Adult Mortality Five Years after a Natural Disaster

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Abstract

Exposure to extreme events has been hypothesized to affect subsequent mortality because of mortality selection and scarring effects of the event itself. We examine survival at and in the five years after the 2004 Indian Ocean earthquake and tsunami for a population-representative sample of residents of Aceh, Indonesia who were differentially exposed to the disaster. For this population, the dynamics of selection and scarring are a complex function of the degree of tsunami impact in the community, the nature of individual exposures, age at exposure, and gender. Among individuals from tsunami-affected communities we find evidence for positive mortality selection among older individuals, with stronger effects for males than for females, and that this selection dominates any scarring impact of stressful exposures that elevate mortality. Among individuals from other communities, where mortality selection does not play a role, there is evidence of scarring with property loss associated with elevated mortality risks in the five years after the disaster among adults age 50 or older at the time of the disaster.

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INTRODUCTION

Projections about the evolution of health and mortality of a birth cohort that are based on information about the health of those alive at a point in time are complicated by at least two factors. First, individuals differ in their health endowments at birth. If a cohort's frailest members are the most likely to die, survivors to a specific age will be selected from among the fittest in that cohort. Put another way, there is likely to be positive "mortality selection" among survivors. Second, individuals also differ in the extent to which debilitating events over their life course "scar" them and leave them more susceptible to mortality. Theoretical models have been developed to explore how these processes and their interactions influence the evolution of mortality (Vaupel and Yashin 1985; Vaupel, Yashin, and Manton 1988), but in most empirical studies, the extent of mortality selection and scarring within a population is unknown and so is either ignored or assumed to follow a particular functional form. Our research uses uniquely rich longitudinal data following a large-scale spatially-concentrated natural disaster that resulted in high levels of mortality and likely scarred a substantial fraction of survivors to provide rigorous evidence on the relative importance of mortality selection and scarring for mortality of adults during the subsequent five years.

Our research advances understanding of how extreme events, including natural disasters, shape subsequent mortality risks and, thereby, population dynamics. We focus on the 2004 Sumatra Andaman earthquake and associated Indian Ocean tsunami, one of the deadliest natural disasters in recorded history. On the one hand, since tsunami-related mortality was high, survivors are likely to have been positively selected. On the other hand, exposure to the waves and their aftermath has been shown to have taken a significant emotional and physiological toll on survivors. Using data that we designed to measure specific exposures to the disaster along with and mortality in each year after the tsunami, we document how selection and scarring interact to shape post-disaster mortality. In addition, the reconstruction effort launched in response to the tsunami is regarded as one of the most successful disaster responses conducted in a developing country. The initial pace of reconstruction was slow. Tracing the changes in the links between tsunami exposures and mortality risks over the five year study period provides clues about whether this post-disaster assistance program has mediated the longer term mortality impacts of the disaster.

Although many countries were affected by the Indian Ocean earthquake and tsunami, Indonesia's Aceh province, on the northern tip of Sumatra, was hardest hit. Waves 30 meters high struck within about 30 minutes of the earthquake, which was centered off the west coast of Sumatra. The waves inundated parts of the coastline and flooded areas as far as 6 kilometers inland (Paris et al. 2007, 6). Estimates put the death toll at 170,000 which is almost 5% of Aceh's population. We use data from the Study of the Tsunami Aftermath and Recovery (STAR), a longitudinal survey representative of all individuals living in districts along Aceh's southwest coast and selected districts on the northeast coast at the time of the baseline survey which was collected nine months before the December 2004 tsunami. We combine data from the baseline with detailed information from five annual follow-ups that we fielded beginning 5 months after the tsunami.

Research on mortality at the time of the tsunami has highlighted three key factors that differentiate survival outcomes: location at the time of the tsunami, age and gender (in part reflecting differences in strength and ability to swim), and household composition (Frankenberg et al. 2011). That work documents the central role of location and the importance of physical strength, describes the relevance of household composition (reflecting the supply of and demands for help during the disaster), and shows that, conditional on these characteristics, socioeconomic factors were not related to survival at the time of the tsunami.

Building on this foundation, we extend the research by documenting the evolution of mortality risks among survivors during the five years after the tsunami and how those risks are affected by exposure to the disaster. Key for this research, we measure exposure not only at the level of the community of residence at the time of the tsunami, but also with individual-specific experiences during the tsunami, including losses at that time.

While there is substantial and statistically significant positive mortality selection among male survivors who were living in areas devastated by the tsunami, there is no evidence of positive mortality selection among female survivors. Nor is there evidence of elevated mortality due to scarring from individual experiences of the tsunami, conditional on local area exposures. The differences between males and females are reconciled taking into account differences by gender in mortality at the time of the tsunami in each community. The pattern of mortality risks over time does not suggest that the influx of resources in the latter half of the period changed mortality risks. We conclude that the population most affected by the tsunami exhibits high levels of resilience in the years after the disaster.

BACKGROUND

Research from different disciplinary perspectives has contributed importantly to understanding of the links between mortality and morbidity differentials and variation in exposure to extreme events. Studies in psychology and medicine have explored whether resilience is innate or develops in response to exposures and sought to identify biological processes that link trauma exposure to physical health sequelae (Richardson 2002; Bonanno 2004; Schnurr and Green 2004; Masten 2001). In the social sciences, Lutz and his colleagues have emphasized the role that human capital, and in particular formal education, play in increasing preparedness for and improving adaptability and recovery after natural disasters (Muttarak and Lutz, 2014; Striessnig, Lutz, and Patt 2013).

There is a paucity of population-representative longitudinal data that can provide evidence on the evolution of mortality risks in the years immediately after extreme events. As a result, most empirical studies rely on natural experiments that compare outcomes measured years after an extreme event for cohorts differentially exposed to the event. While these comparisons can reveal the imprints of the event's impacts on later life health and mortality (see, for example, Elo and Preston, 1992), no clear consensus has emerged regarding how these events impact mortality over the longer term.

For example, the link between exposure to famine in early life and mortality later in life has been extensively studied and even studies of the same event – the Finnish famine of 1866-68 – draw different conclusions. On the one hand, Kannisto et al. (1997) conclude that relative to the cohort born after the famine, cohorts *in utero* or born just before the famine experience elevated risks of mortality up to age 17, but not at older ages. On the other hand, Doblhammer, van den Berg, and Lummy (2013) consider more cohorts and draw comparisons with Swedish data from the same years, using a Gompertz model that allows for the impact of frailty to vary flexibly across cohorts (thereby reflecting cohort differences in mortality selection processes). Their results suggest significant reductions in life expectancy above age 60 for males born during and just before the famine. For females, the results are less clear. Finnish females born in the 10 years before, but not during, the famine experience lower life expectancies at age 60 relative to their Swedish counterparts.

Song (2010) documents mortality differentials through age 22 among Chinese cohorts born before, during, and after the Great Leap Forward famine of 1959-1961. The patterns differ at ages before versus after age 11. Song shows that at ages younger than 11, the pre-famine cohort exhibits higher mortality than the famine cohort, whereas the post-famine cohort exhibits lower mortality. In contrast, between ages 11 and 22, mortality for the pre-famine cohort relative to the famine cohort is the same, but mortality for the post-famine cohort is substantially higher. This cross-over is consistent with the idea that the pre-famine and famine-born cohorts who survive to age 11 are positively selected for subsequent survival relative to the post-famine cohort.

