RIETI Discussion Paper Series 22-E-049

Parental Investment after Adverse Event: Evidence from the Great East Japan Earthquake

INUI, Tomohiko
RIETI

OKUDAIRA, Hiroko
Doshisha University

RIETI
Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
https://www.rieti.go.jp/en/

RIETI Discussion Paper Series 22-E-049
May 2022

Parental Investment After Adverse Event: Evidence from the Great East Japan Earthquake*

Tomohiko Inui
Research Institute of Economy, Trade and Industry

Hiroko Okudaira
Doshisha University

Abstract

Parents often increase private investment in their children when they fear the negative effects of an adverse event. However, such an endogenous response makes it difficult to identify the cost of the adverse event and those disadvantaged by the shock. This study investigates the nature of an adverse shock that leads to endogenous responses by parents. Relying on the types of damage caused by the Great East Japan Earthquake, we find that parents exposed to intense ground motion increased their investment in children's cognitive skills. This positive response survives or becomes even larger after accounting for physical destruction and radioactive contamination.

Keywords: cognitive and noncognitive skills, human capital investment, returns to education, natural disaster.

* This study is conducted as a part of the Project "Human capital (Education· Health) investment and productivity", undertaken at the Research Institute of Economy, Trade and Industry (RIETI). The analysis using the Longitudinal Survey of Newborns in the 21st Century (LSN21) was conducted by following an agreement approved by the Japanese Ministry of Health, Labour and Welfare (MHLW) and the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). The authors are grateful to Ryo Arawatari, Richard Blundell, Christian Dustmann, Kyoji Fukao, Andrew Griffen, Takeo Hoshi, Hirokazu Ishise, Takuma Kamada, Toru Kitagawa, Hyejin Ku, Alice Kugler, Attila Lindner, Daisuke Miyagawa, Masayuki Morikawa, Takeshi Murooka, Hitoshi Shigeoka, Uta Shoenberg, Suk Joon Son, Tatiana Surovtseva, Suphanit Piyamondee, Katsuya Takii, Kensuke Teshima, Michela Tincani, Ken Yamada, Meng Zhao, as well as seminar participants at RIETI, Kyoto University, Osaka University, Doshisha University, Kansai Labor Seminar and TPLS for their helpful comments. Emi Shibata and Noriko Furuya provided excellent research assistance. Authors acknowledge research grants from the Japan Society for the Promotion of Science (Grant-in-aid for Scientific Research #16H02022, #19K01706, #20H00071).

1 Introduction

Adverse events can have long-lasting impacts on children. A large body of the literature has quantified the consequences on children's educational attainment of various types of adverse events such as hurricanes (Sacerdote, 2012; Deuchert and Felfe, 2015), volcanic eruptions (Nakamura et al., 2021), rainfall (Maccini and Yang, 2009; Shah and Steinberg, 2017), earthquakes (Caruso and Miller, 2015; Wang et al., 2017; Ushijima, 2019), radioactive fallout (Almond et al., 2009), famine (Meng and Qian, 2009), forced migration (Bauer et al., 2013; Becker et al., 2020), and epidemics (Almond, 2006; Gensowski et al., 2019).[1] Yet, much less is known about the mediating role played by parental investment in the years following adverse events. Parents may adjust their investment in their children in response to a shock for several reasons. They may attempt to compensate for the human capital damaged by the shock, especially cognitive skills and health, by increasing private investment in their children.[2] Severe adversity may also alter the ways in which parents perceive their returns to investment at home by, for example, shifting their preference from fixed assets toward mobile assets such as human capital (Becker et al., 2020). However, such positive responses by parents make it difficult to identify the real cost of adverse events as well as mask those truly disadvantaged by the shock if parents with sufficient resources only can afford additional investment. Indeed, despite the significant implications for both research and policy design, there is little direct evidence on whether such parental response exists, and if so, how and in what context parents respond to adverse shocks.

This study contributes to the literature by directly observing parental investment after the Great East Japan Earthquake in March 2011. There are two main advantages to using this approach. First, the Great East Japan Earthquake caused several types of damage such

[1] Other studies have examined the long-run impacts of family grief (Black et al., 2016) and maternal stress in general (Aizer et al., 2016).

[2] One strand of the literature has shown that adverse events directly reduce the human capital of children. In particular, prenatal exposure to stressful events such as earthquakes and hurricanes have negative impacts on birth outcomes, health status, and cognitive skill development (Glynn et al., 2001; Almond, 2006; Lauderdale, 2006; Camacho, 2008; Simeonova, 2011; Aizer et al., 2016; Black et al., 2016; Persson and Rossin-Slater, 2018). Almond et al. (2009) reported the detrimental impact of radioactive contamination on children's cognitive skills.

as flooding, collapsed buildings, and radioactive contamination due to the meltdown of a nuclear power station as well as intense ground motion that lasted for nearly three minutes. Regional variations in the extent of the physical damage allow us to disentangle the types of shocks to which parents responded. Second, we have detailed information on the hazard of earthquakes before the shock occurred. Some adverse events are predictable, albeit not perfectly. Parents may thus change their investment behavior in the face of an anticipated hazard, raising an endogeneity concern about the identification of the impact of adverse events. Thanks to the rich information on the pre-earthquake hazard level available publicly in Japan, we can condition on the level of prior risk and compare those affected by the shock with those unaffected.

Deriving data from an administrative longitudinal survey tracking children born in 2001, we estimate the reduced-form impacts of the earthquake shock on parental investment. We compare the trajectories of parental investment before and after the earthquake for those children in severely affected locations with that of children who resided in unaffected locations but suffered the same pre-earthquake hazard level. We first proxy for the extent of the shock by using seismic intensity (Z), a measurement of the magnitude of ground motion. We then examine whether the impact of ground motion survives after controlling for variables measuring physical damage and radioactive contamination, along with other mediating factors.

Our analysis reveals that parents responded to the adverse shock, particularly to ground motion. Specifically, we find that parents exposed to intense ground motion increased their investment in children's cognitive skills. At age 15, the children in the treatment group received 1.5 times higher spending on complementary private education (e.g., tutoring schools) than the children in the control group. Parents partially financed the increase in cognitive skill investment by substituting from their spending on noncognitive skills (e.g., music and sports), although this accounted for only a minor proportion of the increase in cognitive skill investment. Importantly, the increased investment in cognitive skills translated into an improvement in standardized selectivity scores, a proxy of standardized test scores at the time of high school admission. Children exposed to severe ground motion were admitted to high schools with a selectivity score 0.22 standard deviations higher than the high schools to which children exposed to no ground motion were admitted.

To narrow the mechanism behind this behavioral response by parents, since earthquakes affect parental investment for many reasons, we conduct additional analyses. We find that the increased investment in cognitive skills was not driven by attrition, migration, local demand and supply shocks, or other medicating factors such as increases in household income or declines in home education. Moreover, parents did not increase their investment to compensate for reduced public investment in education either. Interestingly, the impact of ground motion on parental investment remained or became larger after we controlled for proxies for the physical destruction of family wealth (e.g., the numbers of flooded households or injured) as well as a proxy for the lower latent human capital (e.g., radioactive contamination). On the contrary, the proxies for physical destruction had *negative* impacts on investment in cognitive skills: the children in regions with high numbers of injured or flooded households received less spending on their cognitive skills from their parents than the children in regions with little physical damage. Thus, parents responded to the earthquake shock, but differently depending on the type of shock. While physical destruction had reducing impacts, the experience of traumatic ground motion raised parental investment in cognitive skills, even in the absence of physical destruction. Our best interpretation of this finding is that such a response is driven by a shift in the preferences of parents toward mobile assets and/or parents' belief that the event directly harmed their children's cognitive skills.

This study contributes to the literature in several ways. First, we provide direct evidence that the same adverse event can change parental investment in both positive and negative ways. To evaluate the effect on educational outcomes, previous studies have paid attention to the positive investment response by parents and even reported suggestive evidence, even though direct measurements of parental investment were often unavailable (Almond et al., 2009; Gensowski et al., 2019; Becker et al., 2020). For example, in their estimations of the impact of in utero exposure to the Chernobyl fallout on school performance, Almond et al. (2009) found that their negative treatment estimate on school grades was larger among children with less educated fathers, implying a mitigating effect of parental investment among children with high endowments. We are by no means the first to examine the direct measurements of parental investment.[3] However, we are one of the first to disentangle the shock owing to physical destruction from the shock owing to the intense experience of adversity, while still observing the direct measurements of parental investment.[4] Our results imply that a simple reduced-form estimate of the impact of adverse events on educational outcomes may be biased upward depending on the size of physical destruction and the extent of the mitigating role played by parents.

Second, this study shows the importance of accounting for the anticipation effect when estimating the impact of natural disasters on individual outcomes. Because individuals with specific traits may self-select into living in regions with a high hazard, the adverse shock from natural disasters is not completely random. In the context of this study, it is also essential to account for regional differences in returns to education before the shock since some families may systematically migrate to regions with a higher return. Previous studies examining the impact of natural disasters have addressed the similar endogeneity concerns by controlling for time-invariant unobservables (Hanaoka et al., 2018; Johar et al., 2022) and exploiting identification variations in the distance to the path of hurricanes in proximate areas (Currie and Rossin-Slater, 2013). We explicitly address the endogeneity concerns by using the pre-earthquake hazard level right before the Great East Japan Earthquake. We provide clear evidence that the significant treatment effect observed in the pre-earthquake period is mitigated substantially once we condition on this pre-earthquake hazard. Controlling for the prior educational environment also plays an important role in

[3] For example, in the developing country context, (Deuchert and Felfe, 2015) observed that a hurricane lowered family wealth, resulting in a decline in parental investment and children's test scores; however, they did not differentiate the physical destruction effect from possible offsetting effect by parents. We interpret that the physical destruction effect dominated any mitigating role played by parental investment in their case.

[4] To the best of our knowledge, the only related evidence is provided by Johar et al. (2022), who found that experiences of flood and earthquake had the opposite effects on risk preferences depending on whether the shock directly or indirectly affected a region.

eliminating the pre-trends.

Finally, this study provides suggestive evidence for estimating a production function of children's skill formation. The literature has identified the technology of children's skill formation, notably the elasticity of substitution between several types of skills and other input factors (Cunha et al., 2010; Boca et al., 2014; Attanasio et al., 2020a,b; Gensowski et al., 2020, etc.). Using a control function approach, studies have often found suggestive evidence of the compensating behavior of parents in the face of a negative shock to their children's development. According to Cunha et al. (2010), the productivity of investment in both cognitive and noncognitive skills is underestimated when they do not account for the endogeneity in the investment decision and time-variant heterogeneous shocks. Attanasio et al. (2020a,b) also adopted a control function approach and reported suggestive evidence of positive parental response to adverse shocks.[5] Hence, while the literature focuses on infants and younger children in developing countries, this study shows that such a behavioral response is more general by providing direct evidence for early teenagers in a developed country.

The rest of this paper is organized as follows. Section 2 introduces the datasets used in the analyses. Section 3 describes the identification strategies. Section 4 presents the main results along with the results of some sensitivity tests. Section 5 narrows the mechanisms driving the main treatment effect. Section 6 concludes.

2 Data

2.1 The Earthquake Shock

To evaluate parental response to a natural disaster, we rely on the large adverse shock caused by the Great East Japan Earthquake in 2011. The major ground motion took place

[5] In particular, under their control function approach, the residual of investment is negatively associated with children's health and cognitive skills (Attanasio et al., 2020a). In addition, they found that their OLS estimates, which considered investment as exogenous, were lower than the estimates dealing with endogenous investment for all ages (5, 8, and 12 years) and for both for health and cognitive skills (Attanasio et al., 2020a).

at 2:46 pm on March 11. The earthquake, magnitude 9.0 on the Richter scale, hit numerous areas along the Pacific coast in eastern Japan. Although Japan is known for its frequent serious natural disasters, the Great East Japan Earthquake caused some of the worst physical destruction in the country's history, leading to 19,667 deaths, 2,566 missing people, and more than 121,000 homes destroyed (Ministry of Internal Affairs and Communications).

