio, wealth index, source of income (agriculture or allied activities, agriculture wage labor, non-agriculture wage labor, independent/petty shop, business/salary/pension or others), ethnicity (SC, ST, OBC or others), religion (Hindu or others), source of drinking water (piped, tube well, hand pump or others), toilet facility (open fields or others), and residence status (urban or rural). Wealth index is measured by the number of assets owned by the household. Agriculture or allied activities is the reference category for the income source. Others are the reference category for ethnicity and religion both. Piped water is the reference category for the source of drinking water.
Data source: IHDS-1.

As found from column (1) of table 2, an additional unit of increase (in MMI) of the earthquake significantly reduces the height of the children in the younger cohort on average by about 2.54 cm (in panel A), and reduces ZHFA by 0.47 standard deviations (in panel B). A one-unit increase in MMI causing a magnitude of about 2.54 cm reduction in adult height may look like quite a significant negative impact, however, the point to note here is that the MMI scale of devastation in our survey districts ranges from 6.5 to 9.5. The way the MMI scale is designed on the basis of its level of expected devastation,[19] it may range from 1 to 12 in reality, where the major impacts start from 6 points onwards. Our sample does not have districts with the lower levels of MMI, the absence of which is expected to pull up average impact due to extreme levels of devastation. Online appendix table A2 (a–c) indicates that we have a large number of districts with MMIs on the higher side. Due to a very small sample size, particularly that of the ZHFA sample, we are unable to check non-linearity of this relationship.[20]

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[19] Source: US Geological Survey, https://pubs.usgs.gov/gip/earthq4/severitygip.html, accessed in December 2019.

[20] The potential selection bias arising due to unavailability of data from all the unaffected districts and the related tests are explained in online appendix section III. We use information from the NFHS data to check the potential differences with the missing districts.

Table 3. OLS-DID estimates: sample of 17 districts of Gujarat and surveyed districts of other states

Panel A: outcome is height (in cm)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Height	Height	Height	Height	Height	Height
Younger cohort × Severely-affected region	−3.318 (2.03)	−2.937 (1.98)	−3.329 (2.04)	−3.063 (2.06)	−2.711 (2.03)	−3.296 (2.06)
Observations	2,146	2,146	2,146	1,985	1,985	1,985
Number of additional controls	Three	Zero	Nine	Three	Zero	Nine
Number of districts	98	98	98	88	88	88
Panel B: outcome is ZHFA (in (−6, 6) range)						
Variables	ZHFA	ZHFA	ZHFA	ZHFA	ZHFA	ZHFA
Younger cohort × Severely-affected region	0.058 (0.32)	0.099 (0.32)	0.05 (0.34)	0.086 (0.32)	0.127 (0.32)	0.042 (0.33)
Observations	2,057	2,057	2,057	1,903	1,903	1,903
Number of additional controls	Three	Zero	Nine	Three	Zero	Nine
Number of districts	98	98	98	88	88	88

Notes: Robust standard errors clustered at the district-age levels are in brackets.
In the first three columns, counterfactuals are all districts of Maharashtra, Rajasthan, Madhya Pradesh and eleven districts of Gujarat. In the next three columns, counterfactuals exclude the ten marginally-affected districts of Gujarat.
Younger cohorts are females who were in-utero or under the age of 3, and older cohorts are females aged 14–19 years, at the time of the earthquake in 2001.
All specifications include age fixed effects, district-specific time trends and survey year fixed effects.
The first and fourth columns include three covariates, such as, ethnicity (SC, ST, OBC or others), religion (Hindu or others) and residence status (urban or rural); the second and fifth columns are without additional covariates; the third and sixth columns include all the nine covariates, such as education of the household head, dependent ratio, wealth index, source of income (agriculture or allied activities, agriculture wage labor, non-agriculture wage labor, independent/petty shop, business/salary/pension or others), ethnicity (SC, ST, OBC or others), religion (Hindu or others), source of drinking water (piped, tube well, hand pump or others), toilet facility (open fields or others), and residence status (urban or rural).
Wealth index is measured by the number of assets owned by the household. Agriculture or allied activities is the reference category for the income source. Others are the reference category for ethnicity and religion both. Piped water is the reference category for the source of drinking water.
Data source: IHDS-1.

The double difference estimates of equation (1) for the height and ZHFA outcomes are presented in panels A and B of table 3 respectively. The first three columns of table 3 have 98 districts in total, where six are severely-affected, treated districts; and the remaining 92 are control districts. The control districts include ten marginally-affected districts and one unaffected district of Gujarat, 27 districts of Maharashtra, 23 districts of Rajasthan and 31 districts from Madhya Pradesh. Since only one district of Gujarat was surveyed from the list of completely unaffected districts, we check the robustness of our estimates by excluding the ten marginally-affected districts of Gujarat in the last three columns.

