NBER WORKING PAPER SERIES

THE EFFECTS OF MORTALITY ON FERTILITY: POPULATION DYNAMICS AFTER A NATURAL DISASTER

Jenna Nobles
Elizabeth Frankenberg
Duncan Thomas

Working Paper 20448
http://www.nber.org/papers/w20448

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 2014

The authors are grateful for comments from David Lam and Jim Walker. This work is supported by the National Institute for Child Health and Human Development (R01HD052762, R01HD051970, R03HD071131), the National Institute on Aging (R01AG031266), the National Science Foundation (CMS-0527763), the Hewlett Foundation, the World Bank and the MacArthur Foundation (05-85158-000). The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

The Effects of Mortality on Fertility: Population Dynamics after a Natural Disaster
Jenna Nobles, Elizabeth Frankenberg, and Duncan Thomas
NBER Working Paper No. 20448
September 2014
JEL No. J11,J13,O1

ABSTRACT

Understanding how mortality and fertility are linked is essential to the study of population dynamics. We investigate the fertility response to an unanticipated mortality shock that resulted from the 2004 Indian Ocean tsunami, which killed large shares of the residents of some Indonesian communities but caused no deaths in neighboring communities. Using population-representative multilevel longitudinal data, we identify a behavioral fertility response to mortality exposure, both at the level of a couple and in the broader community. We observe a sustained fertility increase at the aggregate level following the tsunami, which is driven by two behavioral responses to mortality exposure. First, mothers who lost one or more children in the disaster are significantly more likely to bear additional children after the tsunami. This response explains about 13 percent of the aggregate increase in fertility. Second, women without children before the tsunami initiated family-building earlier in communities where tsunami-related mortality rates were higher, indicating that the fertility of these women is an important route to rebuilding the population in the aftermath of a mortality shock. Such community-level effects have received little attention in demographic scholarship.

Jenna Nobles
University of Wisconsin, Madison
1180 Observatory Drive
Madison, WI 53706
jnobles@ssc.wisc.edu

Elizabeth Frankenberg
Sanford School
Duke University
e.frankenberg@duke.edu

Duncan Thomas
Department of Economics
Duke University
Box 90097
Durham, NC 27708
and NBER
d.thomas@duke.edu

INTRODUCTION

A central line of inquiry in population research assesses whether, when and why fertility changes in concert with mortality. Investigators have hypothesized that exposure to mortality shapes fertility intentions and behaviors of an individual or couple through its impact on expectations about the survival prospects of children. A mortality effect may arise because the death of a child causes replacement of the child, or because expectations about future mortality cause hoarding (Preston 1978; Rosenzweig and Schultz 1983; Montgomery and Cohen 1998; Palloni and Rafilamanana 1999).

Demographic theory is less well-suited to describe fertility responses to large-scale mortality events such as war and natural disasters (Hill 2004). To the extent that a one-time event does not change expectations about future child survival, a fertility response to a temporary mortality increase cannot be attributed a hoarding motive.

Instead, it may be that the replacement motive extends beyond those women whose children die and operates through social *groups*, such as extended families, networks or ethnic groups. When mortality shocks are location-specific, the local community is likely to be a salient group in which a broader replacement and rebuilding motive may operate.

To provide empirical evidence on the extent of both individual and community-level mechanisms, we study the effects of mortality exposure on fertility after a large-scale unanticipated natural disaster, the 2004 Indian Ocean tsunami, which killed over 170,000 people in the coastal areas of Aceh and North Sumatra, Indonesia. This work builds on previous studies that document fertility shifts after earthquakes, hurricanes and famines, economic crises, terrorist attacks, war and genocide (e.g., Heuveline and Poch 2007; Agadjanian and Prata 2002; Lindstrom and Berhanu 1999; Caldwell 2004; Finlay 2005 and the review in Lee, 1997).

Using a sample representative of the pre-tsunami population, we document a positive association between exposure to the 2004 tsunami and subsequent fertility at the aggregate level. We provide evidence that the fertility increase can be attributed to *tsunami mortality* and that it is driven primarily by two groups of women. First, mothers who lost a child in the tsunami were significantly more likely to give birth again after the tsunami, relative to mothers whose children survived. These births account for about 13% of the aggregate increase in fertility due to the tsunami. Second, where local area mortality was higher, women who had not borne children before the disaster were also significantly more likely to give birth after the disaster relative to similar women in communities with lower tsunami mortality.

Several features of the disaster provide leverage to address these questions. First, because the force of the water on land varied with topographical and hydrological features, the tsunami's impact on mortality was idiosyncratic even within small areas (Frankenberg et al. 2011; McAdoo et al. 2007; Umitsu et al. 2007). Second, in contrast to deaths from war or famine, tsunami-related mortality occurred almost entirely within a few hours of the precipitating earthquake, making it possible to pinpoint timing. Third, the tsunami was completely unanticipated. Thus, tsunami-related mortality can legitimately be treated as a mortality *shock* at the local area level.

It has been a challenge to establish a causal link between mortality and fertility in previous research, largely because of data constraints. We use data from a rich longitudinal survey conducted in coastal Indonesia that was designed to address this question. The baseline survey of the Study of the Tsunami Aftermath and Recovery (STAR) was collected 10 months before the tsunami and follow-ups were conducted annually for five years after the tsunami. The survey includes detailed pregnancy and birth histories, combined with information about the disaster collected at the individual and community levels. The survey encompasses heavily damaged communities with high mortality (on average about 30% of residents perished in these communities) as well as nearby communities where the direct effects were much more muted. Data from STAR allow us to relate the experience of mortality within the local area to the fertility of women who were living in that area at the time of the tsunami. This empirical approach is more powerful than relying on temporal variation alone.