We measure the extent of the earthquake shock first by using the seismic intensity measure constructed by the Japan Meteorological Agency (JMA). Seismic intensity (Z) measures the ground motion in a location. The JMA records the seismic intensities of all local ground motions at more than 1700 monitoring stations in Japan. We focus on the main earthquake on March 11, 2011 and construct a location-level (e.g., municipality-level) seismic intensity measurement by taking the weighted average of the seismic intensities at the three monitoring stations closest to the municipality's city hall. The average is then weighted by the inverse of the distance between the city hall and each monitoring station. This measurement was adopted by Hanaoka et al. (2018). According to the JMA, a seismic intensity of four ($Z = 4$) is the level at which people are startled and find hanging objects such as ceiling lights swinging significantly. At a level of five ($Z = 5$), people are frightened, TVs may fall from their stands, and windows may break and smash. In essence, seismic intensity proxies for the extent of the shocks caused by ground motion and subsequent destruction caused by quakes, such as collapsing buildings.[6]

Importantly for our analysis, the degree of the shock differs substantially by location. The left-hand panel of Figure 1 maps the seismic intensities in each location at the time of the earthquake. The darker areas indicate those areas with more intense ground motion, showing that the shock gradually fades as we move away from the epicenter. As illustrated in the figure, the most intense quakes were concentrated on the eastern part of the main island, even though people in the northeast still felt some ground motion.

Although a higher seismic intensity tends to indicate greater physical damage owing to ground motion, the same seismic intensity can indicate different types of shocks. Indeed,

[6] Appendix Figure A1 provides more detailed images of the extent of the shocks at a given seismic intensity.

the Great East Japan Earthquake was characterized by several types of destruction, not only the damage directly caused by ground motion. One prominent shock was caused by the subsequent tsunami. Because the earthquake was triggered at a plate boundary in the Pacific Ocean, it resulted in an enormous tsunami that flooded coastal areas and increased the death toll due to drowning. The subsequent meltdown of the Fukushima nuclear power station was also initiated by the tsunami, and this lead to concern about radioactive contamination across eastern Japan.

Figure 2 shows the relationship between seismic intensity and several measurements of the damage caused by the earthquake. Similar to seismic intensity, the damage data are provided at the location level.[7] We weight the binned scatterplot by the number of observations in the main dataset (i.e., the Longitudinal Survey of Newborns in the 21st Century, LSN21), as shown later. Figure 2 illustrates that 10–20% of the locations were damaged by the earthquake in some way. They also experienced different types of shocks at the same seismic intensity. For example, at a seismic intensity of five ($Z = 5$), some locations had virtually no flooded or damaged houses, whereas others suffered extensive physical damage due to the tsunami or collapse of buildings.

This study exploits the variations in such physical damage to disentangle the characteristics of adverse shocks to which parents respond. In the main analysis, we first define children's treatment status by using the seismic intensity (Z) in the location in which the family lived two months before the earthquake, January 2011. We then control for physical damage to examine whether the treatment effect is nullified or mitigated by factors other than ground motion.

2.2 Anticipation of the Shock

People often anticipate natural disasters, albeit not perfectly. Because parents with specific traits may avoid living in high-risk regions, choice of residence and parental investment are determined endogenously to an adverse shock caused by a natural disaster. To identify

[7] Appendix A presents the information sources.

the impact of an adverse shock, it is therefore crucial to account for the likelihood of the earthquake hazard before it occurs.

In this vein, we draw on the pre-earthquake seismic hazard (H) provided by the Japan Seismic Hazard Information Station, which it estimates based on periodic activities in subduction zones and the location and size of faults. In particular, the pre-earthquake seismic hazard measures the likelihood that a given 250-meter mesh will experience a ground motion intensity exceeding a certain value within a target period. We construct the location-level pre-earthquake hazard by taking the average of the 16 closest meshes surrounding the city hall of the municipality in 2010, right before the earthquake shock occurred. The right-hand panel of Figure 1 maps the location-level pre-earthquake hazard. The Pacific coast, especially the southern central regions along with the Nankai Trough, are known for their high risk of earthquakes occurring.[8] The areas hit by the Great East Japan Earthquake were also those areas originally having a relatively high pre-earthquake hazard before the earthquake in 2011. In the main analysis, we exploit the fact that the shock was exogenous conditional on the initial pre-earthquake hazard. In other words, we compare those families hit by the earthquake shock with those not hit by the shock but who lived in an area with a similar pre-earthquake hazard level.

2.3 Parental Investment and Child Outcomes

We use the LSN21 administered by two Japanese ministries.[9] The LSN21 tracks children born between January 10 and 17, 2001 and it is conducted on January 18 every year. At the time of the Great East Japan Earthquake, these children were 10 years and studying in year 4 at primary school. Data on detailed parental investment have been available since 2009, three waves before the earthquake. We focus on the waves of 2009 to 2016, until age 15 (i.e., right before high school enrollment). Restricting our sample to the children observed in

[8] The Japanese government has aimed to raise awareness of the dangers of earthquakes. For example, the Ministry of Education, Culture, Sports, Science and Technology requires local schools to educate students in years 3–5 about earthquake preparation.

[9] The Ministry of Health, Labour, and Welfare (MLHW), and the Ministry of Education, Culture, Sports, Science, and Technology (MEXT).

these waves leaves us with 7,339 children, approximately 28% of all those born in the same period in Japan. The mortality rate is negligible—even at the time of the earthquake.[10] The attrition rate is not negligible but has no significant associations with the treatment variable (see Section 5.3 and Appendix D).

One advantage of the LSN21 is that it allows us to observe both pecuniary and nonpecuniary investment in children's skills by parents. For pecuniary investment, the survey records three types of monthly expenditure in the month before the survey period (i.e., December): (1) tutoring schools, (2) after-school clubs such as sports and music, and (3) all other expenditure on the child including on food, clothes, tuition, and medical treatment (only in some survey years). Spending on tutoring schools is a popular form of parental investment in East Asia.[11] These tutoring schools directly supplement the child's math, language, and science skills in preparation for entrance exams to advanced schools. We consider expenditure on (1) tutoring schools as a proxy for parental investment in children's cognitive skills. On the contrary, expenditure on music and sports activities are considered to nurture children's confidence and social and emotional skills. Indeed, studies have found positive associations between these activities and the development of noncognitive skills (Hille and Schupp, 2015; Smith et al., 2014; Lees and Hopkins, 2013)[12]. We use expenditure on after-school clubs to capture a proportion of parental investment in noncognitive skills.

For nonpecuniary investment, we observe the extent of the mother's or father's commitment to children's study at home until age 12. The LSN21 also asks whether parents often take children to cultural facilities including museums, zoos, botanical gardens, aquariums

[10] According to the Vital Statistics, the overall mortality rate for children aged 10 to 14 years was 0.000124% in 2011, slightly higher than the rates in 2010 (0.000094%) and 2012 (0.000087%). Altogether, 1% of the reported deaths that resulted from the Great East Japan Earthquake were suffered by the 10–14-year-old age group (Ministry of Health, Labour and Welfare). Although the LSN21 does not identify the attrition due to deaths, the mortality rate due to the earthquake in our sample is considered to be low.

[11] According to a survey in Beijing, Seoul, and Tokyo, the proportions of 10- and 11-year-old children who regularly study at tutoring schools are high: 76.6% in Beijing, 72.9% in Seoul, and 51.6% in Tokyo (Institute and Research, 2006).

[12] One exception is Knaus et al. (2020), who reported that regular physical education negatively affected boys' emotional symptoms. However, they also found that this adverse effect was driven by students engaging in the same sports at school rather than in the sports of their choosing, thereby increasing the tension between winners and losers among peers.

("museums"), and musicals and concerts ("concerts"). Later, we examine whether parents responded to the adverse shock by substituting one type of investment for another.

In addition to parental investment, the LSN21 includes proxies for the child outcome variables. As our main outcome variable, we measure children's cognitive skills by using the standardized selectivity score of the high school to which they were admitted. The selectivity score is constructed from national-level standardized tests and hence is tightly linked to children's test scores in the year before enrolling in high school (year 9).[13] Appendix A describes in detail the procedure used to construct these variables.

Table 1 reports the baseline summary statistics by treatment status. The children in the treatment group comprise approximately 34% of the original sample. As shown in the lower half of the table, the children in our sample expected to have a severe earthquake within the next three decades at a probability of 21.37% in 2010. Treated locations have large standard deviations in the damage measures (i.e., numbers of dead and missing), ensuring large variations in physical damage within the treatment group. Before the Great East Japan Earthquake, the treatment and control groups have some different characteristics. The children in the treatment group are slightly less likely to have no parent or a single parenting status and live with their grandparents than the children in the control group. In the main analyses, we check the sensitivity of the results against the inclusion of these control variables.

Table 2 reports some of the proxies for parental investment and child outcomes across selected survey years. Spending on cognitive skills grows with age, while spending on noncognitive skills declines. Spending on cognitive skills becomes as high as about USD 530 at age 15, three months before the exams for high school admission or winter school break. Parents typically spend more on tutoring schools over school holidays when those schools offer extra programs. Spending on the cognitive skills of children aged 15 diverges

[13] Studies have estimated production functions to identify the technology of children's skill formation, notably the elasticity of substitution of several types of skills. Cunha et al. (2010) estimated the elasticity of substitution between cognitive and noncognitive skills, while Attanasio et al. (2020a) estimated the production functions for cognitive skills and health capital. We do not adopt this approach because of a lack of outcome information in some survey years.

markedly in the treatment and control regions: parents in the treatment group spend an average of 50% more on children's cognitive skills than parents in the control group. The children in the treatment group receive higher spending on average, even at age 8 (i.e., before the earthquake shock). Section 4 shows that the pre-existing difference in parental investment is driven by the pre-earthquake hazard as well as regional differences in school environments. The proportion of mothers or fathers looking after their children's schooling declines as the child ages, suggesting lower nonpecuniary parental investment.

The LSN21 contains other information that could mediate the earthquake's impact on parental investment and child outcomes, including parents' employment status (every year) and income information (available in limited waves). These variables are also used to examine whether the behavioral response by parents was driven by their financial situation or another mechanism (Section 5).

3 Identification Strategy

Our estimation framework relies on geographical variation in the seismic intensities driven by the Great East Japan Earthquake in March 11, 2011. To identify the impact of the earthquake, we compare the outcome variable of those children who were in regions severely hit by the earthquake (treatment group) against those otherwise similar children in regions unaffected by the earthquake (control group). Our baseline model starts with a child-level fixed effect model:

$$Y_{it} = x_{it}\beta + \sum_{s \neq 2011} \gamma^s I(Treat_j) + \tau_t + \theta_i + \epsilon_{it} \tag{1}$$

where Y_{it} is parental investment in child i in year t; $I(Treat_j)$ is an indicator of treatment status, which is defined by the seismic intensity in location j (defined by municipality) in which child i was registered as a resident as of January 2011; x_{it} is a set of time-variant control variables; τ_t is a vector of dummy variables that indicate year t; and ϵ_{it} is a random shock. Because our data consist of one cohort, born in January 2001, the age effects are not separately identified from the year effects.

The parameter estimates for γ provide the treatment effect on parental response in each year (baseline year = 2011). Specifically, we estimate the impact of a high seismic intensity ($Z_j \geq 4.5$) in each year compared with the control group ($Z_j < 2$). Thus, we stack a sample of children in both the control and the treatment groups and estimate the difference between these two groups by year. We define our treatment group in this way because physical damage increases with Z for a seismic intensity of 4.5 or higher (Figure 2). The frequency of earthquake occurrences also declines sharply at a seismic intensity of 4.5.[14] In Appendix B, we also examine the consistency of the main results by altering the treatment thresholds.

In our estimation model, we account for a broad set of time-varying individual and regional traits (x_{it}).[15] These control variables are relevant for interpreting the mechanism of the main results. We first present the estimates without these time-varying variables and then discuss the mechanism in light of the potential sensitivity of our main results by including these control variables (see Section 5). Appendix C also examines the sensitivity of the main results.

To identify the model, it is essential that both the treatment and the control units follow the same outcome path had the treatment group not been hit by the earthquake. One important threat to this common trend assumption arises from the anticipation of the earthquake shock, as explained in Section 2.2. If local governments facing a high hazard invested less in public education to finance disaster prevention, parents may have invested more in

[14] In the 12 months before the earthquake (e.g., March 2010 to February 2011), the average numbers of earthquakes observed at each monitoring station were $N = 1.72$ for $1.5 \leq Z < 2$, $N = 0.94$ for $2 \leq Z < 2.5$, $N = 0.43$ for $2.5 \leq Z < 3$, $N = 0.18$ for $3 \leq Z < 3.5$, $N = 0.07$ for $3.5 \leq Z < 4$, $N = 0.03$ for $4 \leq Z < 4.5$, $N = 0.0017$ for $4.5 \leq Z < 5$, and $N = 0.0006$ for $5 \leq Z < 5.5$. Thus, earthquake occurrences become a disproportionately rare event at a threshold value of $Z = 4.5$.