Relatively few papers consider the impacts of nutritional deprivation at ages beyond early childhood in relation to mortality in later life. Horiuchi (1983) is an exception that uses vital statistics data to examine mortality at older ages for cohorts that were exposed to severe food shortages because of World War I. He identifies a pattern of relatively high "late life" mortality for males born in Germany in 1901-02 who experienced severely constrained access to food in adolescence. Similar patterns exist for males in Austria and France but not for males in countries more distal to the conflict, or for females anywhere. Horiuchi hypothesizes that nutritional deprivation in adolescence differentially affects growth of blood vessel structures in males (whose biological capacity to store fat is lower than for females), which has consequences for the development of and mortality from cardiovascular disease at older ages.

The impact of adult exposure has also been assessed with respect to the mortality of individuals who as Prisoners of War (POWs) experienced disease outbreaks, severe food shortages, and other harsh conditions. Page and Brass (2001) use federal records to track the experiences of returned POWs from World War II and the Korean War. They document an initial pattern of lower death rates from heart attacks and strokes (relative to a control group of veterans who were never POWs), which persists for three decades but then reverses. Above age 75, the risk of death from heart disease is higher for former POWs than for the controls. Costa (2012), using historical records from Union Army POWs, finds that the impact of imprisonment on subsequent mortality varies by age at imprisonment. Among soldiers older than 30 at imprisonment, those who survived prison camps have lower risks of death at older ages than the controls, whereas for those younger than 30 at imprisonment, risks of morbidity and mortality at older ages are higher than for the controls. Costa documents extremely high levels of mortality within camps, particularly among those older than 30. She concludes that whether selection or scarring is dominant is likely to vary as a function of mortality levels during the event itself, a theme that is prevalent in the literature on early life health and nutrition insults (Deaton, 2007).

These studies are limited by lack of knowledge about the actual experiences of individuals during the events being investigated, how those experiences vary among individuals, and whether that variation predicts subsequent mortality. Place or time of birth (or records of imprisonment) in combination with historical evidence about the event are used to assign individuals or cohorts to membership in the "treatment" groups, but historical evidence is often fragmentary and the distinctions between the exposed and unexposed are not always clear (Doblhammer et al., 2013, for example, discuss various pre-famine factors that might have affected health of the pre-famine cohorts). It is also not clear in these studies that exposure can be thought of as random with respect to other factors that might affect subsequent mortality (see Costa, 2012, for an insightful discussion of this question in the context of Civil War POWs).

Only a small number of studies have investigated natural disasters, though such events are increasing in frequency and impact and exposure to them is associated with increased levels of physical, psychosocial, and economic stress (Borque et al. 1988, Rodriguez et al. 2006; Phifer, Kaniasty, and Norris 1988; Uscher-Pines 2009; Wachtendorf et al. 2006). Studies of earthquake survivors provide evidence that exposure is linked to subsequent chronic diseases and mortality several years after the event. Armenian, Melkonian, and Hovanesian (1998) analyze morbidity and mortality in the four years after an Armenian earthquake for a relatively complete group of Ministry of Health employees (based on records of pre-quake employment) who were surveyed two times after the earthquake. Though the study is not population-based, it is unusual in that it considers the impacts of different types of exposures. Among males, but not females, being in a building at the time of the quake is associated with a higher risk of mortality in the first year after the earthquake. For both sexes, injury or death of a family member and property losses are associated with higher odds of developing hypertension, heart disease, diabetes, or arthritis in the first six months after the disaster.

Nakagawa et al. (2016) consider deaths from acute myocardial infarction (AMI) in the three years after the 2004 Niigata-Chuetsu earthquake in Japan, based on death records from areas defined as treatment and control based on reported damage. They find that after the earthquake, AMI mortality in the treatment area increased significantly for both men and women relative to the preearthquake levels, but no change occurred in the control area. The study cannot adjust for selective migration, which is problematic given greater out-migration from the treatment area.

The studies of earthquakes suggest that adult exposure to a highly destructive disaster can elevate morbidity and mortality from chronic diseases in the next several years. They are silent on the possible role of mortality selection at the time of the event, but selection is presumably less important because disaster fatalities appear to have been low for these particular populations. Though a number of high-mortality earthquakes have occurred over the past decade, we know of no work apart from this study that documents their impacts on subsequent mortality for survivors.

With respect to levels of post-exposure mortality (relative to unexposed groups), this literature does not support a definitive conclusion that scarring is a more or less important force than positive mortality selection. Instead, which force appears dominant varies by gender, age at follow up, and age at exposure. Importantly, for the two studies with data for the same cohort observed at multiple time points, the evidence is consistent with the idea of a "cross-over", whereby one force is more dominant for a period of time, after which the other force becomes more important (Song 2010, Page and Brass 2001).

Our research makes several contributions to the literature. First, mortality at the time of the 2004 disaster was extremely concentrated both spatially and temporally, which allows us to identify exposure to risks with much greater precision than is typically possible. Second, because we have detailed information on both the exposure levels of communities where people lived at the time of the event and on individual-level experiences of stressors during the event, we have greater traction with respect to considering the roles of mortality selection, a process that alters the composition of the survivor population including the age and education structure, and scarring that is a result of what happened specifically to the individual. We use multiple measures of exposure, whereas most studies have relied on one spatially- or temporally-based measure to proxy for both selection and scarring. Third, by examining the link between these individual measures and post-tsunami mortality among those who were living in neighboring areas where there was no mortality, we are able to isolate negative effects of scarring that might be overwhelmed by positive mortality selection in areas where tsunami-mortality was high. Fourth, because we have pre-disaster data that is population-representative and attrition among tsunami-survivors is very low (less than 5%), our results are unlikely to be contaminated by selective sample composition that arises in surveys based on samples constructed after the event or in vital statistics data from relatively local areas or periods that may be affected by differential migration. Fifth, by tracing changes in mortality risks over time, it is possible to examine whether exposure impacts differ during the period of the most intense reconstruction efforts.

CONTEXT

On the morning of December 26, 2004, a powerful earthquake occurred about 150 miles off the coast of Sumatra, displacing a trillion tons of water, which in turn produced a series of tsunami waves. In Aceh, communities were engulfed along 800 kilometers of coastline, destroying infrastructure and killing more than 170,000 people.

Impacts varied considerably within local areas. The height and inland reach of water from the tsunami depended on slope, wave features, water depth, and coastal topography (Ramakrishnan et al. 2005). Along parts of the west coast of Aceh, the water removed bark from trees as high as 13 meters (Borrero 2005). At the beachfront in Banda Aceh, the province's capital and largest city, water depths reached approximately 9 meters; further inland they rarely exceeded the height of a two story building (Borrero 2005). The worst-affected areas were low-lying communities within a few kilometers from the coast, which were largely destroyed. Where rivers emptied into the ocean, the water moved inland as much as 9 kilometers, but encroached only 3-4 kilometers in other locations (Kohl et al. 2005; Umitsu et al. 2007). In areas at higher elevations, further inland, or topographically sheltered in some way, flooding damaged many structures and deposited enormous quantities of debris, but larger proportions of the population survived. For some communities the tsunami had few if any direct effects, although the earthquake was felt throughout Aceh and damaged property and infrastructure in areas the water never reached.