The research advances understanding of both replacement fertility of individual women and population rebuilding in the context of high-mortality disasters. In recent years, similarly sudden large-scale events have generated significant mortality shocks in Haiti, Myanmar, Japan, China, and India, among others, and are likely to recur given rising population densities in areas increasingly vulnerable to environmental crises (Marshall and Picou 2008; Vos et al. 2010). By drawing direct comparisons between estimated effects at the community level and estimates of replacement at the individual level, the research provides new evidence on the relative importance of these two effects in population dynamics following disaster.

The study proceeds as follows. We begin by describing theoretical and empirical approaches to establishing links between mortality (or events that cause mortality) and fertility. After documenting aggregate trends in mortality and fertility before and after the 2004 tsunami to provide context for the research, we describe the individual-level data in STAR, our methods and empirical results. A discussion concludes.

FERTILITY IN RESPONSE TO MACRO SHOCKS: EVIDENCE

Population scientists have long studied the demographic consequences of large-scale macro shocks. Effects on fertility have been observed at both the aggregate and individual level. War has received the most systematic attention. Several studies have documented significant declines in fertility, either overall or for more- relative to less-affected subgroups during conflicts accompanied by major social upheaval (Lindstrom and Berhanu 1999; Caldwell 2004; Agadjanian and Prata 2002; Blanc 2004; Heuveline and Poch 2007). In some instances the end of the conflict is accompanied by a fertility increase. Caldwell (2004), for example, documents a fall followed by a rise in fertility for Russia, Spain, and Germany in the context of major disruptions before the 1960s. Famines are characterized by a similar temporal fertility pattern, as evidenced by studies from the Netherlands, China, and Bangladesh (Stein and Susser 1975; Ashton et al. 1984; Watkins and Menken 1985). Isolating proximate mechanisms and disentangling whether fertility increases represent fundamental shifts in fertility desires or simply the realization of deferred reproduction are complicated when the precipitating events occur over multiple years and involve shifting spatial boundaries.

Other research considers spatially and temporally more discreet events such as natural disasters and terrorist attacks. Results are mixed. Using a theoretical framework guided by work in psychology on stress and attachment, Cohan and Cole (2002) analyze rates of marriage, birth, and divorce before and after Hurricane Hugo, in affected and unaffected South Carolina counties. Rates for each of these outcomes rise and then fall, leading the authors to suggest that exposure to a life-threatening event prompted significant actions and measurable changes with respect to close relationships. A similar approach and conclusion is reached with respect to fertility in and around Oklahoma City in conjunction with the 1995 bombing of the federal building (Rodgers et al. 2005). By contrast, despite predictions of a post-September 11th baby boom in the United States (Morin 2002, Scelfo 2002), natality data indicated no such increase (Martin et al. 2003). It is important to note that none of these events have caused large-scale loss of life, and so may provide only limited insights into behavioral responses to the death of a substantial fraction of the population.

Relatively few studies have sought to isolate the impact of large-scale mortality on subsequent fertility. The most comprehensive involves the long-term impact on fertility of excess mortality in Cambodia during the years of Khmer Rouge control (1975-78), when some 25% of the population died as a result of war-related violence and disease (Heuveline 1998; Heuveline and Poch 2007). Using retrospective birth histories collected in 2000 for women (age 15-74) the authors document a sharp decline in the total fertility rate between 1975 and 1978, a near doubling between 1978 and 1980 to levels above the pre-war rate, and then a decline. The period of most dramatic increase occurs shortly after Vietnam took control of the country and the Khmer Rouge-imposed genocide was abruptly halted, leading the authors to conclude that the fertility increase was a response to the high levels of mortality.

Two other studies explore fertility in the aftermath of high-mortality disasters. Finlay (2009), using cross-sectional surveys, considers fertility for three earthquakes, each with death tolls of 15,000 or more. Comparing fertility before and after the earthquake for residents of areas affected by the earthquake with fertility of residents of areas that were not affected reveals greater post-disaster increases in fertility in affected areas. The same approach is adopted, with census data, to examine the impact of the 2003 Bam earthquake in Iran. The authors document a fertility decline in 2004, followed by a rise in 2005-2007 (Hosseini-Chavoshi and Abassi-Shavazi 2013).

FERTILITY IN RESPONSE TO MORTALITY: THEORY

A considerable body of theoretical work posits that fertility levels are in part a response to mortality levels in the broader community and to couples' own experience of child mortality. These ideas have roots in demographic transition theory, as well as in theories from psychology, sociology and economics.

Fertility in Response to Mortality Outside of the Family

The most explicit theoretical link between child mortality occurring outside of the family and fertility decisions—or what Preston (1978) referred to as "extrafamilial effects"—involves the concept of "insurance" fertility, whereby parents bear more children than they ultimately want to have in anticipation that some will not survive (Preston 1978; Cain, 1981; Montgomery and Cohen 1998; Rosenzweig and Schultz, 1983). A few studies have linked fertility timing to declines in child mortality at the level of the village (Atella and Rosati 2000; LeGrand et al. 2003) or the social network (Sandberg 2006). Of course, insurance effects are irrelevant for disasters unless the event shifts expectations about child survival over the longer term and causes parents to produce "extra" children.[1]

Mortality outside the family might affect fertility through other avenues as well. One mechanism may work through risk-sharing at the level of the community or ethnic group, as has been described in some agricultural settings (see Geertz 1968, Townsend 1994, Grimard 1997, Suri 2003, Conning and Udry 2007). If community members benefit from the next *generation* of children, a collective fertility increase might arise in response to child mortality at the community level.