[15] The controlled individual traits include parents' employment status (out of the labor force, employed, no mother/father, and unemployed (baseline)), the number of siblings, a dummy to indicate cohabitation with grandparents, and the BMI and its polynomials. The controlled regional traits include taxable income, the logarithm of population, the logarithm of expenditure on natural disaster restoration (plus 0.01), the logarithm of the teacher-to-student ratio and its polynomials, the numbers of primary and junior high schools per 100,000 pupils and their polynomials, long-term absence per 1000 pupils and its polynomials, average school expenditure per pupil and its polynomials, the CPI for education and its polynomials, and the residualized price for residential land and its polynomials. Appendix A explains how the variables are constructed and their data sources.

their children's education to compensate for the relatively low public investment in local education before the shock. The estimated γ would then be biased upward. If families in high-risk regions were likely to stay in those regions because of the relatively high moving cost, the estimated γ may reflect the credit constraints or low endowments of these families; therefore, they would be downward biased.[16]

To address the endogeneity concern, this study takes advantage of the geographical variations in the pre-earthquake hazard faced by families before the shock occurred. We first classify each child based on the pre-earthquake hazard in the location in which the child was registered as a resident as of January 2011. A child is thus grouped into a quintile bin (q) in accordance with their location at a distribution of the pre-earthquake hazard for all the children in our sample (e.g., 20th, 40th, 60th, and 80th percentiles for the grouping threshold values). We then include the hazard group-specific year effects (h_{qt}) in our baseline model:

$$Y_{it} = x_{it}\beta + \sum_{s\neq 2011} \gamma^{s} I(Treat_{j}) + h_{qt} + \tau_{gt} + \theta_{i} + \epsilon_{it} \tag{2}$$

where q indicates the hazard group to which child i belongs. Since the term h_{qt} sweeps out the between-hazard group variation, the estimates of γ are identified by relying on the variation in each hazard group. Because both the seismic intensity and the pre-earthquake hazard are measured at the location level, the model in equation (2) essentially compares the children in the treatment location ($Z_j \geq 4.5$) with those in the control location ($Z_j < 2$) but with the same pre-earthquake hazard level.

Equation (2) also conditions on the school environment (τ_{gt}) to consider regional differences in private schooling. In 2010, approximately 8% of children were enrolled in private junior high schools rather than public ones (Ministry of Education, Culture, Sports, Science and Technology). Unlike public junior high schools, children must pass the entrance ex-

[16] Appendix Figure A2 examines this point by showing the relationship between the pre-earthquake hazard and educational investment before the earthquake. Although the pattern is not persistent for all pre-earthquake hazard levels, we find a negative association between the two variables among observations in the high pre-earthquake hazard group.

ams to enroll in private school. To prepare for these exams, parents therefore often increase spending on tutoring schools when their child is 9 to 12 years. Because private schools are accessible in the urban areas, we purge out such regional differences in private schooling by adding year effects specific to the region groups (g), defined by the decile of the proportion of private junior high schools in the region of the child's residence as of 2010 (τ_{gt}).

Although the common trend assumption is not directly testable, we ensure the identification assumption in equation (2) by examining any pre-trends in the parameter estimates for γ before 2011. We also compare the estimation results with and without h_{qt} and τ_{gt} to characterize the nature of the bias in ignoring the pre-earthquake hazard or local school environment.

4 Results

4.1 Impact on Parental Investment

We first report our baseline fixed effect estimation results by controlling for the hazard-specific year effects (h_{qt}) and year effects specific to the region groups defined by the local educational environment (τ_{gt}). We then characterize the nature of the biases caused by excluding these two sets of variables. As we show when interpreting the mechanism in Section 5, the reduced-form estimates in this section survive even after we condition on extensive sets of observed individual and region characteristics (x_{it}).

Figure 3 separately plots the baseline estimates of γ for the models with four types of parental investment as the dependent variable. Appendix Table B1 presents the detailed estimation results used to construct Figure 3. We find the statistically significant and lagged behavioral responses to the adverse shock. Parents increased their monthly spending on cognitive skills after age 13 in response to the earthquake. The magnitude of this increase rose at age 15, three months before the exams taken for high school admission. At age 15, children who lived in locations with $Z_j \geq 4.5$ received approximately USD 177 more spending on cognitive skills than children who lived in locations with $Z_j < 2$. Table 1 shows that parents in the control region spent USD 354 on the child cognitive skills at age 15. Thus, the children in the treatment group received 1.5 times higher spending on complementary private education (e.g., tutoring schools) than the children in the control group. Although statistically insignificant, we also observe small positive impacts on other spending, as shown in Panel 3. Parents paid for the additional expenses partly by substituting from their spending on other extracurricular activities. Panel 2 shows a small but statistically significant decline in spending on noncognitive skills. Specifically, parents in the treatment group reduced their spending on noncognitive skills by USD 15 per month. However, this reduction did not cover the full increase in expenses. As shown in Panel 4, parents in the treatment group paid USD 44.2 more in total at age 14 and USD 185.4 more at age 15 than parents in the control group.

The lagged increase in parental investment in cognitive skills implies that parents perceived the return to their investment to be higher at the later stage of the child cognitive development. This is in contrast to studies which have observed dynamic complementarity in parental investment across different stages of the child development (Cunha et al., 2010; Attanasio et al., 2020a,b). However, our finding is consist with a study on parental beliefs about returns to their educational investment across different time periods (Boneva and Rauh, 2018). In particular, Boneva and Rauh (2018) conducted surveys on parents of primary and secondary school children in U.K., asking them about hypothetical investment questions at both early (i.e., years 3 to 6) and late (i.e., years 7 to 10) stages of the children's cognitive development. According to Boneva and Rauh (2018), parents perceived that the early investment was significantly less productive than the late investment, and moreover, parents also believed that the early and late investments were substitutes rather than complements. We interpret the lagged parental response reflecting their belief that the returns to investment is higher at later stage of the cognitive development, similarly in the context of Japanese students of the same age range.

The literature suggests the importance of accounting for the anticipation effect when evaluating returns to education because parents may anticipate policy shocks to their children and reoptimize their decision before the implementation of such policy (Das et al., 2013). Similarly, natural disasters are anticipated to some extent, as shown in Panel B of Figure 1. Given that families facing a relatively low moving cost may move to other regions in the longer run, such anticipation is likely to lead to endogenous responses by parents.

Table 3 explores the factors making the control and treatment groups comparable in Figure 3. Columns 1 and 4 present the results from the baseline model (i.e., the model without adding any controls). Specifically, they show the estimates from equation (2) but without the hazard-specific year effects (h_{qt}) or year effects specific to the region groups defined by the local school environment, namely, the decile of the proportion of private junior high schools in each region (τ_{gt}). The remaining columns add h_{qt} and/or τ_{gt} into this model to examine any changes in the size and significance of the pre-trends. The results in Table 3 confirm the importance of accounting for the anticipation effect in the case of natural disasters. While we obtain significant and sizable estimates of the pre-trends from the baseline models in column 1 and 4, the magnitudes of the pre-trends shrink substantially (see columns 2 and 5) once the hazard-specific year effects are conditioned out. The decline in the negative pre-treatment effects implies that parents who spent less on children's cognitive and noncognitive skills tended to live in regions with a higher risk of an earthquake even in the absence of the earthquake shock.

However, conditioning on the pre-hazard is insufficient to remove the significant pre-trends. The comparison of the columns suggests that the local educational environment is another important factor to remove the pre-trends. Because the proportion of private junior high school is *higher* in treatment regions than in control regions (see Table 1), the results imply that treated regions had higher school quality and that the parents in such regions tended to spend less on their children's cognitive skills before the earthquake. This finding is consistent with previous evidence showing that public educational investment crowds out private educational investment (Bray et al., 2014; Yuan and Zhang, 2015). Taken together, the results confirm the importance of accounting for the anticipation effect when evaluating parental response to earthquake shocks.

Finally, Table 4 examines the heterogeneity of parental responses by dividing the sample by single parenting status and parents' educational status as of 2010, right before the earthquake shock. Almond et al. (2009) reported that the adverse shock of the Chernobyl fallout on children's cognitive skills was larger among parents with a lower education, interpreting this as evidence for the smaller compensatory investment by parents with lower initial endowments. In the case of our earthquake shock, we also observe a slightly larger treatment effect for parents with a higher education compared with the baseline estimates in columns 1 and 5. We also find that children with a single parent received much less compensatory investment. Unlike the other children in the treatment group, they received a smaller increase in spending on their cognitive skills and an even larger decline in spending on their noncognitive skills at age 15 (in 2016). Although these estimates are less precise owing to the smaller sample size, Table 4 shows that parental investment after adverse shocks increases inequality in educational investment among families with and without large initial endowments.

4.2 Sensitivity Analyses

We conduct several sensitivity analyses of the main baseline results, as presented in the figures in the Appendix. In short, we find that the treatment variable $I(Treat_j)$ is consistently defined, as the estimated treatment effects become stronger for higher threshold values of Z_j. Appendix Figures B1 to B4 plot the estimation results from using various alternative treatment definitions but the same control group, which is defined by $Z_j < 2$. While we find a similar positive effect on monthly spending on cognitive skills, the magnitudes of the effects rise when the treatment group is defined by higher threshold values. The largest positive treatment effect (USD 178) is at age 15, when the treatment group is defined by $4.5 \leq Z_j < 5.5$, although the estimates are similar for two other definitions of the treatment groups, namely, $4 \leq Z_j < 5$ (USD 166) and $5 \leq Z_j < 6$ (USD 170). On the contrary, the treatment effect falls slightly when $5.5 \leq Z_j < 6.5$ (USD 150). In Section 5, we show that the smaller effects in more severely hit regions are driven by reduced household resources owing to the physical destruction. Once we control for physical destruction, we find similar sized effects as those observed when $4.5 \leq Z_j < 5.5$.

4.3 Impact on Child Outcomes

To quantify the impact of increased parental investment on child outcomes, we measure children's cognitive ability by using the standardized selectivity score at age 15. The standardized selectivity score, a counterpart of the standardized test score often adopted in the literature (Sacerdote, 2012, etc.) reflects a child's test scores in five main subjects (i.e., math, science, Japanese, English, and social studies). Leading education institutions publish the selectivity score required to be admitted to each high school. We merge these high school-level selectivity scores with the LSN21 by using the name of the high school in which the child is enrolled. Appendix A7 presents the procedure used to construct the selectivity scores. Because the selectivity score is available only at age 15, we estimate the following cross-sectional model:

$$Y_i^{2016} = \gamma I(Treat_j) + h_q + \tau_g + \epsilon_i \tag{3}$$

where h_q and τ_g are dummies indicating the region groups defined by the pre-earthquake hazard and proportion of private junior high schools, respectively.

Table 5 shows the estimation results and reveals that treated children have significantly higher cognitive skills than control children at age 15. Column 4 of Table 5 shows that the standardized selectivity score is higher for treated children by 2.2, that is, 4.1% higher than the one for unaffected children. In column 3, we replace the dependent variable with a dummy indicating high school enrollment and find no significant effect on enrollment. Unfortunately, we cannot control for the child fixed effects in equation (3) due to data limitations. To enhance the validity of the estimation, we also estimate the same cross-sectional model but replace the dependent variable with spending on cognitive and noncognitive skills at age 15, three months before high school admission. The estimates in columns 1 and 2 of Table 5 are comparable to the baseline estimates in Table 3. The reduced-form evidence in this section thus reveals that the increase in parental investment among treated children was accompanied by an increase in children's cognitive skills.

5 Mechanism

The earthquake shock could have increased parental investment in children's cognitive skills in several mechanisms. First, parents may have aimed to compensate for the lower quality and quantity of public education after the earthquake shock. Second, the destruction caused by the earthquake may have affected supply and demand in local markets. If the shock increased demand for rebuilding, it would generate an income effect through higher wages, thereby increasing parental investment. Third, selective attrition and migration to regions with a higher return to education may also account for our results. This section tests these possibilities individually. In short, none of these mechanisms prevails (Sections 5.1 to 5.4). We then disentangle the nature of the adverse shock to which parents responded (Section 5.5). Interestingly, we find that the positive treatment effect survives even after conditioning on physical damage and radioactive contamination. By contrast, we find that parents *reduced* their spending on children's cognitive skills in response to physical damage such as flood and injury. Thus, it is intense ground motion itself, rather than direct physical damage, to which parents positively responded. We interpret such a behavioral response as driven either by parents' belief that children's human capital had fallen or by a shift in parents' preference toward mobile assets.