The first and fourth columns present estimates of the specification of full model (1), including age fixed effects, district-specific time trends, survey year fixed effects, and three household-level covariates.[21] Since IHDS-1 was done from November 2004 to October 2005, we include survey year fixed effects in all specifications of table 3.

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[21] Across all the specifications of every model, we present only the estimates for the variable of interest, i.e., the interaction term in equations (1) and (2).

For robustness checks in columns 2 and 5, we remove the presumably exogenous household-level covariates from model (1). The third and sixth columns present estimates from the full model, along with nine additional covariates as discussed in the previous section.

The estimates for the height (in panel A) and ZHFA (in panel B) outcomes from table 3 seem inconclusive. Since the intensity measure requiring less strong assumptions seems more convincing methodology to us, our primary interpretation is limited to the intensity measure of the earthquake wherever possible. However, it is important to note that the size of the impact on height in table 3 looks very close to that of the table 2 estimates.

The validity of the unconfoundedness assumption can be assessed by testing for the pre-treatment difference between the characteristics of the treated and control *districts* before the earthquake. Unfortunately, we could not examine this due to unavailability of district-level data before the earthquake. In lieu of that, figure 2, establishing the pre-treatment difference across individuals, along with the following two strategies, should be able to justify our identification strategy.

In order to ensure that our results are not mere estimations of any general trend across time or space, we conduct two falsification tests. First, we falsely construct a similar shock received in 1990 so that the women aged 15 to 17 years in 2004–05 who were under the age of 3 in 1990 would become the treated group. Women aged 18 to 23 years old still serve as our control group. Using this newly treated cohort, we re-estimate specifications (1) and (2) and present the estimates for height and ZHFA outcomes in panels A and B respectively of online appendix table A9.

The first column corresponds to the specification of equation (2), whereas the second and third columns estimate equation (1). The only difference between the last two columns is in sample size. The second column has the largest sample with counterfactuals being ten marginally-affected districts and one unaffected district of Gujarat, plus all the surveyed districts of Maharashtra, Rajasthan and Punjab. The third column excludes the ten marginally-affected districts of Gujarat. All the specifications include three additional controls and all fixed effects along with time trends as mentioned in specification (1). As expected, none of the coefficients of the interaction terms in either of the panels for height or ZHFA seem to be significantly negative.

Second, we assume that the earthquake occurred either in Bihar, or in Chhattisgarh, or in Uttar Pradesh (in alternative specification) and not in Gujarat in 2001, so that all the districts of the corresponding states become the severely-affected region (falsely specified as *treated*) in both panels of online appendix table A10. The difference between the two columns in each treated state is the sample size of counterfactuals, which follows the same pattern as the last two columns of online appendix table A9. As expected, the coefficients in both panels of appendix table A10 for height or ZHFA outcomes are not statistically significant, except for a very weak significance for ZHFA outcomes in the last two specifications with UP as falsely *treated*.

We do not find any heterogeneous effects across groups decided by a few standard determinants of stunting, such as various disadvantaged caste and religious groups (see online appendix table A20). Checking the heterogeneity across birth order or gender would be interesting too, but could not be performed due to unavailability of the relevant information in our data.

5.1 Potential mechanisms

A natural disaster like an earthquake brings large-scale destruction in terms of loss of home, livelihoods, death and injuries of family members at the micro level; and damage to public infrastructures like health centers, schools, roads at the macro level. The United States Geological Survey data reports more than 800 thousand estimated deaths due to earthquakes across the world from 2000 to 2015. Wide-scale destruction, leading to unavailability of basic services like nutritious food, clean drinking water (see online appendix table A8 indicating a few of these differences), clothes and shelter, and deteriorated mental health, become a big reason for deprivation of essential nutrients and medical services that are required for pregnant women and for children in early childhood. If healthcare supplies were interrupted, were inadequate or healthcare infrastructures were destroyed due to the earthquake, mothers bearing a child in-utero may not have been able to receive proper antenatal care, which would have affected fetal health. Apart from that, if food supplies were interrupted for a length of time then there would be an insult to in utero health due to poor nutrition of the mother.