DATA

Our sample consists of a subsample of respondents in a large, population-representative socioeconomic survey (SUSENAS) conducted by Statistics Indonesia in February/March 2004, ten months before the tsunami. SUSENAS is representative at the *kabupaten* (district) level and, working with Statistics Indonesia, we selected all enumeration areas included in SUSENAS in the 11 districts that are along the coast of the province of Aceh and were potentially vulnerable to inundation by the tsunami. All members of household enumerated in these districts in the 2004 SUSENSAS serve as the baseline for STAR.

SUSENAS, which collects detailed information on demographic and socioeconomic characteristics of all household members from a key household member, is widely regarded as a very high quality survey and achieves participation rates that exceed 99%. The first STAR follow-up survey was conducted between May 2005 and July 2006 and we conducted four annual follow-ups thereafter, remaining permanently in the field during these five years.

We have established survival status for 99% of the baseline (pre-tsunami) respondents by triangulating multiple sources of information, including interviews with household and family members (whose reports we deem most reliable), community leaders, and neighbors (who provide essential information about households for which we have not located any original members). We developed this procedure in the first follow-up and employed it in subsequent follow-ups, updating the few errors as they were uncovered (Frankenberg et al. 2013). In each follow-up, every household member is interviewed (with parents or caregivers providing information about children age 11 years or younger). The first two follow-up surveys collected detailed information on experiences at the time of the tsunami from each respondent. All surveys include questions on physical health, psycho-social well-being, and behavioral responses to the event, including displacement and migration, as well as information about individual and household demographics and socioeconomic status.

Links between post-tsunami mortality and two types of indicators of exposure to the tsunami are investigated. First, at the community level, tsunami wave characteristics and coastline topography were key determinants of death and destruction at the time of the tsunami. We have constructed a community-specific indicator of geographic exposure based on the location of each respondent's community at the time of the tsunami that combines information on that community's elevation above sea level, proximity to the coastline, and tsunami wave height at the closest coastal point to the community.[1] In the analyses we distinguish respondents who were living in communities that were directly affected by the tsunami ("tsunami-affected") from respondents who were living in communities that were not directly affected ("other") at the time of the tsunami. As we show below, this dichotomy captures tsunami-related exposures well and separates areas where there was tsunami-related mortality from areas where death due to the tsunami was negligible.[2]

Second, STAR is designed to elicit from each individual their own exposure to several different dimensions of the tsunami including, for example, whether the respondent was caught up in or saw others struggling in the waves, lost family members or lost his/her home. Whereas most studies have relied on community or aggregate levels of exposure, these individual-specific indicators of exposure capture the tsunami-related stresses for each respondent with greater precision, an important advantage for the study of scarring and subsequent mortality.

An advantage of the community and individual-level exposure measures is that they are plausibly exogenous, depending primarily on characteristics that were outside the control of the respondents at the time of the tsunami. These include, for example, the topography and location of the community, wave height and wave direction. While the exact location of where the tsunami hit the Aceh coast is reasonably treated as random, residential location is a choice and it is possible that those who were living in areas that were inundated are different from those who were living elsewhere. To directly address this concern, we will also examine the effects of individual-level exposures contrasting individuals within each study community so that the estimates are not contaminated by differences in vulnerability, socio-economic status and the availability of resources across communities.

Comparing mortality during and 5 years after the tsunami

As a first step in examining the evidence for selective mortality and scarring, we compare age- and gender-specific mortality during the tsunami with mortality in the five years after the tsunami, contrasting tsunami-affected and unaffected communities. We focus on mortality of individuals who were at least 35 years old at the time of the tsunami because post-tsunami mortality of younger people was low. We stratify the sample into four age and gender groups: younger (age 35-49 years) and older (age at least 50 years) males and females. Figure 1 displays the percentage of the population that died within 5 days of the tsunami (shaded bars) and, for survivors, during the next 5 years (white bars), distinguishing those who were living in communities that were affected by the tsunami (bars with diagonal lines) from those who were living in other communities that were not directly affected (solid bars).

Mortality at the time of the tsunami was extremely high in tsunami-affected communities, testimony to the tsunami's devastating impact in the locations that bore its full force. Overall 16.7% of the population age 35 and older died in these communities, in comparison with 0.6% in the other communities. As shown in Figure 1, in the tsunami-affected communities, mortality from the disaster is higher for older relative to younger adults and for females relative to males. The gender gap of 7 percentage points is largest (and statistically significant) among younger adults (Frankenberg et al. 2013). Similar findings have been reported in other post-tsunami studies in India, Indonesia, and Sri Lanka (MacDonald 2005; CNN 2005; Doocy et al. 2007). Part of the explanation for women’s elevated mortality during the tsunami likely lies in sex differences in swimming ability, physical strength, and stamina (Frankenberg et al. 2011; Hunter et al. 2015).

These factors all suggest that the force of mortality during the tsunami operated differently by age and sex, raising the possibility that the nature of mortality selection varied across these groups. Indeed, if swimming skills are correlated with strength and socio-economic status and were critical for survival of males but not females, then deaths among females are likely to be less selected than are deaths among males. This has implications for the extent of mortality selection we may observe among male versus female survivors in the tsunami-affected communities.

The white bars of Figure 1 display the percent that died in each group during the five years after the tsunami. As before, patterned bars indicate mortality in tsunami-affected communities, while solid bars refer to other communities.

Importantly, for three groups, the direction of the difference in mortality levels between tsunami-affected and other communities reverses relative to that difference at the time of the tsunami. For younger males, younger females, and older males, in the five years after the tsunami, mortality is *lower* for those from tsunami-affected communities than for those from other communities. The survival advantage for those from tsunami-affected communities is particularly large (and statistically significant) for older males. The fact that the direction of the difference reverses, rather than continuing to penalize those from tsunami-affected communities, provides a first suggestion that positive mortality selection occurred at the time of tsunami and continues to influence mortality patterns over the longer-term.

Another result apparent in Figure 1 is that in the post-tsunami environment, mortality levels change dramatically with age. To highlight this heterogeneity, Figure 2 presents nonparametric estimates of mortality in the five years after the tsunami by age and community type, stratified by sex. Among males (left-hand panel), mortality at all ages is higher for those who, at the time of the tsunami, were living in communities beyond the disaster's reach. After the late 40s the gap increases steadily with age, reaching nearly 10 percentage points by age 75. As discussed with respect to Figure 1, one interpretation is that males who were living in tsunami-affected areas and survived the disaster are positively selected and, if their experiences increased their vulnerability in ways captured by our community-level measure, those scarring effects are dominated by the force of selection. As a result, males who were living in tsunami-affected areas have lower subsequent mortality rates.