5.1 Substitution from Public Schooling

One possible explanation behind the increased spending on cognitive skills is the substitution from public educational investment to private educational investment after the earthquake shock. Previous studies have often reported that parents substitute, rather than complement, public education when deciding whether to invest in private education (Das et al., 2013; Yuan and Zhang, 2015; Ly et al., 2020; Gensowski et al., 2020).[17] As the Great East Japan Earthquake closed many public schools in affected areas, it may have reduced both the quality and the quantity of public education. Some schools managed to restart teaching relatively quickly.[18] The majority of the schools that were irreparably damaged by the earthquake also resumed at alternative locations within a few months.[19] The Ministry sent official notifications to all schools to secure the required hours of classes by opening schools on Saturdays and during holidays (March 25, 2011, Ministry of Education, Culture, Sports, Science and Technology). However, even if schools managed to restart teaching, the earthquake may still have limited their resources and thus lowered the quality of public education. If parents simply offset the lower quality of public education by investing more in private tutoring, the positive increase in spending on cognitive skills would reflect a substitution effect from public to private education.

We examine this possibility by testing whether the positive treatment effect on cognitive skill investment in Table 3 is nullified when we control for a proxy for the quality of public education. To measure the quality of public education in each region, we adopt three proxies, namely, the teacher-to-student ratio, school expenditure per 1000 pupils, and the number of primary and junior high schools per 100,000 pupils, all at the region level. The last variable measures the impact of permanent school closures after the earthquake. Ac-

[17] Yuan and Zhang (2015) found a negative association between household spending on tutoring schools and public spending on education among primary and middle school children in urban China. Ly et al. (2020) observed a similar substitution effect in high school students' allocation of their time between curricular and extracurricular activities in Paris. Studies have also reported substantial heterogeneity in the substitution effects, which are typically strong among low-income families (Yuan and Zhang, 2015) and low-ability students (Ly et al., 2020). By contrast, Gensowski et al. (2020) showed in a randomized policy experiment that this crowding out effect is strong among Danish children with highly skilled parents, while Das et al. (2013) observed the substitution effect only when the increase in public educational investment was anticipated by parents.

[18] The media reported that one primary school in a severely damaged city reopened on March 22 ("How have you been? What were you doing? Kesennuma Elementary School Resumed", *Asahi Newspaper*, March 23, 2011); some children studied at temples until their school opened in Rikuzen Takata City ("Studying at Terakoya until classes resume", *Asahi Newspaper*, April 15, 2011); and four schools started a new semester in one building together in Ohtsuchi Town ("Four schools start in one building together after grouping", *Asahi Newspaper*, April 24, 2011).

[19] According to Kamei (2012) who tabulated statistics obtained from prefecture education committees, 165 public schools in the three most affected regions could no longer use their school buildings. By June 2011, three months after the earthquake, 142 of these 165 public schools were operating in alternative locations, while the remaining schools remained closed owing to the radioactive fallout from the Fukushima nuclear power station (Kamei, 2012).

cording to the estimation results in columns 1 to 4 of Table 6, none of these proxies alter the magnitude or significance of the treatment effect found in the baseline model. Thus, the main treatment effect cannot be explained by a substitution from public education, to the extent that these proxies measure the actual quality of public education. It is also important to note that treated children had significantly higher standardized selectivity scores than control children (Table 5), implying that private educational investment does not simply offset the lower quality of public education, if any. Rather, private investment intensifies.

5.2 Mediating Effects via Other Individual, Family, and Regional Traits

To account for the mediating effects via other time-invariant individual and regional traits, we repeat similar exercises in previous sub-section by replacing one control variable with another taken from these variables in columns 5 to 7 of Table 6. In particular, we examine whether the main treatment effect is mediated by changes in the price of education (column 5),[20] the income effect through a lower property price (column 6),[21] and family characteristics such as the number of siblings, cohabitation status of grandparents, employment status of parents, and child's BMI (column 7).[22] Appendix Table C1 also presents the estimation results with additional regional controls. Appendix Tables C2 and C3 present the same sets of sensitivity analyses when the dependent variable is replaced by spending on noncognitive skills. To summarize our findings, none of these factors explain the main treatment effect found in the baseline model. The only minor exception is the price of education. Column 5 in Table 6 reports that the positive magnitude of the treatment effect declines slightly in 2016 when we control for the CPI for education.

As shown in Appendix Table F1, we conduct a similar sensitivity analysis by controlling for income information (available in a limited number of years). Again, we find no signif-

[20]The CPI for education is measured by price changes in school tuition, education materials, and tutoring schools.

[21]Kawaguchi and Yukutake (2017) found a significant decline in the price of residential land in areas affected by the Fukushima nuclear accident.

[22]The BMI of the child is included to check the mediating effect through changes in their health due to the radioactive fallout. Attanasio et al. (2020a) observed an important dynamic complementary effect of health capital on the cognitive development of children from poor households in India.

icant change in the magnitude of the earthquake shock on parental investment, even after we control for total household income and other income (i.e., social benefits, capital gains, and government subsidies offered to severely affected households). Thus, the increase in spending on cognitive skills shown in the main model is less likely to be explained by government subsidies.

5.3 Selective Attrition and Migration

Selective attrition and migration may confound the main treatment effects. For instance, certain types of families may stop responding to the LSN21. If low-income families in affected regions were more likely to drop out of the sample, this would bias the treatment estimates upward. Likewise, the earthquake shock may have encouraged families to migrate to locations with a higher return to educational investment. Nakamura et al. (2021) used a volcanic eruption in Iceland as a natural experiment that lowered the mobility cost incurred by families whose houses had been destroyed by lava. They found that the children in these families gained from a substantial increase in their years of schooling and interpreted this result as evidence for the benefit of moving to regions with a higher comparative advantage.

In this vein, we estimate a linear probability model to examine whether this mechanism also drives the increase in parental investment after the adverse shock. In particular, we start with a sample of children observed in January 2011 along with information on parental investment. We then create a dummy variable coded one if the child was not observed at least once after the earthquake and zero otherwise. We regress the attrition dummy on a treatment variable, $I(Treat_j)$, and its interaction with a low-income dummy, which is coded one if household income fell below the median household income in January 2011 and zero otherwise. Appendix Table D1 shows that these two variables do not predict the attrition decision.

We also estimate a similar linear probability model of the migration decision. We create a dummy variable coded one if the individual lived in a location different from the one in which they lived in January 2011 at least once after the earthquake and zero otherwise. Appendix Table D1 confirms that the migration decision is not significantly correlated with the treatment and its interaction with the prior income level, although the estimate of the interaction term is slightly large and positive.

5.4 Local Supply and Demand Shocks

Earthquake shocks have a distinct feature from those types of adverse shocks hitting an individual only because they affect an entire region and therefore local markets. In particular, natural disasters inflict physical damage across a vast area and thus raise demand for reconstruction in the local market. The subsequent increased labor demand raises the earnings of those working in sectors related to rebuilding. Similarly, physical destruction may also limit the supply of labor and can increase wages. Groen et al. (2020) found that Hurricanes Katrina and Rita increased earnings for the workers in these sectors, ascribing this rise to the reduced labor supply and increased labor demand.

Appendix H checks whether such an income effect explains the increase in parental investment in children's cognitive skills. Using the regional and industry-level numbers of plants from the Economic Censuses of 2009 and 2014 conducted by the Ministry of Internal Affairs and Communications, our first-difference estimation results show no evidence of increased local demand. Rather, we observe a consistent decline in the number of plants in the majority of industries, including the construction sector. More importantly, we find no mediating effect of household income, as discussed in Section 5.2. The employment status of parents does not play a role either, as shown in column 7 of Table 6. Therefore, we conclude that neither the income effect nor changes in local demand and labor supply explain the main treatment effect.

5.5 Nonpecuniary Parental Investment

The earthquake shock may have changed the composition of pecuniary and nonpecuniary parental investment through price changes in the market for private education. In particular, the adverse shock may have reduced the supply of private tutoring schools due to the physical destruction in the region. This may also have increased demand for private education if the shock lowered the quality or quantity of public education. The reduced supply and/or increased demand would then have risen the price of private education in the region, thus increasing relative demand for home education. Hence, the adverse shock would have skewed parents' spending on the child toward nonpecuniary items if such a market adjustment existed.

We re-estimate equation (2) with the dependent variable replaced by proxies for nonpecuniary investment by parents. Specifically, we estimate a linear probability model on a dummy variable coded one if the mother or father looks after the child's study at home and zero otherwise. The information is available up to 2013 (i.e., age 12). As shown in columns 1 and 2 of Table 7, we find no significant increase in parental involvement in children's home education. We also observe no significant increases in the probability of children being taken to museums or concerts (see columns 3 and 4). Thus, the earthquake shock did not increase nonpecuniary investment.

5.6 Types of Damage

Figure 2 showed that the Great East Japan Earthquake was characterized by several types of adverse shocks. However, the estimates in Figure 3 mask the exact nature of the shocks to which parents responded. Ground motion triggers buildings to collapse, floods, injury, and death. This damage often take place in localized areas, making the identification of each factor difficult. One main advantage of studying the Great East Japan Earthquake is that this physical damage varied conditional on the seismic intensity. Hence, we disentangle the characteristics of the adverse shocks to which parents responded by adding damage proxies into the main model in equation (2):

$$Y_{it} = x_{it}\beta + \sum_{s \neq 2011} \gamma^s I(Treat_j) + \underbrace{\sum_{s \neq 2011} \delta^s F(D_j)}_{Impact of Physical Damage} + h_{qt} + \tau_{gt} + \theta_i + \epsilon_{it} \tag{4}$$

where $F(D_j)$ is the log of the damage proxies (plus 0.01) in location j in which child i lived right before the earthquake. We adopt several measurements of the damage proxies from Figure 2. We expect adding these proxies to nullify the main treatment effect (γ) if parents responded to the adverse shocks caused by physical damage rather than ground motion.

Figure 4 plots the estimates of γ and δ, showing, surprisingly, that none of the damage proxies nullify or mitigate the main treatment effect of ground motion. If anything, the positive impact of intense ground motion *rises* slightly in 2016 after conditioning on the damage. Importantly, some of the damage proxies have *negative* impacts on spending on cognitive skills in some years. For example, the number of flooded households has a short-term negative impact in 2013, while the number of injured has a long-run negative effect in 2015 and 2016. Thus, the physical destruction due to the tsunami reduced family wealth and dampened investment in children's cognitive skills. This finding is consistent with the developing country evidence that parents shift their resources from spending on children to reconstructing family wealth after hurricanes (Deuchert and Felfe, 2015). Further, the level of radioactive contamination had no effect on parental investment in cognitive skills.[23]

Figure 5 presents the results from similar exercises but with the treatment group replaced by those children with $Z_j \geq 5.5$ rather than $Z_j \geq 4.5$, while retaining the same control group ($Z_j < 2$). We find that the impact of intense ground motion becomes even larger and comparable to the estimates for the treatment group with $Z_j \geq 4.5$. In the sensitivity analysis in Section 4.2, we showed that the treatment effect falls when we increase the treatment threshold above $Z_j = 5$. Figure 5 implies that this is due to the mitigating

[23] Almond et al. (2009) found a negative effect of radioactive contamination from the Chernobyl fallout on the grade average in the final year of compulsory school and suggested that the radioactive fallout directly harmed the latent factor in the child development, namely cognitive skills. One interpretation of our zero effect of radioactive contamination is that parents in our sample did not realize the potential damage to their children.

impact of having a negative effect on family wealth.

Appendix E presents the estimate with additional damage proxies. Again, the main treatment effect of intense ground motion remains significant and large. We also find that the closer the household to the nearest nuclear power station, the more parents spent on children's cognitive skills after the earthquake shock (Appendix Figures E1 and E2). The negative impact on spending on noncognitive skills in Figure 3 also remains similar—even after conditioning on the damage proxies (Appendix Figures E3 to E6).