Therefore, using the first two rounds of DLHS data, we investigate the impacts of the earthquake on the antenatal investments. The four outcome variables considered as indicators for antenatal care are: whether any antenatal health worker ever visited the mother during pregnancy; number of visits by the antenatal health worker; whether iron and folic acid tablets were given during the pregnancy; and if a tetanus injection was given during the pregnancy.

$$H_{ihjmt} = \beta(\text{Post}_i \times \text{Severely Affected Region}_j) + \ e_m + \ \delta_t \ + \ \alpha_{jt} + \ \mu X_h + \varepsilon_{ihjmt} \ldots \tag{4}$$

where H_{ihjmt} is one of the above four health outcomes in alternative specification for the woman i who belongs to household h in district j and gave birth in month m of year t. $Post_i$ is a dummy variable indicating whether the woman gave birth after the earthquake (=1) which also means that the particular observation belongs to DLHS-2. *Severely Affected Region*$_j$ is a dummy variable indicating the individual belonging to one of the five[22] severely-affected districts. The remaining surveyed districts of Gujarat, Maharashtra, Rajasthan and Madhya Pradesh were taken as the unaffected region (*Severely Affected Region* = 0). All other variable specifications remaining the same as before, the vector X_h includes additional variables such as the age and education of the woman, her husband's education, age in completed years when the woman started living with her husband, gender of the last born child, and whether the woman lives in a rural or urban area. We also control for birth-month e_m fixed effects to account for time-variant changes that might have happened in both regions, which could also affect the health outcomes.

Using the same specification and the same data, we also explore if the households with potential mothers in the severely-affected regions received negative shocks through damage of household infrastructures that could also affect their antenatal health. The two outcomes considered for this part are type of house (that is, whether the household stayed in a 'pucca'[23] house) and having drinking water facility.

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[22] In the previous analysis we had six severely-affected districts – Ahmedabad, Jamnagar, Kutch, Patan, Rajkot, Surendranagar. Patan could not be included in this analysis as the survey for this district was done in the second phase of DLHS-2, which we do not include in the current analysis.

[23] 'Pucca' is a word in the Hindi language which in the context of building means a house built of concrete walls as opposed to being built of mud and straws.

Panel A of table 4 indicates that the pregnant women in the affected areas seem to have received less medical care after the earthquake. Specifically, those women who gave birth post-earthquake and belonged to a severely-affected region, had 5.8 per cent lower likelihood of receiving any antenatal health worker visit, 0.38 fewer antenatal visits, 6.7 per cent lower likelihood of receiving iron and folic tablets, and 1.4 per cent lower likelihood of getting a tetanus injection during the last pregnancy. Their likelihood of living in a 'pucca' house or having a drinking water facility at home post-earthquake, was 0.04 or 0.15 per cent lower respectively, as compared to their unaffected counterparts.

Using the IHDS-I village level data (2004–05) and the similar specification as above, we also explore if the earthquake-affected districts have higher likelihood of village-level health infrastructures being damaged. In this specification, the outcomes considered are village-level numbers (availability) of AWC centre, Health sub-centre, Primary health care centre, trained *dai*, untrained *dai*, and private *dai*. Panel B of table 4 indicates a lower availability of all the above village-level health infrastructures in the severely-affected villages in the period immediately after the earthquake. Specifically, an extra unit of earthquake intensity significantly reduces the number of trained and untrained *dai* by 0.61 and 0.36 respectively. The earthquake seems to have a negative impact on other village-level health infrastructures as well, but due to high standard errors in some of those coefficients we reserve our conclusions about them.

5.2 Mitigating effects

In order to examine the mitigating effects of provision of public goods, we extend our analysis to check if users of ICDS were able to mitigate the negative impact of the earthquake. ICDS is the largest national program in the world which aims to target long-term nutrition and holistic development of children by providing a range of services in one platform. It operates through the Anganwadi (or childcare) centers (AWCs) located within the villages or the urban wards. Since its inception with 33 projects in 1975, there has been a rapid expansion with 7073 operational projects with around 1.349 million operational AWCs in 2016, which cover almost all the regions of the country (MoWCD, 2017). For this wider coverage and efficient implementation of the scheme, fund allocation has been increased from Rs. 444 billion (US$5.91 billion approximately) in the Eleventh Five-Year Plan (2007–2012) to Rs. 1235.8 billion (US$16.46 billion approximately) in the Twelfth Five-Year Plan (2012–2017).