In contrast, females from tsunami-affected communities have no clear survival advantage in the subsequent five years (right-hand panel). One possibility is that deaths during the tsunami were much more idiosyncratic for females than males (due to lack of swimming skills and lower levels of physical strength) and that positive selection did not operate as strongly for females. Another possibility is that the females who survived in tsunami-affected communities were weakened by their experiences during the tsunami to a degree that any survival advantage was offset by scarring.

To investigate the potential role for scarring of individuals who survived, we turn to multivariate models that harness detailed individual-level information on tsunami exposures. These measures are important because they allow us to differentiate individuals in terms of their specific experiences, rather than only as a function of where they lived at the time of the disaster.

METHODS

We examine the correlates of mortality after the tsunami by estimating a sequence of models that in combination allow us to examine different measures of exposure, vary the comparison group and take into account unobserved community-specific factors by drawing comparisons among survivors who were living in the same community at the time of the tsunami. We analyze a binary dependent variable, θ_{ic}, which takes the value one if the tsunami survivor, i, died during the five years after the tsunami and 0 if the individual survived to five years:

$$\theta_{ic} = \alpha + \beta T_c + \gamma X_{ic} + \varepsilon_{ic} \qquad [1]$$

where T_c indicates whether the respondent's pre-tsunami community was affected by the tsunami, our geographically-based measure of exposure described above which parallels exposure measures in most other empirical work on this topic. The vector X_{ic} includes individual background characteristics measured at the pre-tsunami baseline: age (in single years), education, whether the respondent was married, household expenditures per capita (a well-established measure of economic resources), and controls for household composition (Deaton 1997). Unobserved heterogeneity is captured by ε_{ic}.

The baseline model is extended to examine how individual exposures to the disaster's direct impacts are related to death over the next five years by extending the model:

$$\theta_{ic} = \alpha + \beta T_c + \lambda E_{ic} + \gamma X_{ic} + \varepsilon_{ic} \qquad [2]$$

where the vector of covariates E_{ic} consists of four measures of exposure based on individual reports of experiences and losses at the time of the tsunami. We focus on primary exposures that stem directly from the event in order to spotlight the impact of disaster-related experiences that were beyond the control of the respondents. We do not consider the role of secondary stressors that arise as a function of how the lives of survivors unfolded in the disaster's aftermath (Lock et al. 2012). First, we construct a binary variable based on self-reports of one or more potentially traumatic or immediately life-threatening experiences: (1) sustaining an injury, (2) struggling in the water, (3) seeing family members struggle, (4) seeing family members disappear, (5) seeing friends struggle, or (6) seeing friends disappear. For shorthand, we refer to this indicator as “direct/immediate experience” of the tsunami. Second, two binary variables indicate whether (1) the respondent lost a spouse between the baseline and first follow-up interview and (2) whether the tsunami killed a parent, sibling, or child of the respondent. Third, a binary variable indicates whether the respondent lost his/her home. In combination, these variables summarize exposure to the immediate visceral horrors of the event and to loss of family networks and assets caused by the tsunami.

It is possible that examining mortality over five years masks more immediate impacts of exposure for three reasons. First, the effects of scarring may be short-lived and observed only during the first few years after the tsunami. Second, effects may be moderated by post-tsunami reconstruction which, after several years, resulted in new infrastructure including housing and roads, jobs and higher wages. Third, and related, loss of a home may be associated with greater exposure to pathogens while in makeshift housing, possibly resulting in a rise in infectious diseases (which many predicted); in that case, the impact of property damage may be high in the period immediately after the event, but decline as housing conditions improve (WHO 2005). To investigate these hypotheses, model [2] is re-estimated separately for two periods: 2005-2007 and 2008-2009 and thereby determine whether disaster exposure affects mortality risks in the short term versus over a more extended period.

The community-level measure of exposure potentially reflects a broad set of factors including vulnerability. To address this concern and to highlight the role of individual exposures, the model is extended to draw comparisons in variation in exposure between individuals within the same community:

$$\theta_{ic} = \alpha + \lambda E_{ic} + \gamma X_{ic} + \mu_c + \varepsilon_{ic} \qquad [3]$$

where μ_c are enumeration area (EA) fixed effects that absorb the influence of all community-level variation that does not change over time and affects mortality in a linear and additive way. This includes levels of vulnerability that are shared by community members, the extent of damage in the community because of the earthquake and tsunami, post-tsunami reconstruction, and pre-tsunami levels of infrastructure and economic activity, as well as other unobserved factors that might be correlated with both choice of pre-tsunami location and mortality.

It is possible that any negative scarring effects are dominated by positive mortality selection in the tsunami-affected areas. However, we can put selection aside in areas that were not directly affected by the tsunami, where there was effectively no tsunami-related mortality, and interpret the estimated effects as indicative of scarring. To test this hypothesis, [3] is re-estimated stratifying by our dichotomous measure of community-level impact. This specification has the additional advantage of allowing the impacts of personal exposures to differ depending on whether there was mortality at the time of the tsunami in the community if, for example, local area mortality exacerbates the effects of individual exposures.

All models are estimated by the method of ordinary least squares and the resulting linear probability estimates are multiplied by one hundred so that they can be interpreted in percentage terms. We report estimates from linear probability model for two reasons. First, the coefficient estimates are directly comparable with estimates of the percent that died displayed in the figures and discussed above. Given the dramatically different mortality rates across the different age and gender groups in Figure 1, percentage effects are easier to interpret across the models than, for example, odds ratios from logit estimates. Second, whereas the linear probability models with community fixed effects yield consistent estimates, the logit model is non-linear and suffers from the well-known incidental parameters problem when fixed effects are included. However, none of our conclusions is affected by whether we estimate or logit or linear probability models. The linear probability estimates are not homoscedastic and so all estimates of variance-covariance matrices and test statistics take into account clustering at the enumeration area level and are robust to arbitrary forms of heteroscedasticity (Huber, 1981).

RESULTS

Exposure to the tsunami and characteristics of survivors

Table 1 presents descriptive statistics for the analytical samples of individuals who survived the tsunami, stratified by whether the community was affected by the tsunami (before the tsunami slightly over half the sample of survivors lived in a tsunami-affected community).[3] Relative to other communities, survivors that had lived in tsunami-affected communities had a slightly higher proportion of males than females and was somewhat younger. Regardless of community type, just over four-fifths were married at the baseline interview. Education levels are somewhat higher in the tsunami-affected communities, where adults have attained an average of 7.2 years of education, versus 6.5 years in other communities.

With respect to the individual-level measures of exposures, each of the four experiences is much more common among surviving respondents from tsunami-affected communities than among those from other communities. About one in five respondents from affected communities directly experienced the tsunami themselves, versus one in twenty-five for those from "other" communities. Nearly one quarter of respondents from affected communities lost a parent, sibling, or child in the disaster, whereas 10 percent of those from other communities did. Loss of home occurs in both areas (in other areas damage resulted from the earthquake), although rates are higher for those from tsunami-affected communities. Finally, in the five years after the tsunami 7 and 8 percent of adults died in affected and other communities, respectively.