[1] As an example of a shift in perceptions occurring in the context of mortality *increase,* Trinitapoli and Yeatman (2011) observe an association between uncertainty about survival driven by the AIDS epidemic in Malawi and the desired timing of fertility initiation among adolescents.

Though demographers have emphasized ties between child mortality and fertility, the literature on resilience in psychology suggests a different motivation for the links between fertility and mortality more generally. Specifically, the experience of mortality may shift preferences towards goals with intrinsic meaning, such as interpersonal connection and community development rather than extrinsic goals, such as amassing wealth and status (Vail et al. 2012). The logic suggests that, among other things, a renewed investment in family will emerge in response to an awareness of human frailty (Fritsche et al. 2007, Nakonezny, Reddick, and Rodgers 2004).

Related research views fertility as taking on symbolic meaning in the aftermath of population trauma. When crises disrupt individuals' perceptions of the world as ordered and reliable, births represent renewal and a "return to normal" (e.g. Carta et al. 2012; Rodgers et al. 2005; Norris et al. 2002). Other scholarship describes the pronatalist sentiment emerging from mortality shocks that disproportionately affect (or target) certain ethnic groups (Borneman 2002; Jansen and Helms 2009) or hypothesize its existence in settings where a substantial fraction of the population has perished (Heuveline and Poch 2007).

Behavioral fertility responses to contextual mortality shocks are likely to vary by women's fertility goals, parity, and the age composition of surviving children. Women who are childless or at lower parities will on average desire more children, and *ceteris paribus*, will exhibit stronger behavioral fertility response to mortality shocks.

Of course, births in the months following a macro shock may be reduced because of miscarriage. A mortality shock may lower population fertility over the longer term through other avenues as well. Witnessing the deaths of family and friends may induce psychopathologies (Norris et al. 2002; Neria, Nandi, & Galea 2008). These may reduce the desire for children, coital frequency, relationship quality, and women's physiological capacity to carry a child to term (Segraves 1998; Parker and Douglas 2010; Nakamura, Sheps, and Arck 2008). How and when the psychological response to mortality produces family building rather than family disruption is not well understood (Cohan 2010).

Fertility in Response to Mortality of own Children

Though theory supports a role for contextual effects of mortality, many studies have focused on whether the event of an "own child" death prompts a couple to conceive again, so that the child who died is "replaced" by one that would not otherwise have been born. Preston (1978) lays out the pathways of individual replacement behavior. Replacement may arise as an artifact of physiology: a child death can increase fertility simply because a woman stops breastfeeding and resumes menstruating. Alternatively, after the death of a child, couples may intentionally try to conceive.

Micro-level research documents these phenomena, finding that both physiologically-induced and volitional replacement operate in various contexts, but that neither exhibits large population-level impacts on fertility (Montgomery and Cohen 1988; Frankenberg 1998; Kuate Defo 1998; Grummer-Strawn, Stupp and Mei 1998; Rosero-Bixby 1998; Palloni and Rafalimanana 1999; Hossain et al. 2007). This literature considers settings where child mortality levels are relatively stable and volitional replacement is a response to an event about which parents can form reasonable expectations—an orientation with origins in demographic transition theory. As a result, bias from omitted variables or endogeneity is an oft-referenced issue (Palloni and Rafalimanana 1999).

Studies of unanticipated disasters help put these concerns aside, but for relatively few high-mortality disasters are individual-level studies possible. The 2008 Wenchuan earthquake in Sichuan, China is an exception. Thousands of parents lost their only child. In response, the state sponsored fertility programs, which helped a number of women to explicitly "replace" the child that perished (Qin et al. 2009; Pinghui 2013).

The Indian Ocean tsunami provides a similarly powerful context in which to study both "replacement" fertility and a potential response to mortality within the community. The longitudinal data supports estimation of whether a woman who lost a child in the tsunami subsequently bore another child, which speaks directly to the question of an individual response.

Moreover, STAR provides evidence on the relationship local area tsunami mortality and subsequent fertility among residents of the area at the time of the tsunami, and thereby allows us to contrast the relative importance of extra- and intra-family responses to a large-scale mortality shock.

MORTALITY AND FERTILITY DURING THE 2004 TSUNAMI

The 2004 Indian Ocean tsunami was exceptional in magnitude and scope. On the 26th of December an earthquake measuring 9.3 on the Richter scale displaced a trillion tons of water. The resulting tsunami slammed into the Indonesian coastline, reaching some areas as little as 15 minutes after the earthquake. Aceh and North Sumatra were the provinces hardest hit. In some areas of Aceh, water heights exceeded 15 meters (Umitsu 2011, pp 54,58) and the water travelled inland via riverbeds for as much as 6 kilometers. About 170,000 people died and over 500,000 were displaced, losing their homes and livelihoods (Doocy et al. 2007, Athukorala and Resosudarmo 2005, Gray et al, 2014).

The magnitude of the tsunami's overall impact masks considerable spatial variation, arising from the idiosyncrasies of coastal topography that shaped variation in the waves' force and extent of inundation (McAdoo et al. 2007; Ramakrishnan 2005; Umitsu et al. 2007). Neighboring communities experienced markedly different degrees of damage as a function of elevation and orientation relative to the shoreline. STAR is designed to capture this heterogeneity.

For the purposes of assessing the impact of mortality on subsequent fertility, we analyze data from communities that experienced substantial tsunami mortality and communities *from the same districts (kabupaten)* that did not. Communities are excluded from our sample if no area in the district was affected by tsunami mortality, yielding a sample in which comparison areas (no tsunami-related mortality) are close enough geographically to be similar to areas that sustained tsunami-related mortality.