Using the available information on the actual consumption of any ICDS component by the households for the last two births after January 2000, we estimate the following equation for the subsample of our younger cohort aged 3–5 years old (during survey) and born after January 2000:

$$\begin{aligned} H_{ihkt} = {} & \beta_1(\text{NonUser in severely affected region}_i) + \beta_2(\text{NonUser in control region}_i) \\ & + \beta_3(\text{User in control region}_i) + \pi Male_i + \delta_t + \boldsymbol{\mu X}_h + \boldsymbol{\alpha D}_k + \varepsilon_{ihkt} \end{aligned} \quad (5)$$

To evaluate the mitigating effects of ICDS, we generate four interdependent binary variables using all possible combinations of ICDS usage and households belonging to *Severely Affected Regions*. The four dummy variables are households which: do not use ICDS belonging to a severely-affected region (*Non-user in severely affected region*); do not use ICDS belonging to a marginally-affected or unaffected region (*Non-user in control region*); use ICDS while staying in a marginally-affected or unaffected region (*User in control region*); use ICDS while staying in a severely-affected region (*User in severely*

Table 4. OLS estimates of the earthquake: sample of 12 districts of Gujarat plus surveyed districts of other states

	Shock to health services				Shock to household infrastructures	
Panel A (Source: DLHS 1-2): Variables	(1) Visit by ANH	(2) No. of visits by ANH	(3) IFA tablets given	(4) Tetanus injection given	(5) Type of House ‘Pucca’	(6) Drinking water – Tap/Handpump
Post × Severely-affected region	−0.058 (0.032)	−0.380 (0.159)	−0.067 (0.025)	−0.014 (0.020)	−0.038 (0.036)	−0.151 (0.050)
Observations	25,293	25,293	25,293	25,293	116,664	116,664
R^2	0.115	0.074	0.216	0.197	0.397	0.282
Panel B (Source: IHDS-1):	Shock to health infrastructure (Health facility in numbers)					
	AWC Center	Health Sub-Center	Primary Health Health Center	Trained *dai*	Untrained *dai*	Private *dai*
Earthquake intensity	−0.696 (0.537)	−0.132 (0.076)	−0.054 (0.040)	−0.606 (0.230)	−0.355 (0.053)	−0.055 (0.203)
Observations	61	61	61	61	60	61
R^2	0.092	0.060	0.040	0.161	0.125	0.004

Notes: In panel A, Robust standard errors clustered at the district-birth year and district-interview year levels are in brackets for columns (1) to (4) and (5) to (6). In panel B, we cluster them at the district level.

In panel A, 12 districts based on the two rounds of DLHS data include five severely-affected and seven marginally-affected districts. In the main analysis based on IHDS-1 data, we had six severely-affected districts – Ahmedabad, Jamnagar, Kutch, Patan, Rajkot, Surendranagar. Patan is not included in this analysis as the survey for this district was done in the second phase of DLHS-2 which we do not include in the current analysis. Post takes a value 1 if the observation belongs to first phase of DLHS-2 surveyed in 2002 and it takes a value 0 if it belongs to DLHS-1 which was conducted in two phases in 1998 and 1999. We do not use the second phase of DLHS-2 as there was gap of three years between the earthquake (2001) and the second phase of DLHS-2 (2004). Columns (1) to (4) include child’s month of birth fixed effects, child’s birth year fixed effects and district-specific time trends. Columns (5) and (6) include survey year fixed effects and district-specific time trends. All the columns in panel A include six additional covariates, such as, age of the woman, education of the woman, education of the spouse, age at cohabitation, and residence status (urban or rural). Moreover, columns (1) to (4) include the gender of the last-born child.

In panel B, 12 districts based on the IHDS-1 data include five severely-affected and seven marginally-affected districts. In the main analysis based on IHDS-1 data, we had six severely-affected districts – Ahmedabad, Jamnagar, Kutch, Patan, Rajkot, Surendranagar. Rajkot is not included in this analysis as the village level survey for this district is not available. Out of ten marginally-affected districts included in the main analysis, Amreli, Bhavnagar and Surat could not be included in this village analysis as the village level survey for these districts are not available.