The positive effect of intense ground motion in Figures 4 and 5 can be explained by two main mechanisms. One possibility is a direct impact on the children's skill. Health, cognitive and nocognitive skills are important latent variables in the production process of the children's human capital (Cunha et al., 2010; Attanasio et al., 2020a,b). If the adverse shock directly reduces the latent variable, say children's cognitive skill, parents would mechanically increase their investment in that skill as long as the production process exhibits diminishing marginal productivity. Indeed, the literature has shown that in utero exposure to stressful events had negative impacts on cognition and health (Glynn et al., 2001; Almond, 2006; Lauderdale, 2006; Camacho, 2008; Almond et al., 2009; Simeonova, 2011; Aizer et al., 2016; Black et al., 2016; Persson and Rossin-Slater, 2018).[24] Because children in our sample were 10 years old already at the time of the earthquake, and because the estimated treatment effect survives even after being conditioned on the BMI (column 7 of Table 6), the intense ground motion is less likely to affect the health capital of the child directly. We are also unaware of studies showing direct mechanisms through which the intense ground motion affects the child cognition. Yet, it is possible that parental belief toward the extent of the damage matters to their investment decision. If the intense ground motion made parents believe that the ground motion reduced the cognition of the children, parents would increase the investment in the children's cognitive skills.

[24] Depending on the complementarity and substitutability of these latent factors, the impact on one factor can increase the investment in the other skills. For example, if the adverse shock reduced noncognitive skills and if noncognitive skills are substitute to cognitive skills, parents may increase the investment in the child cognitive skills. Bulaon and Shoji (2022) reported a suggestive evidence that exposure to more tropical cyclones in utero or at infancy hampered the adults' growth mindset.

Another possibility is a shift in the preferences of parents toward mobile assets. Previous studies have provided some evidence in line with this possibility. For example, Becker et al. (2020) showed that families' forced migration after World War II shifted their preferences toward mobile assets over fixed assets. There is also evidence that earthquake shocks alter preference parameters (Cameron and Shah, 2015; Hanaoka et al., 2018; Akesaka, 2019, to mention a few).[25] The intense quake in the Great East Japan Earthquake lasted nearly three minutes in some areas, five times longer than that during the Hanshin-Awaji Earthquake in Kobe in 1995; indeed, it took six minutes for all the ground motions to dissipate and more than 500 afterquakes still followed (Fire and Agency, 2013; Kitajima, 2015). Such an intense experience may have traumatized parents and made them prone to prefer mobile assets, or invest in children's cognitive skills. Unfortunately, we cannot distinguish the two underlying mechanisms owing to data limitations. Thus, our best interpretation is that the positive parental response to the intense ground motion is driven by a shift in the preferences of parents toward mobile assets and/or parents' belief that the earthquake damaged children's human capital, particularly their cognitive skills.

6 Conclusion

Faced with adverse shocks such as wars and natural disasters, parents may increase private investment in their children to offset the negative effects on their children's development. Such an endogenous response makes it difficult to identify the real cost of adverse events, which can mislead the design of policies that aid those truly disadvantaged by the shock. Despite a large body of the literature investigating the long-term consequences of adverse events on child outcomes, however, little is known about the types of adverse shocks to which parents respond and how they do so. To identify the exact way in which a shock

[25] Hanaoka et al. (2018) exploited the regional variation in ground motion during the Great East Japan Earthquake and found that men exposed to a seismic intensity of four or higher ($Z_j \geq 4$) became more risk prone. By contrast, researchers in Indonesia have found evidence that inhabitants of regions hit by earthquakes are more risk averse (Cameron and Shah, 2015). Using panel data in Australia, Johar et al. (2022) argued that these contradictory findings depend on whether people's homes are destroyed.

triggers compensating behavior by parents, we take advantage of the natural experiment provided by the Great East Japan Earthquake in March 2011, which caused various types of damage such as flooding, collapsed buildings, and radioactive contamination due to the meltdown of a nuclear power station. Exploiting information on the extent of the physical damage allows us to disentangle the types of adverse shocks to which parents responded and how.

Relying on an administrative longitudinal survey tracking children born in 2001, we estimated the reduced-form impacts of the earthquake shock on parental investment. We compared the trajectories of parental investment before and after the earthquake for children in severely affected locations with those of children who resided in unaffected locations but with the same pre-earthquake hazard level. We found that parents responded to the adverse shock, particularly to ground motion. More specifically, those exposed to intense ground motion increased their investment in their children's cognitive skills. At age 15, the children in the treatment group received 1.5 times higher spending on complementary private education (e.g., tutoring schools) than the children in the control group. Parents partially financed this increase by substituting their investment in their children's noncognitive skills with that in their cognitive skills. Importantly, the impact of ground motion remained or even became larger after we controlled for proxies for the loss of family wealth (e.g., the numbers of flooded households or injured) as well as a proxy for the lower latent human capital (e.g., radioactive contamination). Thus, the experience of an immense adverse shock per se, particularly ground motion, triggered changes in parental investment—even in the absence of physical destruction. Our best interpretations of these findings are that such a response was driven by a shift in the preferences of parents toward mobile assets and/or that parents' believed that the event directly harmed their children's cognitive skills, although we cannot disentangle these two factors due to data limitations.

Our results have important policy implications. Previous studies have shown that parental investment often reinforces, rather than compensates for, differences in child endowments (Currie et al., 1999; Currie and Moretti, 2007; Almond et al., 2009; Datar et al., 2010). In other words, parents with sufficient resources increase their investment in their offspring more to mitigate the damage to the children's endowments owing to an adverse shock than those parents with limited resources. Such a finding has implications for designing policies to aid those disadvantaged by adversity because parental investment would then exacerbate the inequality in educational resources and facilitate the intergenerational transmission of initial endowments. In line with early works, we also found the reinforcing effect of parental investment in that—after adverse shocks—it increases the inequality in educational investment among families with and without large initial endowments. In particular, children in a single parent family receive far less positive compensatory investment: they experience a smaller increase in spending on their cognitive skills compared with the treatment group and an even larger decline in spending on their noncognitive skills at age 15. Hence, our results suggest that public subsidies after natural disasters should target not only those directly affected by physical damage but also those families with low socioeconomic status.

References

Aizer, Anna, Laura Stroud, and Stephen Buka, "Maternal Stress and Child Outcomes: Evidence from Siblings," *The Journal of human resources*, 9 2016, *51*, 523.

Akesaka, Mika, "Change in time preferences: Evidence from the Great East Japan Earthquake," *Journal of Economic Behavior Organization*, 10 2019, *166*, 239–245.

Almond, Douglas, "Is the 1918 influenza pandemic over? Long-term effects of in utero influenza exposure in the post-1940 U.S. population," *Journal of Political Economy*, 8 2006, *114*, 672–712.

_, Lena Edlund, and Mrten Palme, "Chernobyl's subclinical legacy: Prenatal exposure to radioactive fallout and school outcomes in Sweden," *Quarterly Journal of Economics*, 2009, *124*, 1729–1772.

Attanasio, Orazio, Costas Meghir, and Emily Nix, "Human Capital Development and Parental Investment in India," *The Review of Economic Studies*, 2020, *87*, 2511–2541.

_, Sarah Cattan, Emla Fitzsimons, Costas Meghir, and Marta Rubio-Codina, "Estimating the Production Function for Human Capital: Results from a Randomized Controlled Trial in Colombia," *American Economic Review*, 2020, *110*, 48–85.

Bauer, Thomas K., Sebastian Braun, and Michael Kvasnicka, "The Economic Integration of Forced Migrants: Evidence for Post-War Germany," *The Economic Journal*, 9 2013, *123*, 998–1024.

Becker, Sascha O., Irena Grosfeld, Pauline Grosjean, Nico Voigtlnder, and Ekaterina Zhuravskaya, "Forced migration and human capital: Evidence from post-WWII population transfers," *American Economic Review*, 5 2020, *110*, 1430–1463.

Black, Sandra E., Paul J. Devereux, and Kjell G. Salvanes, "Does Grief Transfer across Generations? Bereavements during Pregnancy and Child Outcomes," *American Economic Journal: Applied Economics*, 2016, *8*, 193–223.

Boca, Daniela Del, Christopher Flinn, and Matthew Wiswall, "Household Choices and Child Development," *The Review of Economic Studies*, 1 2014, *81*, 137–185.

Boneva, Teodora and Christopher Rauh, "Parental Beliefs about Returns to Educational InvestmentsThe Later the Better?," *Journal of the European Economic Association*, 12 2018, *16*, 1669–1711.

Bray, Mark, Shengli Zhan, Chad Lykins, Dan Wang, and Ora Kwo, "Differentiated demand for private supplementary tutoring: Patterns and implications in Hong Kong secondary education," *Economics of Education Review*, 2 2014, *38*, 24–37.

Bulaon, Patrick Roque and Masahiro Shoji, "Disaster Exposure in Childhood and Adult Noncognitive Skill: Evidence from the Philippines Evidence from the Philippines," *MPRA Paper*, 2022, *112913.*

Camacho, Adriana, "Stress and Birth Weight: Evidence from Terrorist Attacks," *American Economic Review*, 5 2008, *98*, 511–15.

Cameron, Lisa and Manisha Shah, "Risk-Taking Behavior in the Wake of Natural Disasters," *Journal of Human Resources*, 2015, *50*, 484–515.

Caruso, Germn and Sebastian Miller, "Long run effects and intergenerational transmission of natural disasters: A case study on the 1970 Ancash Earthquake," *Journal of Development Economics*, 11 2015, *117*, 134–150.

Cunha, Flavio, James J Heckman, and Susanne M Schennach, "Estimating the Technology of Cognitive and Noncognitive Skill Formation," *Econometrica*, 5 2010, *78*, 883–931.

Currie, Janet and Enrico Moretti, "Biology as Destiny? Short-and Long-Run Determinants of Intergenerational Transmission of Birth Weight," *Journal of Labor Economics*, 2007, *25.*

— **and Maya Rossin-Slater**, "Weathering the storm: Hurricanes and birth outcomes," *Journal of Health Economics*, 2013, *32*, 487–503.

— **, Rosemary Hyson, and Nber ; Hyson**, "Is the Impact of Health Shocks Cushioned by Socioeconomic Status? The Case of Low Birthweight," *AEA Papers and Proceedings*, 1999, *89*, 245–262.

Das, Jishnu, Stefan Dercon, James Habyarimana, Pramila Krishnan, Karthik Muralidharan, and Venkatesh Sundararaman, "School Inputs, Household Substitution, and Test Score," *American Economic Journal: Applied Economics*, 4 2013, *5*, 29–57.

Datar, Ashlesha, M. Rebecca Kilburn, and David S. Loughran, "Endowments and Parental Investments in Infancy and Early Childhood," *Demography*, 2010, *47*, 145.

Deuchert, Eva and Christina Felfe, "The tempest: Short- and long-term consequences of a natural disaster for childrens development," *European Economic Review*, 11 2015, *80*, 280–294.

Fire and Disaster Agency, "Great East Japan Earthquakes Archive (in Japanese, Higashi Nihon Daishinsai Kirokushu)," 2013.

Gensowski, Miriam, Rasmus Landers, Dorthe Bleses, Philip Dale, Anders Hjen, and Laura Justice, "Public and Parental Investments and Childrens Skill Formation," *Rockwoolfondens Study Papers*, 2020, *155.*

_, Torben Heien Nielsen, Nete Munk Nielsen, Maya Rossin-Slater, and Miriam Wst, "Childhood health shocks, comparative advantage, and long-term outcomes: Evidence from the last Danish polio epidemic," *Journal of Health Economics*, 2019, *66*, 27–36.

Glynn, Laura M., Pathik D. Wadhwa, Christine Dunkel-Schetter, Aleksandra Chicz-DeMet, and Curt A. Sandman, "When stress happens matters: effects of earthquake timing on stress responsivity in pregnancy," *American journal of obstetrics and gynecology*, 2001, *184*, 637–642.

Groen, Jeffrey A., Mark J. Kutzbach, and Anne E. Polivka, "Storms and jobs: The effect of hurricanes on individuals employment and earnings over the long term," *Journal of Labor Economics*, 2020, *38*, 653–685.

Hanaoka, Chie, Hitoshi Shigeoka, and Yasutora Watanabe, "Do risk preferences change? Evidence from the Great East Japan Earthquake," *American Economic Journal: Applied Economics*, 4 2018, *10*, 298–330.

Hille, Adrian and Jrgen Schupp, "How learning a musical instrument affects the development of skills," *Economics of Education Review*, 2 2015, *44*, 56–82.

Institute, Benesse and General Education Research, "Basic Study Survey: Questionnair on International Comparison Among Six Cities.," 2006.