Linear Probability Models of Mortality

Mortality Among Tsunami Survivors

Table 2 presents results from regressions that relate the risk of dying during the five years after the tsunami to our community-level measure of tsunami exposure, individual background characteristics measured at baseline (age, education, marital status, and economic resources), and personal exposure at the time of the disaster. Results are stratified by age group and gender, as in the descriptive statistics presented earlier.

Among survivors, being from a tsunami-affected community is not associated with higher mortality in the five years after the disaster. In fact, a clear survival advantage emerges for older men from tsunami-affected communities (column 3). Their probability of dying is on average 5 percentage points lower than that of men from other communities. For the other three age-gender groups, differentials by community type are small and not statistically significant.

Figure 2 illustrated that the probability of death in the five years after the tsunami rises rapidly with age. The regressions in Table 2 indicate that apart from age, other factors such as socioeconomic status and marital status are not significantly related to mortality in the five years after the disaster. This is the case for both younger and older men and women.

Although mortality at the time of the tsunami was dramatically higher in tsunami-affected communities, afterwards, being from a tsunami-affected community is significantly associated with mortality only for older men, and this effect is negative. The community-level measure may reflect a combination of two competing effects: positive mortality selection ("survival of the fittest") and the negative impacts of exposure to stress (i.e., scarring), which is more common among those from tsunami-affected communities. The first effect may dominate among older men, while the two effects may balance each other out for the other three groups. Community exposure, however, is only a rough proxy for what individuals actually experienced during the disaster. Adding direct measures of traumatic experiences and of loss of family and assets may better separate selection and scarring.

It turns out that the addition of these fine-grained individual exposure measures (columns 5-8) does not change the impact of being from a tsunami-affected community either for older males (for whom community exposure continues to be negatively and significantly associated with mortality) or for women (for whom the community measure is not statistically significant). For younger males, the coefficient on community exposure remains negative and becomes larger and marginally significant (column 5).

None of the detailed individual-level measures (columns 5-8) is significantly related to subsequent mortality for younger men and women. For those under age 50, individual experiences of trauma and loss during the tsunami do not appear to have weakened survivors in ways that influence their risk of death over the next five years relative to those without such experiences.

For older survivors, some of the individual exposures are related to subsequent mortality. Their impact, however, is to *reduce* mortality risks rather than to heighten risks, as one would expect if scarring were a dominant factor in the evolution of survival prospects after the tsunami . For older males, the impacts of both immediate/direct exposure to the tsunami and loss of close kin are negative, statistically significant, and substantively large. For older women, direct experience of the tsunami is not statistically significant but it is also negative and substantively large. These exposures appear to identify individuals with characteristics associated with greater longevity after the tsunami and, therefore, likely reflect mortality selection among the exposed in this age group.

Effects by Period

We have shown that the impacts of individual exposures to the tsunami are inconsequential for younger adults and are associated with lower mortality for older individuals, particularly for older males. However, as discussed above, the roles these exposures play may vary over time. To investigate this hypothesis, we divide the five year follow-up period into an earlier period, 2005-2007, and a later period, 2008-2009 (conditional on surviving to 2008). We re-estimate Model 2 stratifying by age, sex, and period (Table 3).

Among individuals under 50 years of age no evidence of exposure impacts emerges for either period (columns 1-4). For older men, death of a parent, child, or sibling is associated with lower mortality in the first two years after the tsunami, whereas being from a tsunami-affected community or having direct experience of the tsunami also predict lower mortality in the latter half of the period. These likely reflect mortality selection, the effect of which was strongest in the shorter term among those who lost family members and subsequently dissipated.

For older women, losing a home is predictive of lower mortality in the first two years after the event, but it is positively related to mortality among older women during the subsequent two years. The estimated impact of home loss in the second period is the only indicator whose sign is consistent with the scarring effect of a stressful exposure raising subsequent mortality risks.

However, both of the estimated impacts for older women are only significant at a 10% size of test and the emergence of scarring in the later period is difficult to reconcile with the influx of resources, including new homes, during that time. We will return to the interpretation of this effect in the next sub-section.

Exposure Impacts within Communities

Our dichotomous measure of community-level exposure is unlikely to capture all variation across communities in the tsunami's impact. To more fully control for community-level impacts and thereby sharpen the spotlight on the role of individual exposures, we turn to specifications that add community fixed effects, [3]. To increase power, we pool males and females but retain the age stratification because exposure impacts appear to differ by age group. The results are presented in Table 4.

For comparison, we first estimate the model on the pooled samples without the community fixed effects. Among younger adults, there is a small but negative impact of being from a tsunami-affected community ($p<0.10$), indicating some positive mortality selection for this group (column 1). Consistent with our previous results, none of the individual exposure measures is related to subsequent mortality. Among older adults (column 5) being from a tsunami-affected community is not related to subsequent mortality, but there is a strong negative impact of individual direct exposure to the tsunami.

The second specification adds community fixed effects (in columns 2 and 6). In these models the estimates reflect the effects of particular exposures for individuals within a community relative to individuals from the same community who were not similarly exposed. These estimates sweep out common elements shared by all residents from the community and thus control more completely for variation across communities in tsunami impacts.

If exposures to trauma and loss of family or homes weaken individuals, then among individuals from the same community, those with more harrowing exposures and greater losses should be more likely to die than those with more muted exposures. But this is not what we see. For younger adults (column 2), none of the personal exposures matters, even within communities. For older adults (column 6), direct experience with the tsunami continues to serve as a marker for attributes associated with greater longevity and thus likely captures selective mortality at the time of the tsunami.

In all of the preceding models, we combine individuals from tsunami-affected and other communities and control for community-level features either through our geographic exposure measure or using fixed effects. This approach does not allow for the possibility that the impacts of individual exposures vary between affected and other communities. Such a stratification is potentially informative because a sizable share of the population was killed in the tsunami-affected communities but death in the tsunami was effectively absent in the other communities. Thus, mortality selection is only likely to be relevant in the tsunami-affected areas, whereas scarring potentially occurred in both areas. To assess the evidence for differential impacts we re-estimate model [3] separately by whether the community was tsunami-affected. For the "other" communities we drop the indicators for direct experience of the tsunami and for death of a spouse, as very few individuals in these communities report those exposures.

For younger adults, individual exposures do not predict subsequent mortality in either type of community (columns 3 and 4). All of the estimated coefficients are small in magnitude and none is statistically significant.

The stratification by level of community impact does shed light on the processes at play for older adults. In tsunami-affected communities, direct experience of the tsunami is associated with an 8 percentage point reduction in mortality risk over the next five years, and loss of close kin is associated with a 6 percentage point reduction. These are large effects that are statistically significant.

For older adults from other communities, loss of a home is associated with an almost 8 percentage point increase in mortality which, since these communities were not affected by disaster-related mortality**,** is evidence of the negative impact of scarring. The impact is concentrated on males who are over 13 percentage points more likely to die within 5 years of the tsunami, suggesting that the loss of economic assets took a greater toll on them relative to females.