Table 5. Mitigating effects of ICDS usage in earthquake-affected areas on height and ZHFA for the younger cohort (0–3 years old)

Variables	(1) Height in cm	(2) ZHFA in (-6,6)
ICDS Non-users in severely-affected region	−6.826	−1.061
	(3.54)	(0.54)
ICDS Non-users in control region	2.080	0.126
	(2.75)	(0.17)
ICDS Users in control region	2.757	0.298
	(2.69)	(0.14)
Observations	896	807
Age FE	Yes	Yes
Survey year FE	Yes	Yes
Number of additional controls	Eight	Eight

Notes: Regressions are estimated by OLS. Robust standard errors clustered at the district level are shown in brackets. Control group in terms of space includes all the districts of Maharashtra, Rajasthan, Madhya Pradesh and eleven districts of Gujarat. ICDS users in severely-affected region is the reference category.
Eight additional controls are gender of the child, ethnicity (SC, ST, OBC or others), religion (Hindu or others) and residence status (urban or rural), percentage of villages in a district which have medical facility in their village, percentage of villages in a district which have paved road in their village, percentage of rural population in the district, gender ratio.
Data source: IHDS-1.

affected region). The last group being the reference group, we expect β_1 to be significantly negative, as the impact is expected to be more among non-users in comparison to users in a severely-affected region. Other variables have the same definitions as previous equations, apart from an additional male dummy of children, and a vector of district-level observables ($\boldsymbol{D}_k$). Since this specification does not allow us to control for district fixed effects, we control for time invariant differences across the districts (denoted by vector $\boldsymbol{D}_k$) by including four covariates from the 2001 Census data. The covariates are: (1) percentage of villages in a district k having medical facilities, (2) and having paved roads, (3) percentage of rural population in the district, and (4) gender ratio in the district.

Our estimates from table 5 indicate that the height and ZHFA are about 6.8 cm and 1.1 standard deviations lower respectively for the non-users in a severely-affected region as compared to users. The estimate of the third row indicates that among users, the households in unaffected regions seem to have marginally better health outcomes only when ZHFA is considered, but otherwise those households do not seem to have a large difference, which could be secondary evidence of mitigating effects of ICDS usage. One could worry about the usage of ICDS services being endogenous to the households. We argue that after conditioning on a large number of household- and district-level observables including birth-year specific fixed effects, the differential impact is primarily generated by the ICDS usage. Moreover, this mitigating ability of the ICDS is supported by the findings of Dhamija and Sen (2020), who find that a 10–13 year old cohort fully exposed to the ICDS during the first three years of their life had about 2.3 cm higher height as compared to their unexposed counterparts.[24]

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[24] We also examine the heterogeneous effects by gender and birth order of the child (see online appendix table A21). However, the mitigating effect does not vary by gender or birth order.

6. Concluding comments

The human development literature establishes a strong linkage between early life health and later life welfare outcomes. Any negative shock at this stage creates a lasting impact, and positive inputs targeted to overcome deficiencies at this stage are found to produce strong positive outcomes (see Dhamija and Sen, 2020). In this study, we evaluate the impact of the Gujarat earthquake of 2001, on the anthropometric outcomes of children who were in-utero or under the age of three years at the time of the earthquake. Exploiting the exogenous variation in the exposure to this unfortunate shock and the birth year of children, we find that girls in the younger cohort, exposed to the shock in the early years of lives, seem to have 3 cm lower height and lower ZHFA.

The data limitation restricts our estimation of treatment effects to the female cohort in all our specifications because the anthropometric information is not available for the male cohort of 18–23 years age. However, in a separate analysis (online appendix table A16), we compare the health outcomes of the boys belonging to the younger cohort between the severely-affected districts and the remaining unaffected districts using the following regression framework[25]:

$$H_{ihkt} = \beta(Intensity_k) + \delta_t + \boldsymbol{\mu X}_h + \boldsymbol{\alpha D}_k + \varepsilon_{ihkt}. \tag{6}$$

here, we restrict the sample to those children who were in-utero or under the age of three at the time of the earthquake, as we do not have any counterfactual older cohort in this specification. Hence, our main variable of interest, $Intensity_k$, measures the MMI of the earthquake in district k as discussed in equation (2). $\boldsymbol{D}_k$ represents the same time-invariant district-level vector as explained in equation (5). All other variable specifications being the same as in equation (2), a simple linear regression estimation among the boys sample indicates that boys belonging to a severely-affected region at the time of the earthquake have lower height and ZHFA on average by 4.9 cm and 0.64 standard deviations respectively.

Our findings conform to the existing literature (Thamarapani, 2021), which also finds negative effects of early life disasters, including earthquakes. While examining the potential mechanisms, we find the affected regions to have less ‘pucca’ house or drinking water facilities after the earthquake. The antenatal facilities seem to have been affected too. The households having access to ICDS services seem to show lesser impact on their children, which reaffirms the effectiveness of child development services in early life, as found earlier (Dhamija and Sen, 2020).