Johar, Meliyanni, David W. Johnston, Michael A. Shields, Peter Siminski, and Olena Stavrunova, "The economic impacts of direct natural disaster exposure," *Journal of Economic Behavior Organization*, 4 2022, *196*, 26–39.

Kamei, Katsuyuki, "The Great East Japan Earthquake and Crisis Management in School (in Japanese)," *Kodomo no Anzen to Risuku Commyunicasyon*, 2012, pp. 111–129.

Kawaguchi, Daiji and Norifumi Yukutake, "Estimating the residential land damage of the Fukushima nuclear accident," *Journal of Urban Economics*, 5 2017, *99*, 148–160.

Kitajima, Hideaki, *Dictionaries of Severe Disasters in Japan and the World (Sekai to Nihon no gekijin saigai jiten : jumin kara mita 100 jirei to Higashi Nihon Daishinsai)*, Maruzen Publisher, 7 2015.

Knaus, Michael C., Michael Lechner, and Anne K. Reimers, "For better or worse? The effects of physical education on child development," *Labour Economics*, 12 2020, *67.*

Lauderdale, Diane S., "Birth outcomes for Arabic-named women in California before and after September 11," *Demography*, 2006, *43*, 185–201.

Lees, Caitlin and Jessica Hopkins, "Effect of aerobic exercise on cognition, academic achievement, and psychosocial function in children: A systematic review of randomized control trials," *Preventing Chronic Disease*, 2013, *10*, 1–8.

Ly, Son Thierry, Eric Maurin, and Arnaud Riegert, "A pleasure that hurts: The ambiguous effects of elite tutoring on underprivileged high school students," *Journal of Labor Economics*, 2020, *38*, 501–533.

Maccini, Sharon and Dean Yang, "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall," *American Economic Review*, 6 2009, *99*, 1006–26.

Meng, Xin and Nancy Qian, "The Long Term Consequences of Famine on Survivors: Evidence from a Unique Natural Experiment using China's Great Famine, 1959-61," *NBER Working Paper*, 2009, *14917.*

Nakamura, Emi, Jsef Sigurdsson, and Jn Steinsson, "The Gift of Moving: Intergenerational Consequences of a Mobility Shock," *The Review of Economic Studies*, 9 2021.

Persson, Petra and Maya Rossin-Slater, "Family Ruptures, Stress, and the Mental Health of the Next Generation," *American Economic Review*, 4 2018, *108*, 1214–52.

Sacerdote, Bruce, "When the saints go marching out: Long-term outcomes for student evacuees from hurricanes Katrina and Rita," *American Economic Journal: Applied Economics*, 1 2012, *4*, 109–135.

Shah, Manisha and Bryce Millett Steinberg, "Drought of opportunities: Contemporaneous and long-term impacts of rainfall shocks on human capital," *Journal of Political Economy*, 4 2017, *125*, 527–561.

Simeonova, Emilia, "Out of Sight, Out of Mind? Natural Disasters and Pregnancy Outcomes in the USA," *CESifo Economic Studies*, 9 2011, *57*, 403–431.

Smith, Jordan J., Narelle Eather, Philip J. Morgan, Ronald C. Plotnikoff, Avery D. Faigenbaum, and David R. Lubans, "The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis," *Sports Medicine*, 2014, *44*, 1209–1223.

Ushijima, Koichi, "Decline in Employment Opportunities and Human Capital Investment (in Japanese)," *Financial Review*, 2019, *6*, 65–85.

Wang, Jun, Juan Yang, and Bo Li, "Pain of disasters: The educational cost of exogenous shocks evidence from Tangshan Earthquake in 1976," *China Economic Review*, 12 2017, *46*, 27–49.

Yuan, Cheng and Lei Zhang, "Public education spending and private substitution in urban China," *Journal of Development Economics*, 7 2015, *115*, 124–139.

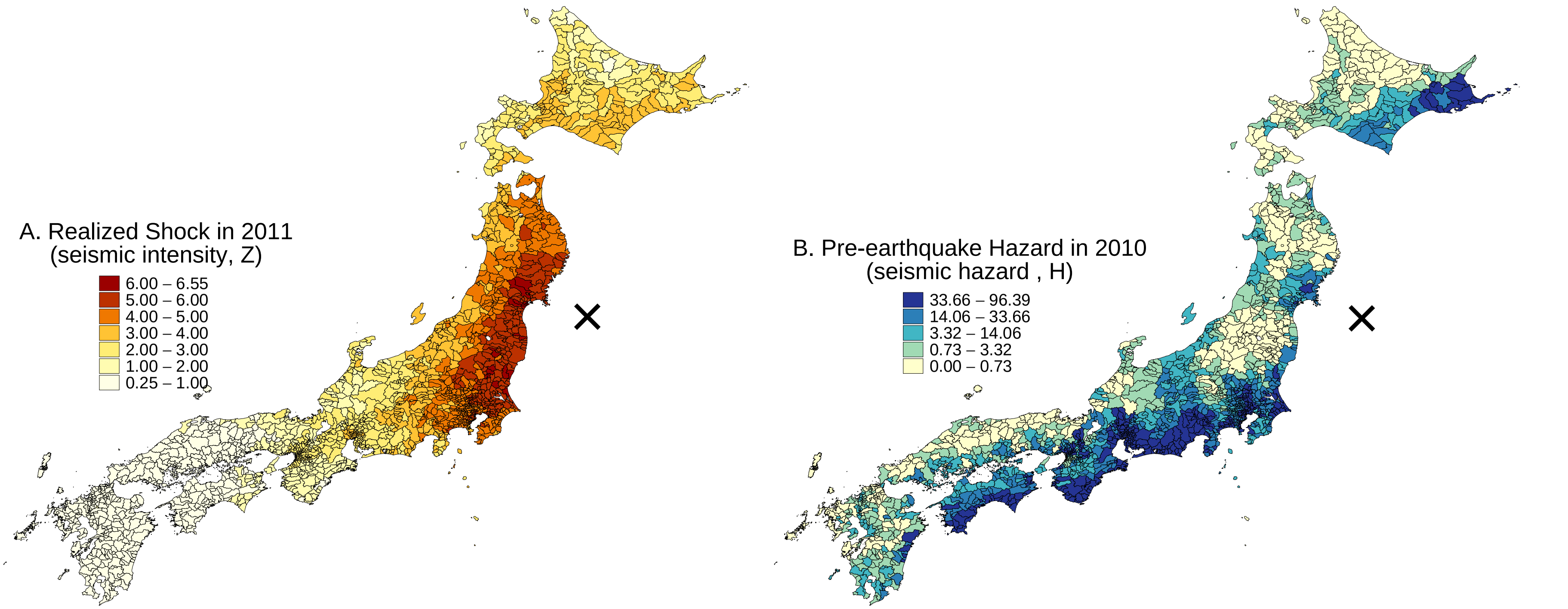

Figure 1: Realized Shock (left) and Pre-earthquake Hazard (right)

Note: Maps show location-level exposuer to the realized earthquake shock (left) and the esatimated pre-earthquake hazard right before the realization of the shock (right). Seismic intensity (Z) measures the scale of the ground motion owing to the earthquake at PM 2:46, March 11, 2011, taken from the National Research Institute for Earth Science and Disaster Resilience (NIED). Pre-earthquake hazard (H) measures the probability of an earthquake with $Z \geq 5.5$ in the next 30 years as of 2010. Seismic hazard is taken from Japan Seismic Hazard Information Center (JSHIC) and is estimated from periodic activities in subdoction zones and locations of faults. Appendix A contains details about data source. The epicenter of the Great East Japan Earthquake (March 11, 2011) is marked with a cross. Souhtern islands are excluded from the maps to enhance visibility, although observations in these locations are included in the main analysis.

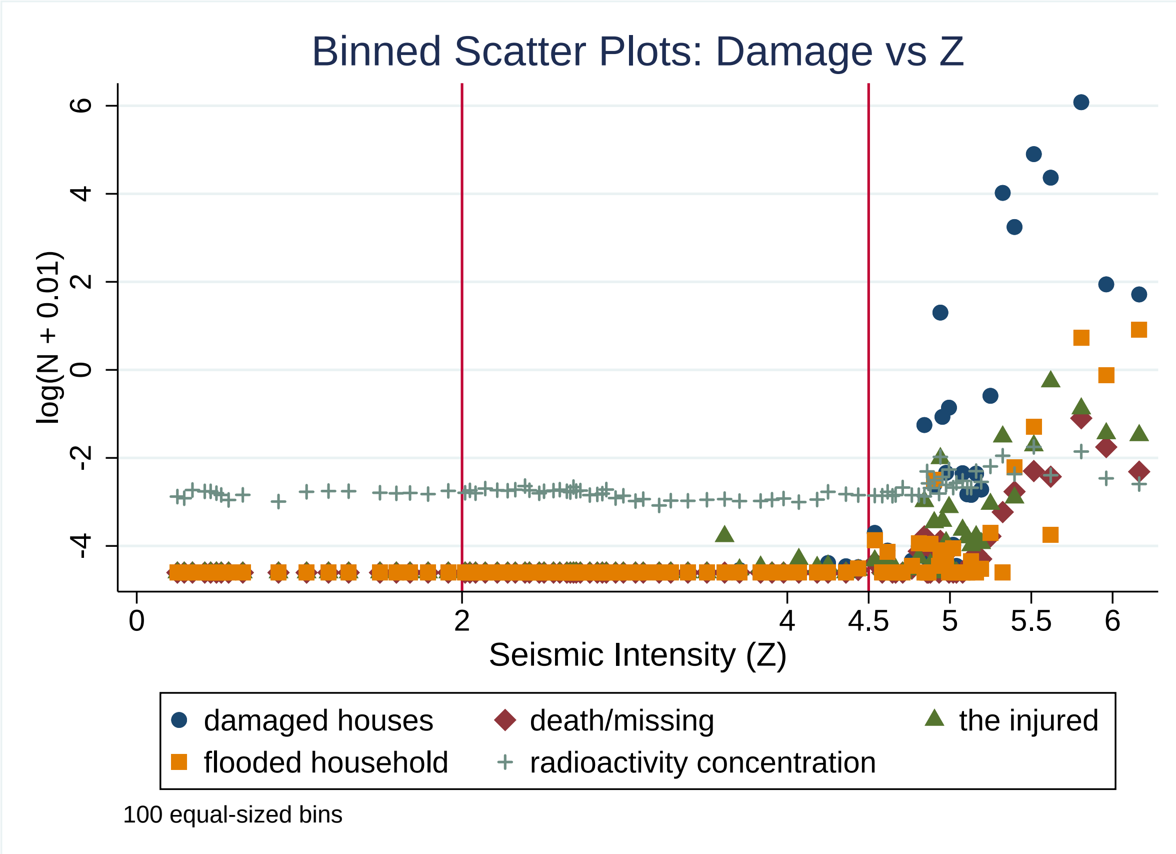

Figure 2: Severity of the Damage Increases with Seismic Intensity

Note: Graphs shows binned scatter plots weighted by the number of observations in our main data (LSN21). The physical damage data (N) is measured in per 10000 resident unit.

Table 1: Baseline Summary Statistics

	All	Control $Z < 2$	Treatment $Z \geq 4.5$
Individual (N)	7339	1916	2485
Female	0.51	0.52	0.50
	(0.50)	(0.50)	(0.50)
BMI	16.32	16.33	16.31
	(2.20)	(2.12)	(2.27)
Number of siblings in 2010	1.19	1.26	1.14
	(0.73)	(0.76)	(0.71)
Single or no parent in 2010	0.05	0.06	0.04
	(0.22)	(0.23)	(0.21)
Living with grand parent(s) in 2010	0.36	0.35	0.31
	(0.71)	(0.70)	(0.66)
Location (N)	1233	423	302
Seismic intensity (Z)	2.80	0.75	5.15
	(1.79)	(0.58)	(0.44)
N of the dead/missing per 10000 residents	1.35	0	5.5
	(16.02)	(0)	(32.06)
N of damaged properties per 10000 residents	73.31	0	299.23
	(307.49)	(0)	(564.95)
N of the injured per 10000 residents	0.33	0	1.33
	(3.28)	(0)	(6.53)
N of flooded households per 10000 residents	52.75	0	215.35
	(439.10)	(0)	(868.35)
Radioactivity concentration ($\mu Sv/h$)	0.058	0.050	0.084
	(0.037)	(0.012)	(0.065)
Pre-earthquake hazard in 2010 (%)	21.37	12.33	25.35
	(24.15)	(17.65)	(20.67)
Proportion of private junior HS in 2010	0.052	0.047	0.070
	(0.050)	(0.026)	(0.075)

Note: Standard deviations in parentheses. Summary statistics on location (e.g., municipality) traits are weighted by the number of children in LSN21.