Data from the first follow up wave of STAR regarding survival status of survey respondents provides our primary source of information for classifying communities. Survival status was ascertained by identifying an individual who was a household member at the baseline survey and could confirm other members' survival statuses. If no original household member could be located, death information was derived from interviews with multiple people who were living in the community at baseline and by cross-checking rosters of the dead maintained in the community. Mortality status was determined for 97.4 of the STAR sample. Other sources of information are used to cross-validate community classifications, including questions to community leaders on tsunami deaths, water inundation, and destruction, damage observations of survey supervisors, and levels of exposure to the tsunami reported by residents. A community is classified as mortality-affected if one or more STAR respondents died because of the tsunami, unless the number of deaths is very small and no other corroborating evidence suggests that the tsunami acted with any force on the community.[2]

Table 1 presents descriptive statistics on the tsunami's impact, estimated separately for communities directly affected by tsunami mortality and for comparison communities from the same districts. As they should be, differences in the mortality rates are stark. In mortality-affected communities the tsunami killed 29% of the population. In the communities with no tsunami-related mortality, about half a percent died. Within the mortality-affected communities rates vary by demographic group. About one-third of children under five and one-third of reproductive age women perished, whereas among prime-age men the rate is 19%.

The next rows focus on destruction to the built and natural environment, using two approaches. The first is based on satellite imagery before and after the disaster. Gillespie et al (2007), using images from NASA's MODIS sensor taken on December 17, 2004 and December 29, 2004, developed a measure of destruction to ground cover for a small area surrounding each of the center points of the communities surveyed in STAR (based on GPS). In the mortality-affected communities, the average number of pixels indicating complete destruction of ground cover is 5 (out of 9), but it is less than one in communities not affected by mortality. Our second approach relies on reports by village leaders about particular types of destruction. Damage to roads,

[2] In these cases, deaths are thought to have arisen as a result of residents having been elsewhere during the tsunami.

contaminated water, and problems with debris are all more common in mortality-affected communities (affecting about two thirds of the communities), but they occur in non-mortality communities as well, where rates range from 12-21% across the indicators.

Finally, community leaders were asked how life had changed in the year after the tsunami. For the mortality-affected communities 73% of leaders report a downturn in quality of life, and fully 21% of them explicitly mention population loss as a problem (price increases and reductions in economic opportunity are other common responses). In the communities unaffected by mortality, about one third of leaders felt that life became worse. Population loss is not the problem, but rising food prices and fewer jobs and business opportunities are.

In combination, these indicators capture an important aspect of the tsunami. Although mortality and the most devastating physical destruction were concentrated in a subset of communities along the west coast, the geographical reach of disruption is much broader. Our comparison communities are affected by the disaster, but not by the mortality it caused.

We turn now to macro-level evidence of fertility change. To document patterns of fertility before and after the disaster, we calculate age-specific probabilities of live birth for each quarter-year between 2000 and 2009 for reproductive-age women interviewed in the baseline survey.[3] The rates pertain to the period before the tsunami, January 2000-December 2004, and to the period after the tsunami, January 2006-December 2009. We exclude births in 2005 because fertility during most of that year will not be attributable to behavioral decisions made in response to the disaster (and was complicated by miscarriages after the tsunami) (Hamoudi et al. 2014).

Figure 1 displays these rates, stratified by period and mortality zone (dashed red lines indicate communities experiencing tsunami mortality). For the 2000-2004 period the estimated total fertility rates are 2.18 and 2.74 in the areas with and without tsunami-related mortality, respectively. After the tsunami, fertility rates by zone change in opposite directions. In the mortality-affected communities, fertility increases, particularly for women 20-34, and the overall

[3] For each quarter-year, each woman who is alive and aged 15-49 contributes an observation; the pooled data include 176,862 observations for 6,363 women. The sample includes all age-eligible women who were interviewed in the pre-tsunami baseline survey and therefore represent the pre-tsunami population.

rates in 2006-2009 are 2.67 and 2.52 in the mortality-affected versus comparison communities. The difference between the increase in the mortality-affected communities and the decrease in communities that did not experience tsunami-related mortality is 0.71 which is statistically significant at 5% size of test. (The bootstrapped standard error is 0.21.[4]) The "difference-in-difference" for the underlying ages (displayed in the inset table) confirms that the largest changes in mortality-affected communities occur for women between the ages of 20 and 34.

At the population level, a 0.7 increase in TFR for the four year period after the tsunami constitutes a large effect. Similar magnitudes are reported by Finlay (2009), who identifies an effect of roughly a fifth of a child ever-born per woman, observed one year and four years after major earthquakes in Pakistan and Turkey, respectively. By comparison, the birth increase attributed to the Oklahoma City bombing was less than one birth per thousand women over the three years after the event (Rodgers et al. 2005).

To what extent can the change in fertility be attributed to a response to mortality? Couples who lost children may want to replace them. But mortality *outside* the family may also influence reproductive choices. Theory suggests the strongest response to mortality is likely to occur within units of social salience for respondents. Because the impact of the tsunami was location-specific and because the community (*desa* or *kelurahan*) is highly salient in Indonesian society, we focus on responses to community-level mortality.