One potential threat to the validity of the identifying assumption in this analysis is that the socio-demographic composition of mothers giving birth could be correlated with the timing of exposure to the earthquake. To check this, using both rounds of DLHS data, we regress the main variable of interest ($\text{Post}_i \times \text{Severely Affected Region}_j$) on the following variables:- age in completed years when the wife started living with her husband, whether the wife can read or write, levels of education completed by the wife, whether the husband can read or write, levels of education completed by the husband. In these specifications, we also control for birth-year fixed effects δ_t and birth-month e_m fixed effects to account for time-variant changes. We also include time trend of districts to control for unobserved differences over time. Estimates (in online appendix table A7) indicate no statistically significant correlations.

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[25] The complete regression results are available from the authors on request.

One could also raise the criticism that the impact of the earthquake is estimated on the surviving children only, and we are unable to estimate the impact on children who have not been able to survive till later years of their lives. Since the surviving children are expected to belong to better-off households, along with improved human development outcomes to begin with, what we end up estimating may be a lower bound of true estimate at the maximum.

Additionally, comparison of certain indicators in the sample before earthquake (DLHS-1) and after earthquake (DLHS-2) in online appendix table A6 indicates that earthquake-affected areas may have been better-off in certain developmental aspects at the baseline. However, if we expect our estimates of impact to be biased due to this, those will be underestimations at the most. Our secondary estimation strategy involves using the marginally-affected districts of Gujarat as the counterfactuals because the IHDS-1 does not collect data from more than one unaffected district. This strategy may raise skepticism about the magnitude of the estimated impact if the difference in outcomes between marginally-affected districts and unaffected districts are large. However, our primary methodology being based on intensity measures requiring less strong assumptions and the impacts on height by both methods being very close, we believe that the estimates of intensity measures are able to capture true effects at the least.

Trezzi and Porcelli (2014) find that destruction of physical capital as aftereffects of the quake causes loss of economic activity, whereas large-scale grants from multilateral agencies for reconstruction work boosts economic activity. However, they show that effects of economic activities are non-persistent and tend to be reabsorbed within two years of the earthquake. The earthquake in Gujarat also raised huge concerns inside the country and among the international community, which was followed by the large scale of grants from different domestic and international agencies. It would be interesting to explore if the intervention of funding agencies and other related activities from all around the world were indeed able to boost large-scale reconstruction activity helping improvement of local conditions, and if that may have more than compensated for the destruction of physical infrastructures caused by the earthquake (Porcelli and Trezzi, 2019). Since, it is difficult to clearly identify the net outcome on economic activity post-earthquake, we focus on two primary channels. They are: destruction of household infrastructures in the affected districts; and access to health-related infrastructures by the households that could affect the health-seeking behaviors of the households.

Therefore, with these results, we add to the existing literature that attempts to understand the linkage between various natural shocks such as health and educational outcomes. As established in the existing literature, a 2.5–3 per cent loss of height in early childhood can lead to cumulative loss in labor market returns (wage) of 2 to 2.4 per cent on average in adulthood.[26] From a public policy perspective one can recommend that the vulnerable sections of society such as pregnant women, and children under the age of three, should be provided with sufficient nutrition and care. Sufficient aid and relief should also be made available to the other sections of the society at the time of a natural shock because the effects of any negative shock earlier in life is not only observed in the shorter run but creates a lasting impact.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X2200016X.

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[26] See online appendix section IV for a detailed discussion on this speculation.

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References

ACC/SCN (2000) *Fourth Report on the World Nutrition Situation: Nutrition Throughout the Life Cycle*. Geneva: ACC/SCN in collaboration with IFPRI.

Alderman H, Hoddinott J and Kinsey B (2006) Long term consequences of early childhood malnutrition. *Oxford Economic Papers* **58**, 450–474.

Almond D (2006) Is the 1918 influenza pandemic over? Long-term effects of in utero exposure in the post-1940 US population. *Journal of Political Economy* **114**, 672–712.

Almond D and Currie J (2011) Human capital development before age five. In Ashenfelter O and Card D (eds), *Handbook of Labor Economics*, 1st Edn, vol. **4**. Elsevier, Amsterdam, pp. 1315–1486.

Almond D and Mazumder B (2005) The 1918 influenza pandemic and subsequent health outcomes: an analysis of SIPP data. *American Economic Review* **95**, 258–262.

Andrabi T, Daniels B and Das J (2021) Human capital accumulation and disasters: evidence from the Pakistan earthquake of 2005. *Journal of Human Resources*, published ahead of print on June 9, 0520-10887R1.

Blackwell DL, Hayward MD and Crimmins EM (2001) Does childhood health affect chronic morbidity in later life? *Social Science and Medicine* **52**, 1269–1284.