Table 2: Summary Statistics across Selected Survey Years

	2009 Age 8	2013 Age 12	2016 Age 15
Control group, $Z < 2$			
Spending on cognitive skills/month (100 JPY)	32.66	124.79	354.23
	(61.21)	(217.56)	(333.80)
Spending on noncognitive skills/month (100 JPY)	91.05	87.73	42.17
	(68.47)	(80.92)	(92.32)
Other spending/month (100 JPY)	228.90	276.40	417.28
	(159.45)	(238.37)	(343.08)
Mother looks after the child's study (= 1)	0.96	0.77	
	(0.20)	(0.42)	
Father looks after the child's study (= 1)	0.67	0.50	
	(0.47)	(0.50)	
High school enrollment (= 1)			0.998
			(0.046)
Selectivity score (conditional on HS enrollment)			53.94
			(9.20)
Treatment group, $Z \geq 4.5$			
Spending on cognitive skills/month (100 JPY)	37.54	189.44	529.82
	(57.65)	(288.57)	(407.87)
Spending on noncognitive skills/month (100 JPY)	112.14	97.62	39.16
	(78.24)	(90.43)	(95.44)
Other spending/month (100 JPY)	257.30	307.24	506.47
	(201.15)	(248.02)	(385.54)
Mother looks after the child's study (= 1)	0.96	0.78	
	(0.19)	(0.42)	
Father looks after the child's study (= 1)	0.67	0.52	
	(0.47)	(0.50)	
High school enrollment (= 1)			0.996
			(0.060)
Selectivity score (conditional on HS enrollment)			56.01
			(9.27)

Note: Standard deviations in parentheses. 100 JPY $\approx$ 1 USD as of January 2021. "Spending on cognitive skill" stands for monthly spending on tutoring school. "Spending on noncognitive skill" stands for monthly spending on after school clubs (music, sports, etc.). "Other spending" stands for other expenditures for the child including foods, clothes, tuition, and expenses on medical treatment.

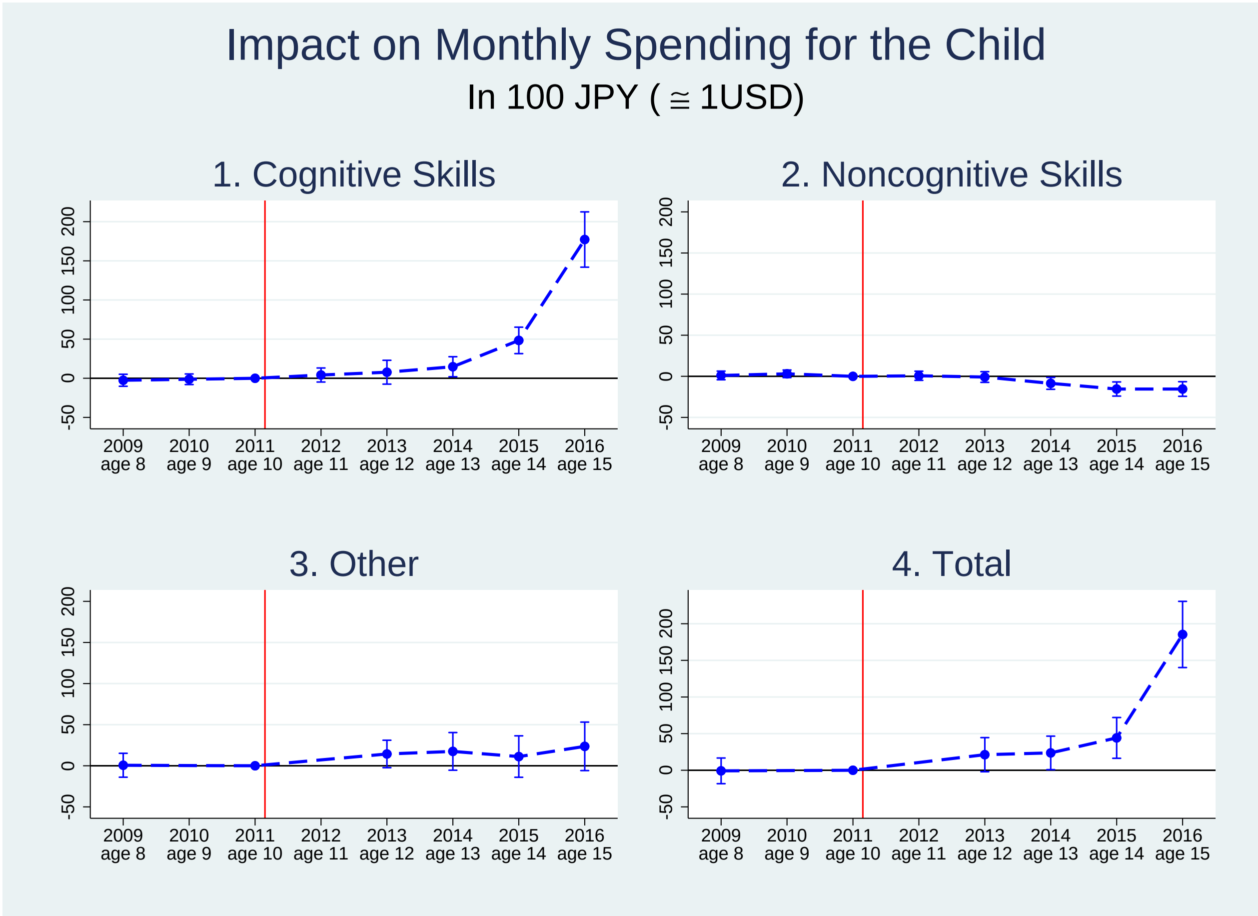

Figure 3: Baseline Estimates for the Impact of Adverse Shock (Treatment: $Z \geq 4.5$)

Note: 100 JPY $\approx$ 1 USD as of January 2021. Each graph shows the estimated impacts of high seismic intensity from a separate individual-level fixed effect model. Control group consists of children exposed to $Z < 2$. Dependent variable in panel 1 = monthly spending on tutoring schools. Dependent variable in panel 2 = monthly spending on after school clubs (music, sports etc.). Dependent variable in panel 3 = other monthly expenditures for the child including foods, clothes, tuition, and expenses on medical treatment. Information on other investment in panel 3 is not available in 2010 and 2012 due to changes in the questionnaire. N = 35208 in Panels 1 and 2. N = 26406 in Panels 3 and 4. The model controls for child effects and year effects specific to the region groups defined by the decile of the proportion of private junior high schools in each region, in addition to hazard group-specific year effects. Spikes indicate 95% confidence interval.

Table 3: What makes control and treatment groups comparable?

	Spending on cognitive skills			Spending on noncognitive skills		
	(1)	(2)	(3)	(4)	(5)	(6)
	no control	+ hazard	+ hazard + private	no control	+ hazard	+ hazard + private
2009	-26.06	-11.46	-2.534	5.448	2.930	1.071
	(4.559)	(3.942)	(3.908)	(2.255)	(2.298)	(2.675)
2010	-18.70	-8.244	-1.265	5.729	3.649	3.068
	(3.679)	(3.291)	(3.431)	(1.971)	(2.101)	(2.338)
2012	20.19	4.952	1.279	-3.840	-0.459	0.136
	(10.95)	(7.306)	(3.164)	(2.599)	(2.567)	(2.358)
2013	33.71	11.25	7.760	-5.760	-1.083	-0.858
	(8.299)	(7.725)	(7.765)	(2.961)	(3.170)	(3.308)
2014	-1.731	2.091	14.75	-16.09	-9.011	-8.552
	(6.343)	(6.341)	(6.518)	(3.309)	(3.367)	(3.681)
2015	40.24	38.12	48.39	-20.15	-15.88	-15.44
	(7.680)	(7.633)	(8.602)	(3.475)	(3.884)	(4.388)
2016	144.6	144.8	177.2	-18.65	-16.08	-15.45
	(14.71)	(15.74)	(17.98)	(3.577)	(3.896)	(4.524)
Hazard-year FE	No	Yes	Yes	No	Yes	Yes
Private-year FE	No	No	Yes	No	No	Yes

Note: Each column presents estimation results from a separate individual-level fixed effect model. Base year = 2011. Control group consists of children exposed to $Z < 2$. Treatment group consists of children exposed to $Z \geq 4.5$. N = 35208. Dependent variable in columns 1 to 4 = monthly spending on tutoring schools in 100 JPY. Dependent variable in columns 5 to 8 = monthly spending on after school clubs (music, sports etc.) in 100 JPY. 100 JPY $\approx$ 1 USD as of January 2021. All models control for year effects. "Private-year FE" controls for year effects specific to the region groups defined by the decile of the proportion of private junior high schools in each region. Robust standard errors clustered at location level in parentheses.

Table 4: Parental Response by Pre-determined Traits

	Spending on cognitive skills				Spending on noncognitive skills			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Baseline	Single parent	Yrs. of school ≥ 16 father	Yrs. of school ≥ 16 mother	Baseline	Single parent	Yrs. of school ≥ 16 father	Yrs. of school ≥ 16 mother
Treatment effect ($Z \geq 4.5$)								
2009	-2.53	13.73	-0.34	4.14	1.07	-11.47	-0.27	-0.40
	(3.91)	(24.12)	(6.31)	(10.78)	(2.68)	(15.84)	(4.51)	(7.35)
2010	-1.27	14.42	1.29	7.23	3.07	-6.49	2.44	-4.82
	(3.43)	(18.92)	(5.90)	(10.42)	(2.34)	(12.31)	(3.52)	(5.79)
2012	4.20	10.95	2.21	22.03	0.65	2.14	2.86	2.82
	(4.56)	(20.34)	(8.69)	(12.72)	(2.84)	(11.95)	(4.36)	(6.09)
2013	7.76	47.83	3.45	33.06	-0.86	-3.01	2.23	8.15
	(7.76)	(32.72)	(14.01)	(21.40)	(3.31)	(12.06)	(6.06)	(8.54)
2014	14.75	-10.62	23.87	39.10	-8.55	-28.60	-4.45	0.86
	(6.52)	(32.62)	(11.14)	(18.16)	(3.68)	(14.04)	(5.58)	(8.28)
2015	48.39	41.57	66.98	55.98	-15.44	-17.68	-14.06	-11.89
	(8.60)	(39.28)	(14.56)	(22.14)	(4.39)	(16.29)	(6.05)	(10.19)
2016	177.21	137.40	180.45	209.25	-15.45	-51.96	-14.25	-17.71
	(17.98)	(66.99)	(27.19)	(39.85)	(4.52)	(14.90)	(6.53)	(8.66)
N of obs.	35,208	1,888	16,504	6,920	35,208	1,888	16,504	6,920
N of children	4,401	236	2,063	865	4,401	236	2,063	865

Note: Each column presents the estimated treatment effect from the same baseline model in Panel 1 of Figure 3, but with observations limited to those children with specific pre-determined traits. Control group consists of children exposed to $Z < 2$. Dependent variable in columns 1 to 4 = monthly spending on tutoring schools. Dependent variable in columns 5 to 8 = monthly spending on after school clubs (music, sports etc.). 100 JPY $\approx$ 1 USD as of January 2021. "Single parent" indicates a single-parenting status as of January 2011, right before the earthquake. Robust standard errors clustered at location level in parentheses.

Table 5: Impact on Outcomes at Age 15 (Treatment Group: $Z \geq 4.5$)

	(1) Spending on cognitive skills	(2) Spending on cognitive skills	(3) High school enrollment (= 1)	(4) Selectivity score
	180.095	-6.927	-0.002	2.208
	(17.676)	(3.700)	(0.002)	(0.514)
N of obs.	4,401	4,401	4,401	3,878

Note: Control group consists of children exposed to $Z < 2$. Models control for earthquake hazard group effects and group effects defined by the proportion of private junior high schools as of January 2011. Robust standard errors clustered at location level in parentheses.