In combination, these results suggest that, for older adults, positive mortality selection was the dominant force in communities where disaster-related mortality occurred, but in areas without tsunami-related mortality, disaster-related experiences took a toll on survival over the next five years, particularly for males. It is possible that experiences of the tsunami also scarred individuals in the tsunami-affected communities—we cannot observe what post-tsunami mortality would have been in the absence of the exposures that survivors from tsunami-affected communities accrued.

CONCLUSION AND DISCUSSION

Using uniquely-rich longitudinal data from STAR, we have investigated the extent to which positive mortality selection and scarring affect mortality risks among survivors of the 2004 Indian Ocean tsunami who were exposed because of the vulnerability of their community of residence (defined by the intersection of geography and tsunami wave height at the coast) when the tsunami struck or through their personal experiences during the disaster. We compare survival in the first five years after the tsunami for these individuals to survival among individuals who were living in areas that were not directly exposed to mortality because of the tsunami. Critical to interpretation of our results is that key determinants of surviving the disaster itself are the exposure of one's community at the time of the disaster, sex, and, to a lesser extent, age. Among adults, males under the age of 50 are the most likely to have survived the tsunami.

In the five years after the disaster, community-level geographic exposure continues to influence mortality. It is especially important for males. Males who were living in highly vulnerable areas before the disaster but who survived the tsunami have substantially lower mortality risks in the next five years than males from less vulnerable areas. The survival advantage is greater for older than for younger males, consistent with higher rates of mortality at the time of the tsunami among older males. We find no evidence of positive selection for females. A plausible interpretation of this gender difference is that deaths of females during the tsunami were not as selective as deaths of older males and the impact of this mortality difference at the time of the tsunami is reflected in the selectivity of the population of survivors and therefore also in post-tsunami mortality.

We also consider the roles that individual experiences and losses during the tsunami play in determining subsequent mortality risks. This feature of the study is particularly unusual because very few studies at the population level have detailed information on the individual experiences of survivors. We find that mortality risks are not raised by any of these experiences among individuals who were living in areas where mortality selection at the time of the tsunami changed the composition of the population. For males and females less than 50 years of age, the individual exposure measures are unrelated to subsequent mortality. For older males and females, direct experience and loss of close kin are related to subsequent mortality, but they *reduce* rather than heighten mortality risks in comparison to individuals without those experiences, indicating that whatever scarring impacts these exposures had, they are dominated by the mortality selection of those who survived the exposures. This result holds both overall and when we restrict the comparison to individuals living in the same community at the time of the tsunami.

For older adults both our geographic measure of risk, which parallels the type of exposure measure used in other papers, and our fine-grained measures of individual exposures point to positive mortality selection operating to reduce mortality risks in the years after the tsunami. These results hold across multiple approaches used to construct comparison groups.

The only evidence that scarring plays a role is for older adults who were from communities where there was effectively no disaster-related mortality because the communities were located away from the tsunami's direct path. Within this group those who lost a home experienced elevated mortality in the five years after the disaster. This effect is concentrated among older males. The potential scarring effects of loss of kin are not manifest in subsequent mortality risks among those in areas that were not directly affected by the tsunami.

It is useful to place these results in the context of other work on this topic. Our study considers mortality in the five years after the tsunami. Relative to some of the papers we discuss, our follow-up period is quite short. Charting the continued evolution of relative mortality risks will be important if the effects of the stresses cumulate over time and as more of our sample reaches ages where chronic diseases, which exposure to stress has been shown to increase, are the major sources of mortality.

Several other differences distinguish the Indian Ocean tsunami from the focal events considered in other papers. First, the other papers on earthquakes focus on events where mortality from the event itself was much lower than for the tsunami, which necessarily limits the role that selective mortality could play. Second, the papers on famines and POW experiences center on exposures of longer duration than the tsunami. Mortality caused by the tsunami was concentrated within a very narrow window of time and resulted almost entirely from drowning. Unlike famines and imprisonment, death from the tsunami did not occur after weakening from months of exposure to harsh conditions. This difference may alter the potential role for debilitation, in that the tsunami was not a disaster during which debilitation and death co-evolved in a slow and progressive way, killing some and leaving others on death's doorstep.

After the tsunami, individuals from tsunami-affected communities may well have continued to accrue experiences that altered their mortality trajectories. Some of these-- displacement, life in makeshift housing, and a period of severe inadequacies in food and drinking water-- were negative. Others were likely positive, such as infusions of aid, improvement in health care via reconstruction of infrastructure, housing assistance, and livelihood restoration projects. In this paper, we have focused only on primary features of the disaster experience that we can plausibly treat as exogenous. But the evolution of exposures among survivors after the event and the role they play in shaping the evolution of health and mortality is extremely important, if complicated, and will be investigated in future work.

[1] Estimates of wave height draw on data on tsunami run-up heights compiled by the National Oceanic and Atmospheric Association (NOAA).

[2] Our main results do not depend on this particular dichotomization. For example, our conclusions are the same if the sample is split by whether or not tsunami-related deaths occurred to community members. They are also the same if we restrict "other" communities to those relatively close to the coast.

[3] Of the baseline sample of 6,687 respondents, 10% died and of the survivors, 95% have been followed-up in the post-tsunami surveys so that the analytical sample includes 5,640 respondents who were living in 334 communities at the time of the tsunami. Of those, 3,005 respondents were in living in 192 tsunami-affected communities. Attrition is low because we put considerable effort into tracking survivors who moved including those who moved to other parts of the island of Sumatra and to Java. Attrition rates are comparable in the tsunami-affected and other communities with about two-thirds due to movers who we did not find and one-third due to refusal.