Bossavie L, Alderman H, Giles J and Mete C (2021) The effect of height on earnings: is stature just a proxy for cognitive and non-cognitive skills? *Economics & Human Biology* **43**, 101046.

Caruso G and Miller S (2015) Long run effects and intergenerational transmission of natural disasters: a case study on the 1970 Ancash earthquake. *Journal of Development Economics* **117**, 134–150.

Case A and Paxson C (2008*a*) Stature and status: height, ability, and labor market outcomes. *Journal of Political Economy* **116**, 499–532.

Case A and Paxson C (2008*b*) Height, health, and cognitive function at older ages. *American Economic Review* **98**, 463–467.

Chen Y and Zhou LA (2007) The long-term health and economic consequences of the 1959–1961 famine in China. *Journal of Health Economics* **26**, 659–681.

Colella F, Lalive R, Sakalli SO and Thoenig M (2019) Inference with arbitrary clustering. IZA Discussion Paper No. 12584.

American Academy of Pediatrics, Committee of the Fetus and Newborn, American College of Obstetricians and Gynecologists and Committee on Obstetric Practice (2006) The Apgar score. *Pediatrics* **117**, 1444–1447.

Datar A, Liu J, Linnemayr S and Stecher C (2013) The impact of natural disasters on child health and investments in rural India. *Social Science & Medicine* **76**, 83–91.

Del Ninno C and Lundberg M (2005) Treading water: the long-term impact of the 1998 flood on nutrition in Bangladesh. *Economics and Human Biology* **3**, 67–96.

Dercon S and Porter C (2014) Live aid revisited: long-term impacts of the 1984 Ethiopian famine on children. *Journal of the European Economic Association* **12**, 927–948.

Dhamija G and Sen G (2020) Lasting impact of early life interventions: evidence from India's integrated child development services. *The Journal of Development Studies* **57**, 106–138.

Dinkelman T (2017) Long-run health repercussions of drought shocks: evidence from South African homelands. *The Economic Journal* **127**, 1906–1939.

DLHS-1 (District Level Household and Facility Survey 1) (1998-99) International Institute of Population Sciences, Mumbai, India. Available at http://www.iipsindia.ac.in/#.

DLHS-2 (District Level Household and Facility Survey 2) (2002-2003) International Institute of Population Sciences, Mumbai, India. Available at http://www.iipsindia.ac.in/#.

Duflo E (2004) The medium run effects of educational expansion: evidence from a large school construction program in Indonesia. *Journal of Development Economics* **74**, 163–197.

Finlay J (2009) Fertility response to natural disasters: the case of three high mortality earthquakes. World Bank Policy Research Working Paper 4883.

Fukuda M, Fukuda K, Shimizu T and Møller H (1998) Decline in sex ratio at birth after Kobe earthquake. *Human Reproduction* **13**, 2321–2322.

Gignoux J and Menéndez M (2016) Benefit in the wake of disaster: long-run effects of earthquakes on welfare in rural Indonesia. *Journal of Development Economics* **118**, 26–44.

Gorgens T, Meng X and Vaithianathan R (2012) Stunting and selection effects of famine: a case study of the great Chinese famine. *Journal of Development Economics* **97**, 99–111.

GSDMA (Gujarat Earthquake Reconstruction and Rehabilitation Policy) (2002) Gujarat State Disaster Management Authority, Government of Gujarat. Available at http://www.gsdma.org/Content/gujarat-earthquake-rehabilitation-and-reconstruction-policy-4240.

Haas SA (2007) The long-term effects of poor childhood health: an assessment and application of retrospective reports. *Demography* **44**, 113–135.

Hoddinott J and Kinsey B (2001) Child growth in the time of drought. *Oxford Bulletin of Economics and Statistics* **63**, 409–436.

Hombrados JG (2020) The lasting effects of natural disasters on property crime: evidence from the 2010 Chilean earthquake. *Journal of Economic Behavior and Organization* **175**, 114–154.

Hough SE, Martin S, Bilham R and Atkinson GM (2002) The 26 January 2001 M 7.6 Bhuj, India, earthquake: observed and predicted ground motions. *Bulletin of the Seismological Society of America* **92**, 2061–2079.

IHDS-1 (India Human Development Survey-1) (2005) ICPSR22626-v11. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2016-02-16. Available at https://www.icpsr.umich.edu/icpsrweb/DSDR/studies/22626.

IIPS (International Institute for Population Sciences) (2001) Reproductive and Child Health Project, Rapid Household Survey (Phase I and II), 1998–1999: India.