Table 6: Substitution from Public Schooling?
Y = monthly spending on cognitive skills in 100 JPY

	(1) baseline	(2) + price of education	(3) + teacher-student ratio	(4) + school expense	(5) + number of schools	(6) + property prices	(7) + family traits	(8) all included
Treatment effect ($Z \geq 4.5$)								
2009	-2.53	-1.14	-2.49	-3.42	-5.25	-2.51	0.26	5.03
	(3.91)	(4.09)	(3.97)	(3.88)	(4.80)	(3.91)	(4.43)	(5.65)
2010	-1.27	-1.76	-1.43	-5.81	-2.05	-1.14	-2.58	-4.24
	(3.43)	(3.72)	(3.44)	(3.79)	(3.48)	(3.45)	(3.88)	(4.76)
2012	4.20	4.83	3.62	4.03	4.91	4.07	3.14	0.53
	(4.56)	(4.75)	(4.60)	(4.70)	(4.54)	(4.56)	(4.56)	(5.28)
2013	7.76	8.65	6.83	9.47	9.08	7.63	6.48	4.88
	(7.76)	(7.98)	(7.80)	(7.73)	(7.66)	(7.76)	(7.98)	(8.24)
2014	14.75	12.88	13.27	14.07	16.68	14.40	13.23	15.76
	(6.52)	(6.74)	(6.56)	(6.55)	(6.65)	(6.53)	(6.85)	(7.47)
2015	48.39	45.48	46.46	46.80	47.18	48.10	49.19	41.30
	(8.60)	(8.76)	(8.61)	(8.53)	(9.09)	(8.61)	(8.90)	(9.82)
2016	177.21	159.16	174.89	176.99	176.49	176.56	178.11	174.50
	(17.98)	(17.75)	(18.03)	(17.75)	(18.34)	(17.97)	(17.84)	(18.26)
Hazard and private FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other control variables	No	No	No	No	No	No	No	Yes

Note: Each column presents estimation results from a separate individual-level fixed effect model. Base year = 2011. Control group consists of children exposed to $Z < 2$. 100 JPY $\approx$ 1 USD as of January 2021. Column 1 replicates in the baseline model presented in Panel 1 in Figure 3. "Prices of education" indicates CPI growth rate for tuition and educational materials at each prefecture and its polynomials."Teacher-student ratio" indicates teacher-to-student ratio and its second and third polynomials at each location. "School expense" indicates school expenditures per 1000 pupils at primary schools and junior high schools at each prefecture. "property prices" indicates average residualized prices of residential land at each location. "family traits" include employment status of parents, the number of siblings, and a dummy to indicate that grandparent(s) lives with the child, and BMI of the child. Robust standard errors clustered at location level in parentheses.

Table 7: Substitution from Other Types of Parental Investment (base year = 2011)

	(1) Mother looks after study (= 1)	(2) Father looks after study (= 1)	(3) Often takes to museums (= 1)	(4) Often takes to concerts (= 1)
Treatment effect ($Z \geq 4.5$)				
2009	-0.010	-0.030	-0.0002	-0.014
	(0.016)	(0.026)	(0.038)	(0.026)
2010	0.009	-0.002		
	(0.015)	(0.024)		
2012	-0.003	-0.011	-0.040	-0.005
	(0.017)	(0.022)	(0.030)	(0.020)
2013	-0.005	0.008	-0.050	-0.015
	(0.021)	(0.025)	(0.036)	(0.026)
Mean	0.903	0.616	0.321	0.120
N of obs.	14,775	14,775	7,260	7,260
N of children	2,955	2,955	1,815	1,815

Note: Each column present estimation results from a linear probability model. Control group consists of children exposed to $Z < 2$. Data on dependent variables in columns (1) and (2) is available between 2009 and 2013, and those in columns (3) and (4) are available in 2009 and 2011 to 2013. The model controls for the same sets of control variables in column (8) in Table 6. Robust standard errors clustered at location level in parentheses.

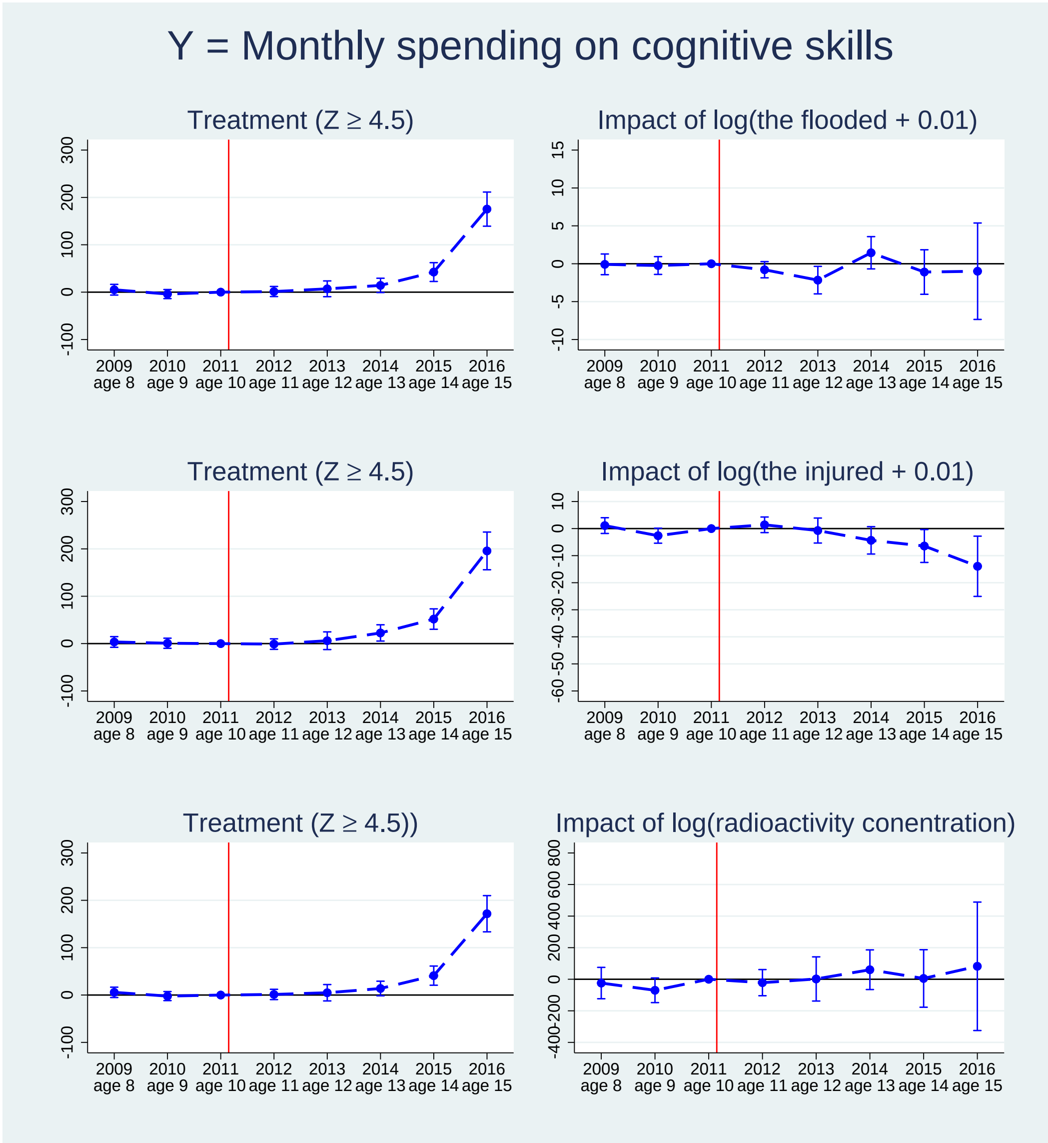

Figure 4: Does Physical Damage Explain the Main Result? (Treatment = $Z \geq 4.5$)

Note: Dependent variable = monthly spending on tutoring schools in 100 JPY. 100 JPY $\approx$ 1 USD as of January 2021. The two graphs in each row present the estimated treatment effects from the same individual-level fixed effect model. Righthand side graphs show the estimates for the damage variables interacted with year effects (base year = 2011). The numbers of the flooded house and the injured are modified by adding 0.01 before taking the logarithm. All models also controls for the same sets of control variables included in column 8 in Table 6. Control group consists of children exposed to $Z < 2$. Spikes indicate 95% confidence interval.

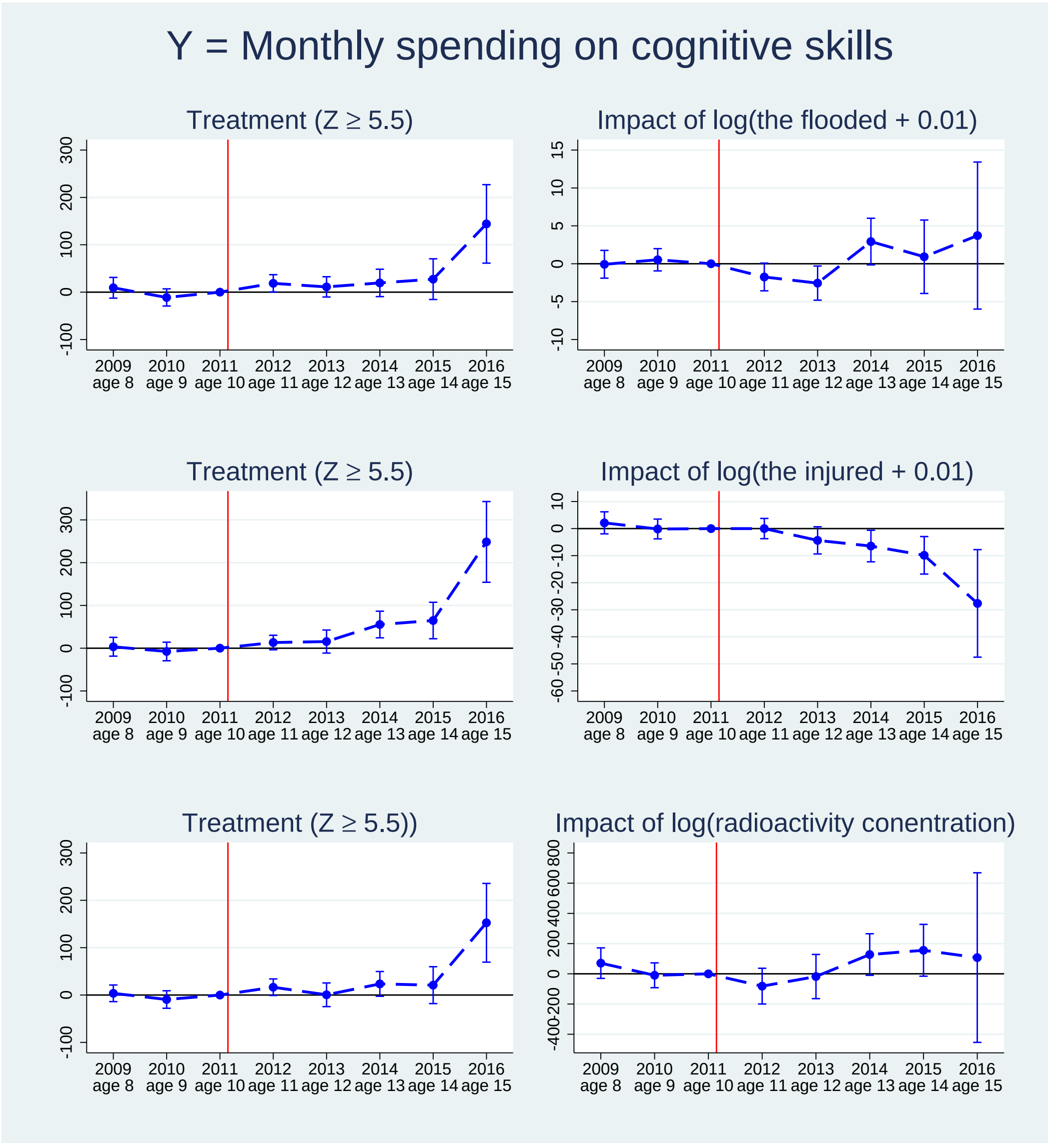

Figure 5: Does Physical Destruction Explain the Main Result? (Treatment = $Z \geq 5.5$)

Note: Dependent variable = monthly spending on tutoring schools in 100 JPY. 100 JPY $\approx$ 1 USD as of January 2021. The two graphs in each row present the estimated treatment effects from the same individual-level fixed effect model. Righthand side graphs show the estimates for the damage variables interacted with year effects (base year = 2011). The numbers of the flooded house and the injured are modified by adding 0.01 before taking the logarithm. All models also controls for the same sets of control variables included in column 8 in Table 6. Control group consists of children exposed to $Z < 2$. Spikes indicate 95% confidence interval.