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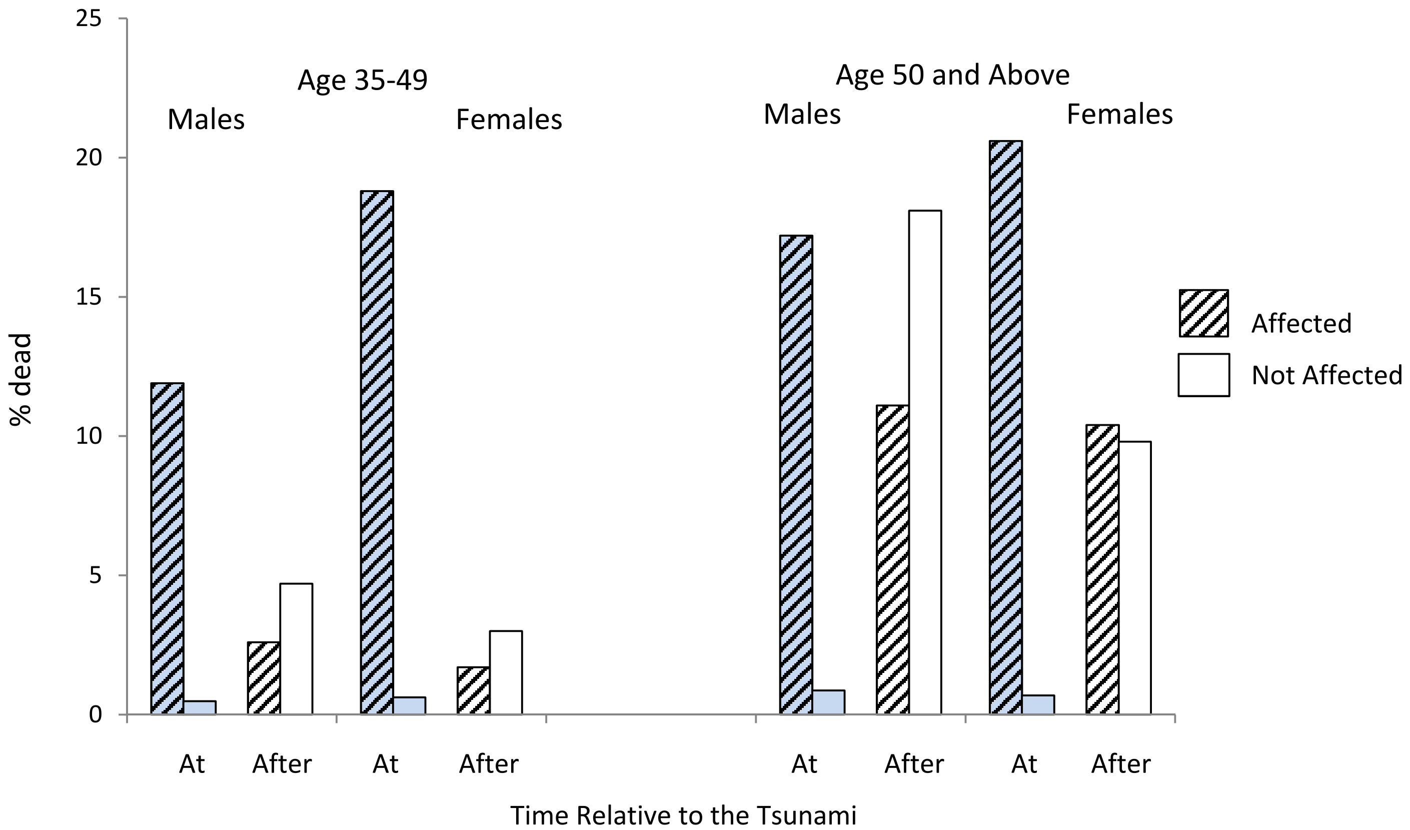
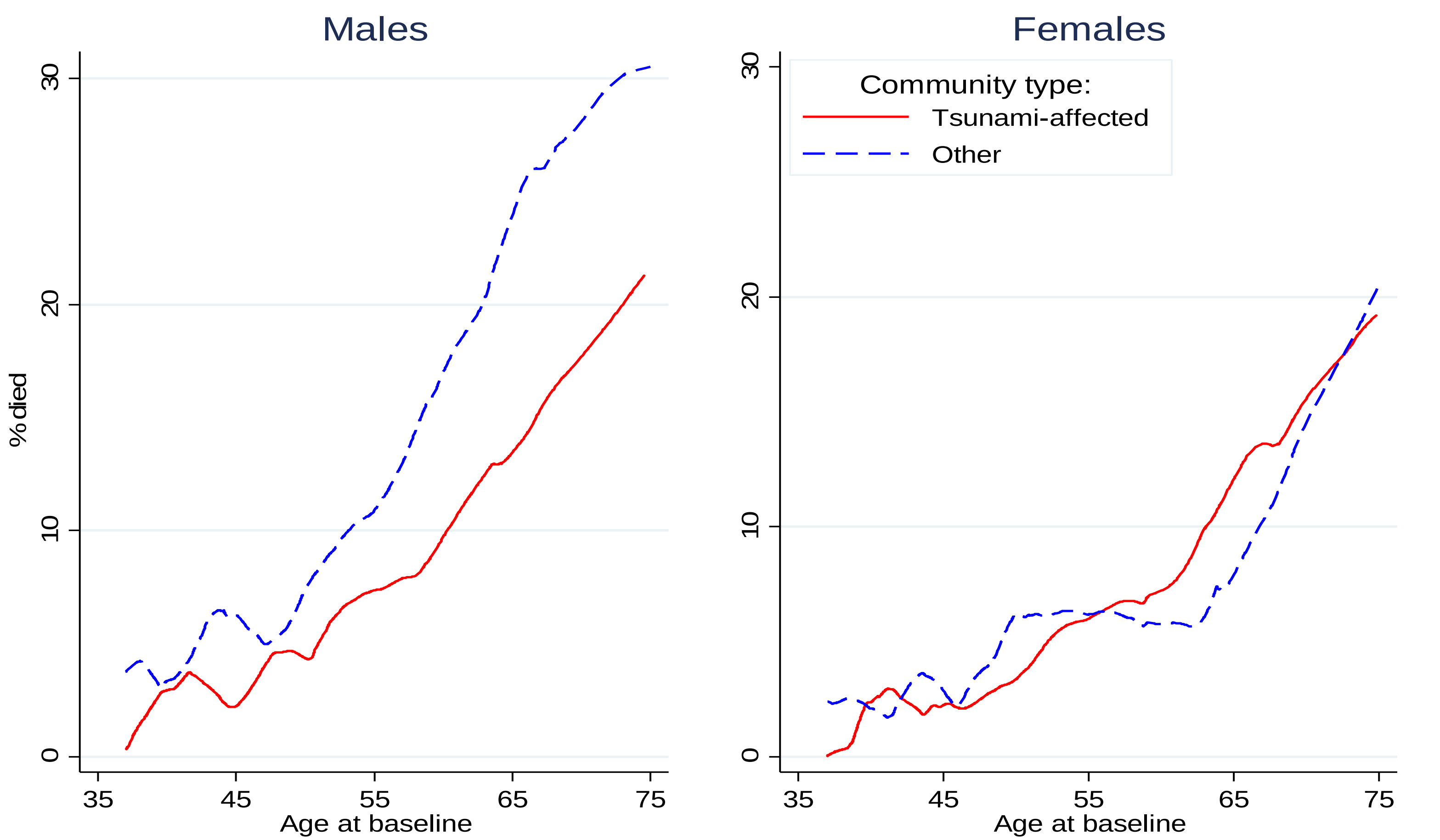
Figure 1: Mortality at and in the five years after the tsunami
by Age Group, Gender, and whether the Community (at the time of the tsunami) was Affected



Notes: Based on 6,687 baseline respondents and 5,639 respondents who survived to the first post-tsunami interview. Communities are classified as "affected" or "not affected" based on their elevation, distance from the coast, and the height of the tsunami wave at the closest coastal point.

Figure 2. Mortality (% died) in the five years after the tsunami
By gender, age and location at the time of the tsunami



Non parametric estimates constructed from 5,639 respondents who survived to the first post-tsunami interview. Communities are classified as "affected" or "other" (not affected) based on their elevation, distance from the coast, and the height of the tsunami wave at the closest coastal point.