METHODS

Empirical issues in linking mortality and fertility

Establishing a causal effect of mortality on fertility poses several challenges. Detailed data on the timing and locations of births and deaths of children are essential, but may not be sufficient to disentangle associations that reflect micro- versus macro-level forces (Guha-Sapir and Below 2006; Montgomery and Cohen 1998; Palloni and Rafalimanana 1999; Sandberg 2006). Perhaps most problematic, deaths are typically not random events. The antecedents of

[4] Standard errors are estimated by bootstrapping the sample using 10,000 replications (Efron and Tibshirani 1994).

mortality–economic conditions, health endowments, and the health-service environment–are also typically correlated with fertility (Olsen 1980). Moreover, reverse causality poses difficulties because birth spacing and parity affect infant mortality (e.g., Palloni and Tienda 1986). Without adjustments for these processes, associations between mortality and fertility are likely upwardly biased.

Some of these challenges can be addressed by examining fertility in the context of mortality shocks. The timing, location, and magnitude of some disasters are unexpected and can be located precisely in time and space. As a result, the behavior preceding and following the disaster is easier to distinguish and attribute to unexpected mortality. Some disasters occur idiosyncratically, which reduces the likelihood that child deaths are correlated with factors associated with prior fertility choices and outcomes. When the precipitating event is unexpected and short-lived, fertility changes are unlikely to reflect tempo effects of fertility delays.

Apart from Heuveline and Poch (2007; studying the Khmer Rouge), no other analysis of fertility in the wake of humanitarian crisis explicitly ascribe fertility changes to the *mortality* generated by these events. Several difficulties hamper doing so. In the context of disaster, facets of family and community life other than mortality change rapidly as well. Because these may also influence fertility, it is difficult to attribute a fertility response to the death of a child rather than some other contemporaneous process such as loss of livelihoods, dependence on government aid or reduced contraceptive access (Hapsari et al. 2009, Hill 2004). In addition, data on the same population before and after exposure to the disaster are rare.

Our study develops an empirical strategy that capitalizes on the longitudinal and multi-level nature of the STAR data. We analyze the fertility of individual women in STAR with information collected in both the pre-tsunami baseline and five annual post-tsunami survey rounds. Each post-tsunami survey provides detailed information about the mortality of household members since the pre-tsunami baseline. The most detailed information on fertility comes from complete pregnancy histories asked of reproductive-age women in the second follow-up round, with updates in each subsequent round. For pregnancies ending in live births, each child's survival status is updated at the time of the interview. Information on date and age of death is available for each child who died, along with whether the death was related to the tsunami.

Recontact rates in STAR are high. Among reproductive-age women who survived the tsunami, 93% were surveyed in the 2010-2011 follow-up (STARF), and the rates are similar for women regardless of whether or not their community was affected by tsunami mortality in spite of the high level of devastation and dislocation caused by the tsunami.

Response to death of own children.

We begin with the question of how the death of a child affects the mother's fertility. Detailed fertility histories collected in the second post-tsunami follow-up along with any updates collected in each of the three subsequent waves are used to create a dichotomous indicator, B_{ic}, for whether a mother *i* who was living in community *c* at the time of the tsunami had at least one live birth between January 1, 2006 and December 31, 2009.[5] In order to compare the post-tsunami fertility of mothers who lost a child with the fertility of mothers who did not, the model includes an indicator variable M_{ic} which takes the value 1 if the mother lost at least one child in the tsunami and zero otherwise.

$$B_{ic} = \gamma_0 + \gamma_1 M_{ic} + \gamma_2 X_{ic} + \nu_c \qquad [1]$$

In each model, the woman's characteristics, X_{ic}, include factors likely to predict both fertility and *vulnerability* to child mortality in the context of the disaster. These are measured *before* the disaster using the baseline, pre-tsunami survey and include women's parity, age (specified with a piecewise linear spline with knots at 5 year intervals), and education (measured with dichotomous indicators capturing completion of junior high and completion of high school). To control for individual experiences in the disaster, we include an indicator of whether the respondent was swept up in the water or saw family or friends struggle or disappear in the water.

[5] While the data are designed to support analysis of fertility timing using, for example, an event-history approach, the main goal of this research is to measure the extent to which there has been successful population rebuilding five years after the tsunami which is provided by an estimate of γ_1 in model [1].

As in many societies, fertility in the region is patterned by socioeconomic status. For this reason, we also include household per capita expenditure and indicators of home ownership and land ownership (all measured in 2004, before the disaster).

Means of the key variables related to fertility, child mortality, and exposure to the tsunami are provided in Panel A of Table 2. The first column aggregates women regardless of child mortality experience. Subsequent columns present the differences in these variables for women who lost a child relative to those who did not. Overall, among the 2,301 women who were mothers at the time of the tsunami, just over 5% lost a child during the disaster and just over 10% of women were exposed to the tsunami waves. Exposure rates are much higher for women who lost a child in the tsunami than for those who did not. Overall a little less than a third of women gave birth to another child after the tsunami. While the rate is higher for those who lost a child, relative to those who did not, the difference is not statistically significant. With respect to other demographic and socioeconomic features (prior fertility, age, and education), women who lost a child are no different from women whose children survived. These results are consistent with the idea that, apart from losing a child as a result of the disaster, our two groups of women are largely similar.

Some community-level aspects of the tsunami such as loss of natural resources and sources of livelihood have the potential to affect subsequent fertility. If these factors are also correlated with whether women lost children, failure to include them will bias estimates of M_{ic}. To address this concern, we estimate a model taking into account all community-level characteristics that are fixed during the post-tsunami study period, 2006-2009, and affect post-tsunami fertility in a linear and additive way:

$$B_{ic} = \gamma_0 + \gamma_1 M_{ic} + \gamma_2 X_{ic} + \mu_c + \upsilon_{ic} \quad [2]$$

In this specification, μ_c is a community-level fixed effect that absorbs community-level tsunami impacts and pre-tsunami resources.