IIPS (International Institute for Population Sciences) (2006) District Level Household and Facility Survey (DLHS-2), 2002–04: India.

Jensen R (2000) Agricultural volatility and investments in children. *American Economic Review* **90**, 399–404.

Kelly E (2011) The scourge of Asian flu: in utero exposure to pandemic influenza and the development of a cohort of British children. *The Journal of Human Resources* **46**, 669–694.

Knudsen EI (2004) Sensitive periods in the development of the brain and behavior. *Journal of Cognitive Neuroscience* **16**, 1412–1425.

Lahiri AK, Sen TK, Rao RK and Jena PR (2001) Economic consequences of Gujarat earthquake. Economic and Political Weekly **36**, 1319–1332. Available at http://www.jstor.org/stable/4410512.

Lin MJ and Liu EM (2014) Does in utero exposure to illness matter? The 1918 influenza epidemic in Taiwan as a natural experiment. *Journal of Health Economics* **37**, 152–163.

Maccini S and Yang D (2009) Under the weather: health, schooling and economic consequences of early-life rainfall. *American Economic Review* **99**, 1006–1026.

Marcell AV (2007) Adolescence. In Kliegman RM, Behrman RE, Jenson HB and Stanton BF (eds), *Nelson Textbook of Pediatrics*, 18th Edn. Philadelphia, PA: Saunders Elsevier, pp. 60–64.

Martorell R and Habicht J-P (1986) Growth in early childhood in developing countries. In Falkner F and Tanner JM (eds), *Human Growth: A Comprehensive Treatise*, 2nd Edn, vol. **3**. New York: Plenum Press, pp. 241–262.

Mishra PK (2004) *The Kutch Earthquake 2001: Recollections, Lessons, and Insights*. New Delhi, India: National Institute of Disaster Management.

Morgane PJ, Austin-LaFrance R, Bronzino J, Tonkiss J, Diaz-Cintra S, Cintra L, Kemper T and Galler JR (1993) Prenatal malnutrition and development of the brain. *Neuroscience & Biobehavioral Reviews* **17**, 91–128.

MoWCD (2017) Annual Report. Ministry of Women and Child Development, Government of India.

Nandi A, Mazumdar S and Behrman JR (2017) The effect of natural disaster on fertility, birth spacing, and child sex ratio: evidence from a major earthquake in India. *Journal of Population Economics* **31**, 267–293.

Negishi H, Mori J, Sato T, Singh R, Kumar S and Hirata N (2002) Size and orientation of the fault plane for the 2001 Gujarat, India earthquake (Mw7.7) from aftershock observations: a high stress drop event. *Geophysical Research Letters* **29**, 10-1–10-4.

Nobles J, Frankenberg E and Thomas D (2015) The effects of mortality on fertility: population dynamics after a natural disaster. *Demography* **52**, 15–38.

Oreopoulos P, Mark S, Randy W and Leslie LR (2008) Short-, medium-, and long-term consequences of poor infant health: an analysis using siblings and twins. *Journal of Human Resources* **43**, 88–138.

Porcelli F and Trezzi R (2019) The impact of earthquakes on economic activity: evidence from Italy. *Empirical Economics* **56**, 1167–1206.

Roodman DM, MacKinnon JG, Nielsen MØ and Webb M (2019) Fast and wild: bootstrap inference in Stata using boottest. *The Stata Journal: Promoting Communications on Statistics and Stata* **19**, 4–60.

Strauss J and Thomas D (1998) Health, nutrition, and economic development. *Journal of Economic Literature* **36**, 766–817.

Tan CE, Li HJ, Zhang XG, Zhang H, Han PY, An Q, Ding WJ and Wang MQ (2009) The impact of the Wenchuan earthquake on birth outcomes. *PLoS ONE* **4**, e8200.

Tempesta D, Curcio G, De Gennaro L and Ferrara M (2013) Long-term impact of earthquakes on sleep quality. *PLoS ONE* **8**, e55936.

Thamarapani D (2021) Natural disasters and child health. *Environment and Development Economics* **26**, 26–44.

Trezzi R and Porcelli F (2014) Reconstruction multipliers. FEDS Working Paper No. 2014-79. Available at https://ssrn.com/abstract{\mathsurround=\opskip$=$}2511233.

Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L and Sachdev HS (2008) Maternal and child undernutrition: consequences for adult health and human capital. *The Lancet* **371**, 340–357.

Vogl T (2014) Height, skills, and labor market outcomes in Mexico. *Journal of Development Economics* **107**, 84–96.

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