Table 1

Descriptive Statistics for Survivors of the Tsunami (Adults aged 35 and Older), % or mean (SD)

	Tsunami-Affected	Other
Baseline Characteristics		
% Female	47.6	50.1
Age	49.3 (11.5)	50.0 (11.5)
% Married	83.6	82.5
Years of Education	7.2 (4.4)	6.5 (4.1)
Per capita HH expenditures (log)	12.7 (0.6)	12.7 (0.5)
Individual Exposures		
% with Direct experience of tsunami	19.6	4.0
% with Parent, Sibling, or Child killed	23.9	9.9
% Widowed by Tsunami or First Follow-Up	7.9	4.5
% Lost Home in Disaster	37.6	13.3
% Died during the follow-up period	7.0	8.1
Number of Individuals	3,005	2,634
Number of Communities	192	142

Table 2 Mortality in the Five Years After the Tsunami

	Less than 50 yrs		50 yrs or older		Less than 50 yrs		50 yrs or older	
	Males	Females	Males	Females	Males	Females	Males	Females
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tsunami-affected community	-1.19	-0.67	-5.00*	1.87	-1.91+	-0.72	-4.43*	2.19
	[0.92]	[0.77]	[2.12]	[1.77]	[1.04]	[0.79]	[2.22]	[1.98]
Direct experience of tsunami					2.18	-0.03	-6.41*	-4.69
					[1.64]	[1.25]	[2.83]	[3.27]
Parent, Sibling, or Child killed					1.14	0.12	-5.48*	-0.04
					[1.42]	[1.11]	[2.57]	[2.45]
Widowed by Tsunami or B ivw					-1.61		6.57	-0.63
					[2.15]		[4.94]	[3.40]
Lost Home in Disaster					0.71	0.14	3.02	0.91
					[1.20]	[0.94]	[2.53]	[2.06]
Married at Baseline	-1.93	0.10	-4.10	0.26	-1.88	0.09	-4.84	0.14
	[3.09]	[1.17]	[5.39]	[1.98]	[3.11]	[1.18]	[5.30]	[2.00]
Education (years)	0.04	0.01	0.09	-0.19	0.04	0.01	0.10	-0.16
	[0.11]	[0.11]	[0.29]	[0.28]	[0.11]	[0.11]	[0.29]	[0.29]
per capita HH Expenditure (ln)	-0.76	0.42	1.70	-0.61	-0.85	0.42	2.15	-0.51
	[0.86]	[0.78]	[1.92]	[1.73]	[0.87]	[0.77]	[1.95]	[1.75]
Number of adult males	0.57	-0.36	0.84	1.23	0.51	-0.36	1.02	1.23
	[0.91]	[0.41]	[1.04]	[0.87]	[0.87]	[0.41]	[1.05]	[0.88]
Number adult females	0.81	-0.07	1.39	1.59	0.82	-0.07	1.54	1.64
	[0.77]	[0.43]	[1.18]	[1.03]	[0.78]	[0.43]	[1.17]	[1.02]
Number of Children	0.26	0.27	-1.78*	0.86	0.25	0.27	-1.63+	0.78
	[0.45]	[0.36]	[0.90]	[1.12]	[0.46]	[0.36]	[0.90]	[1.13]
Constant	9.56	-3.42	-10.44	4.24	10.51	-3.49	-15.85	3.06
	[12.01]	[9.52]	[25.40]	[22.84]	[12.0]	[9.3]	[25.9]	[23.0]
Observations	1,703	1,609	1,187	1,140	1,703	1,609	1,187	1,140

Estimated by ordinary least squares (linear probability estimates are multiplied by 100). Measures of exposure and marriage at baseline are indicator variables. Robust standard errors in brackets. Includes controls for age measured in single years.
** p<0.01, * p<0.05, + p<0.1

Table 3 Mortality after the Tsunami, by Time Period

	Less than 50 Years Old				50 years or older			
	Males		Females		Males		Females	
	2005-07	2008-09	2005-07	2008-09	2005-07	2008-09	2005-07	2008-09
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tsunami-affected community	-1.05	-0.89	-0.30	-0.42	-1.26	-3.83*	1.29	1.10
	[0.67]	[0.87]	[0.59]	[0.55]	[1.62]	[1.84]	[1.45]	[1.57]
Direct experience of tsunami	0.73	1.49	0.34	-0.39	-0.49	-6.45**	-3.08	-1.50
	[1.12]	[1.33]	[0.80]	[0.98]	[2.60]	[2.07]	[1.94]	[2.77]
Parent, Sibling, or Child killed	0.27	0.89	-0.09	0.21	-5.34**	-0.44	-0.43	0.19
	[0.97]	[1.12]	[0.71]	[0.88]	[1.94]	[2.16]	[1.68]	[1.97]
Widowed by Tsunami or B ivw	-0.61	-1.04			1.59	6.03	-1.40	0.65
	[1.38]	[1.69]			[3.70]	[4.47]	[2.36]	[2.66]
Lost Home in Disaster	-0.16	0.86	0.24	-0.11	0.53	2.92	-2.51+	3.42+
	[0.77]	[0.95]	[0.74]	[0.61]	[1.93]	[1.88]	[1.42]	[1.79]
Constant	6.57	4.06	-1.04	-2.49	0.05	-14.30	-10.20	13.85
	[7.88]	[9.08]	[6.79]	[6.79]	[18.35]	[22.57]	[18.73]	[17.32]
Observations	1,703	1,674	1,609	1,591	1,187	1,091	1,140	1,076

Estimated by ordinary least squares (linear probability estimates are multiplied by 100). Measures of exposure are indicator variables. Robust standard errors in brackets. Includes controls for age measured in single years, years of education, marital status at baseline, per capita household expenditures, and household composition.
** p<0.01, * p<0.05, + p<0.1

Table 4 Mortality after the Tsunami by Community Type

	Less than 50 Years Old				50 years or older			
	Combined		Tsunami Affected		Combined		Tsunami Affected	
			Yes	No			Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tsunami-affected community	-1.24+				-0.72			
	(0.65)				(1.59)			
Direct experience of tsunami	1.40	1.29	0.65		-4.40*	-5.94+	-7.91*	
	[1.11]	[1.31]	[1.34]		[2.20]	[3.09]	[3.36]	
Parent, Sibling, or Child Killed	0.73	0.92	1.38	0.04	-2.78	-2.46	-6.13*	0.79
	[0.88]	[1.00]	[1.21]	[1.78]	[1.87]	[2.12]	[2.71]	[3.43]
Widowed by Tsunami or B Ivw	-1.39	-1.96	-0.35		1.51	3.16	6.44	
	[1.36]	[1.38]	[1.88]		[2.79]	[3.08]	[4.85]	
Lost Home in Disaster	0.25	-0.10	0.23	-0.71	1.79	0.16	-3.12	7.58*
	[0.81]	[0.96]	[1.05]	[2.04]	[1.71]	[2.50]	[3.25]	[3.83]
Constant	3.67	10.16	-5.17	26.23	-13.45	0.40	-17.81	17.56
	[7.4]	[10.8]	[12.3]	[17.4]	[17.7]	[29.3]	[45.9]	[37.4]
Community Fixed Effect	No	Yes	Yes	Yes	No	Yes	Yes	Yes
N	3,312	3,312	1,796	1,516	2,327	2,327	1,209	1,118

Robust standard errors in brackets. Includes controls for age measured in single years, years of education, marital status at baseline, per capita household expenditures, and household composition.
** p<0.01, * p<0.05, + p<0.1