A concern that has received considerable attention in the literature is whether an observed fertility response after a child's death arises because of a conscious (a volitional effect) or inadvertently via increased fecundability after breastfeeding stops (a physiological effect). To investigate this question we consider two additional pieces of evidence.

First, we assess whether deaths of children who have aged out of the period when children are typically breastfed predicts subsequent fertility. The median duration of any breastfeeding is about 20 months, but supplements are typically introduced within a few months of birth (CBS 2008). Children two and older are not breastfed enough to prevent ovulation in their mothers. We extend Model [2] by replacing the indicator of child death (M_{ic}) with two indicator variables that capture, first, the loss of a child who was under the age of two (<1% of women) and, second, the loss *only* of children two and older (4% of women). A positive coefficient on the indicator of at least one death to a child under two may arise either because of a physiological response to the cessation of breastfeeding or intentional behaviors to increase family size. By contrast, a positive coefficient on the indicator of death(s) of only older children is almost certainly *not* working through breastfeeding behavior.

Our second approach adds an interaction between the loss of a child and an indicator that a woman's parity exceeded two children at the time of the disaster. Previous research predicts a more muted response to child death among higher parity women who may have already exceeded their desired family size.

Finally, to explore variation by socioeconomic status, we interact loss of a child with whether the mother completed high school. In all the empirical models, standard errors take into account clustering at the community level (as well as arbitrary forms of heteroskedasticity, Huber, 1967).

Relationship between community-level mortality and post-tsunami fertility

We turn next to the association between post-tsunami fertility and community-level mortality. An association between fertility and exposure to mortality at the community level is likely to mask substantial heterogeneity in responses across women. As noted above, the relationship may differ for mothers who experienced at least one child death relative to those mothers who did not. In addition, the fertility-mortality relationship likely varies with parity. Our model is specified as follows:

$$B_{ic} = \beta_0 + \beta_1 M_c D_{ic} + \beta_2 M_c N_{ic} + \beta_3 X_{ic} + \mu_c + \zeta_{ic} \quad [3]$$

As before, M indicates exposure to mortality, but here M_c is a community mortality rate, measured as the percentage of STAR respondents killed by the tsunami. D_{ic} is an indicator variable for women who experienced the death of at least one child in the tsunami and N_{ic} is an indicator for women who had not borne a child at the time of the tsunami. Estimates of β_1 and β_2 measure the differential effect of variation in community-level mortality on each of these two groups of women relative to the excluded group, women whose children survived the tsunami. Assuming there are no unmeasured characteristics that are correlated with unobserved heterogeneity, ζ_{ic}, estimates in [3] can be given a causal interpretation.

In the model, comparisons are drawn between women who were living in the same community at the time of the tsunami and so the women are likely to have much in common. However, their own experience of the tsunami differed, at least for those who lost a child. Our estimates attempt to take this into account and we interpret β_1 as measuring the difference between the impact of a higher level of community mortality and a lower level of community mortality on the post-tsunami fertility of mothers who lost a child relative to those who did not. A parallel comparison is drawn for β_2 which measures the impact of different exposures to community-level mortality between women who had not yet borne a child at the time of the tsunami and women who were already mothers but did not lose a child.

For these models, the sample of mothers is supplemented with women with no previous births at the time of the tsunami (total N=3,936 women). Characteristics of the sample are summarized in Panel B of Table 2.[6] Overall, about 4% of the population was killed in the tsunami. The sample of all women is similar to the sample of mothers with respect to exposure to the tsunami and post-tsunami fertility. Parity at the tsunami and exposure to child mortality before

[6] The number of communities is smaller than shown in Table 1 because the analysis is conditioned on women of reproductive age *surviving* the disaster and being in interviewed in follow-up surveys.

the tsunami are a little lower, and the sample is younger and a little better educated, as one would expect with the addition of woman who had not yet had children. With respect to the differences in women from mortality-affected versus mortality-unaffected communities, women in the mortality-affected communities were more likely to have been exposed to the tsunami, and are more likely to have completed a high school education (for which we will control), but are otherwise similar.

RESULTS

The Effect of Own-Child Death on Maternal Fertility

Evidence of a behavioral fertility response to the death of a child is explored with models [1] and [2]. Table 3 displays linear probability estimates of a birth between 2006 and 2009 for women with at least one pre-tsunami birth. The first column presents OLS results; column 2 provides estimates from a model that includes community fixed effects. Conceptually, the fixed effects model comparisons are drawn between mothers who were living in the same community at the tsunami, one of whom lost a child and the other did not (controlling the characteristics X_{ic} in the table).

As shown in column [1], mothers who lost at least one child are 6 percentage points more likely to have an additional birth in the post-tsunami period. The effect is not statistically significant. With inclusion of community fixed effects, mothers who lost at least one child are 14 percentage points more likely to have an additional birth in the post-tsunami period—an effect that is statistically significant. A Hausman test rejects the hypothesis that the OLS and FE models are equivalent (χ^2=34.54, p value<0.01). Given that 27 percent of women in the sample had an additional birth, the 0.10 effect represents about a 37% increase in the probability of an additional birth associated with death of one's own child. If one measures own child mortality as the number of children that died (column 3), the effect, 0.07, is further evidence of a strong fertility response to child death.

Interpreting these results with respect to theory or women's welfare depends in part on whether the pattern represents volitional behavior. Column 4 presents the results from a specification that includes indicators distinguishing death of a young child from deaths only of children two and older. The coefficient for losing only older children, at a statistically significant 0.098, is nearly as large as the result for losing any children in Column 2. For women who lost a child under two, the coefficient is 0.094 and is not statistically significant. Given these results, breastfeeding cessation cannot be the sole explanation for the pattern in column 2 suggesting that intentional replacement plays a role.

Comparisons are also drawn between lower parity (3 or less) and higher parity (>3) mothers (column 5). Women at lower parities are 11 percentage points more likely to have an additional birth after losing a child than women who did not lose a child. The gap for higher parity mothers is just over half the size (6.6 percentage points) and not statistically significant. All evidence, then, indicates *volitional* replacement behavior by mothers whose child(ren) died during the tsunami.

The last column in the table considers whether the strength of the response to own child death varies by womens' educational level—specifically whether women completed high school. The coefficients on death of a child are 0.153 for women who did not graduate and 0.086 for women who did. The former is statistically significant; the difference between the estimates is not.

The Fertility Effects of Mortality in the Community

We turn now to the models for response to the level of tsunami mortality within the community. Because this question is relevant for women with and without children, we add childless women to the sample. Our models distinguish both women without children and mothers who lost a child, relative to the omitted group of mothers whose children all survived the tsunami.

Results from model [3] using a linear probability specification are presented in Table 4. Estimates of the coefficient on mortality at the community-level for mothers who lost at least one child are reported in the first row of the table. Estimates for women with no children before the tsunami are in the second row of the table. As before, standard errors take into account clustering of the sample and heteroskedasticity of arbitrary form; all models include the individual controls listed in the table.

Both for women who lost a child and for women without children at the time of tsunami, the effects of the level of community mortality on bearing a child after the tsunami are strong and positive, and they are identical in size. For each additional one percentage point increase in the population killed, mothers who lost at least one child are 0.460 percentage points more likely to have a birth after the tsunami than other mothers. For women who had not borne a child at the time of the tsunami the estimate is 0.468 relative to mothers who did not lose a child.

The results are striking. In the absence of community mortality, women without children before the tsunami are significantly less likely to have a child between 2006-2009 than are mothers whose children survived, and mothers who lost a child are no more likely to reproduce than women whose children survived. But in communities with higher levels of mortality, both groups of women have appreciably higher fertility.

Additional columns explore whether the community mortality effects are stronger for particular subgroups of women. Results are stratified by parity in columns 2 and 3. For mothers who lost at least one child, a strong fertility response is observed only among those with fewer than three children. For these women the coefficient is 0.578, versus 0.056 for women of parity three and higher. Column 4 presents estimates for women who were age 25 to 34 at the time of the tsunami. Women in this age range who were childless pre-tsunami have an especially strong fertility response to higher rates of mortality in the community. Each one percentage-point increase in mortality is accompanied by an increase of 1.2 percentage points in the probability of a birth. Finally, by schooling attainment, women who completed high school have a stronger fertility response to community mortality than women with less education, particularly for women who lost a child. For these women the coefficient is 1.077 for high school graduates, relative to 0.204 for those without a degree.

The final column tests the sensitivity of the central result to substituting the fraction of the community's children that perished for the fraction of the total population that died. Results do not change substantially, which is not surprising given that the correlation in child and total death rates is over 0.9.

DISCUSSION

Mortality shocks arising from natural disasters are not unusual. Worldwide, between 2000 and 2010, 1 in 28 people were affected by some form of mortality-inducing disaster arising from natural hazards (Guha-Sapir and Hoyois 2012). Studying fertility in the wake of these events sheds light on fundamental aspects of population rebuilding and provides a new lens through which to consider the relationship between mortality and fertility.

We document a large increase in fertility after the 2004 Indian Ocean tsunami that is concentrated in communities where mortality from the tsunami was high. In these areas, during the second half of the 2000-2009 decade, total fertility was nearly half of a birth higher per woman than would have been expected in the absence of the tsunami.

We find evidence of a statistically significant increase in fertility among women who lost one or more children. The results are consistent with a volitional effort to increase fertility in response to the deaths of one's children. However, the effect is estimated to be only about 0.10 additional births, which does not come close to replacing the children these mothers lost, let alone accounting for the large increase in the total fertility rate after the tsunami. What explains these additional births?

Over and above evidence of partial replacement after the death of one's own child, we also find a powerful effect of mortality at the community level on subsequent fertility. These effects are largest among mothers who lost a child in the tsunami and among women who had not borne a child at the time of the tsunami, and are very similar in magnitude for both groups of women, amounting to almost 0.5 additional births for each additional one percentage point increase in mortality in the community. For women who lost a child, the estimate reflects both the impact of that death and the death of children in the community. For women who had not borne a child, the 0.5 additional births reflects the impact of community-level mortality. With additional waves of STAR it will be possible to determine whether this pattern reflects accelerated timing of births or results in larger completed family sizes.

Based on the fixed effects estimates in column 1 of Table 4, we estimate there were 9,500 more births between 2006 and 2009 in the study area than would have occurred in the absence of tsunami-related mortality. Of those births, 13% occur to mothers who lost at least one child in the tsunami and 87% occur to women who had not borne a child prior to the tsunami.

The estimated effects are not likely to reflect a motivation of "hoarding" or "insurance" as traditionally theorized in demographic transition literature. A tsunami of this magnitude had not affected mainland Aceh for five centuries, and it is unlikely that most women expected an event of this magnitude to occur again.

Instead, the disaster may have increased broad pronatalist sentiment and a desire to "rebuild" communities. Women without children at the time of the disaster would be expected to respond more readily to this kind of sentiment, and the response might be magnified in closely-knit communities that share strong kin ties. In that case, community members may have sped up family building to replace the *villages*' lost children.

Entrance into new unions is also part of the story. Marriage is nearly universal in Aceh and marriage and childbearing are tightly connected. Births outside of marriage are nearly non-existent. Because men were more likely to survive the disaster and more likely to re-partner in its wake, some new unions with younger women were formed (Burrows et al. 2011). But it does not follow that that the new births are an accidental afterthought of the new unions. Instead, these new unions were almost certainly generated with the intent of childbearing. In this context, intentions related to union formation and childbearing cannot be cleanly separated.

Thus, the fertility increases observed after the disaster likely arose from multiple mechanisms operating simultaneously. For childless women, a desire to contribute to rebuilding families and communities through reproduction may have increased fertility. For mothers who suffered the death of children, the desire to have another child in the aftermath of a child loss raised fertility.

Our study provides a complementary lens on questions central to the study of population dynamics. Importantly, we do not directly address some of the hypotheses in the earlier demographic transition literature linking mortality and fertility *decline*. The fertility effects of mortality increase and mortality decrease are likely asymmetric for a number of reasons, including differences in how increases and decreases in mortality are perceived (e.g., Montgomery 2000).

Instead, the contributions of this study include the use of several design elements to ensure that the measured fertility changes arise at least partially in *response* to the loss of children and to the loss of community members. Using data from a population-representative sample established before the disaster and following those respondents, including movers, over time mitigates legitimate concerns about sample-selection bias. In addition to taking into account individual and community attributes measured before the disaster that likely capture pre-existing vulnerability to mortality (and may be correlated with fertility behavior), we estimate models that include community fixed effects and draw comparisons between women living in the same community. We thereby reduce the chance that our estimates are contaminated by unobserved heterogeneity. Adjusting for exposure and including community fixed effects reduces the likelihood that we are measuring a fertility response to other changes occurring in the context of the disaster—and are instead measuring a response to the loss of a child and exposure to mortality in communities.

The disaster effects observed here (Figure 1) are quite large in comparison with events like Hurricane Hugo, the September 11th attacks, and the Oklahoma City bombing. Instead they more closely align with the events such as the high mortality earthquakes in Iran (Finlay 2009; Hosseini-Chavoshi and Abbasi-Shavazi 2013). One clear difference between events in the United States and earthquakes is the magnitude of the accompanying mortality increase. This explanation is consistent with the evidence presented here that the mortality shock *itself* had a sizeable influence on fertility in damaged communities. By contrast, the aggregate effect on fertility is substantially smaller than observed after the mortality increases accompanying the reign of the Khmer Rouge in Cambodia (Heuveline and Poch 2007), or after World War II in Western Europe. Among other things, war-related crises tend to last longer; it may be that periods of conflict often generate delayed fertility, whereas natural hazards support a much smaller tempo effect.

Evidence from the Cambodian population suggests that a tempo effect may have been operating in tandem with some of the other contextual mechanisms we have identified as potentially relevant for the post-tsunami Acehnese. As in Aceh, part of the fertility boom in Cambodia is attributable to women who were young and likely nulliparous at the time of the Cambodian genocide (Heuveline and Poch 2007).

A further distinguishing factor of the 2004 tsunami for the Indonesian population is the differential mortality for adult women relative to men (Frankenberg et al. 2011). If the fertility response to death emerges in part through family building—a phenomenon noted as early as Eversley's (1957) study of 18th century England—the effects observed here will be more relevant to mortality shocks that, through direct or indirect means, influence entrance into new unions.

Looking ahead, it will be important to understand the long-term impact of the tsunami on Indonesian families. A five-year follow-up post-disaster is unusually long in length. It is possible to assess the extent to which families of older women look markedly different as they age out of their reproductive years than they did prior to the disaster. For younger women, we cannot yet assess whether the increase in fertility observed from 2006-2009 translates into larger completed family sizes or simply reflects a shift in fertility timing, but answers to this question will emerge as additional data are collected.

REFERENCES

Agadjanian, V. & N. Prata. (2002). War, peace, and fertility in Angola. *Demography* 39(2): 215-231.

Ashton, B., K. Hill, A. Piazza, & R. Zeitz. (1984). Famine in China, 1958-61. *Population and Development Review* 10(4):613-645.

Athukorala, P-C. & B.P. Resosudarmo. The Indian Ocean Tsunami: economic impact, disaster management, and lessons. *Asian Economic Papers* 4(1):1-39.

Atella, V. & Rosati, F.C. (2000). Uncertainty about children's survival and fertility: a test using Indian microdata. *Journal of Population Economics* 13:263-278.

Blanc A. (2004). The Role of Conflict in the Rapid Fertility Decline in Eritrea and Prospects for the Future. *Studies in Family Planning* 35(4):236-245.

Borneman, J. (2002). Reconciliation after Ethnic Cleansing: Listening, Retribution, Affiliation. *Public Culture* 14(2): 281-384.

Burrows, M., E. Frankenberg, P. Katz, B. Sikoki, & D. Thomas. (2012). Family formation in Indonesia after the 2004 Indian Ocean Tsunami. Population Association of America Meetings.

Cain, M. (1981). "Risk and insurance: Perspectives on fertility and agrarian change in India and Bangladesh." *Population and Development Review*, 9.4:688-702.

Caldwell, J.C. (2004). Social upheaval and fertility decline. *Journal of Family History* 29(4):382-406.

Carta, G., A. D'Alfonso, I. Colagrande, P. Catana, M. Casacchia, F. Patacchiola. (2012). Post-earthquake birth-rate evaluation using the brief cope. *Journal of Maternal-Fetal and Neonatal Medicine* 25(11):2411-2414.

Central Bureau of Statistics (CBS) [Indonesia] and State Ministry of Population/National Family Planning Coordinating Board (NFPCB) and Ministry of Health (MOH) and Macro Intemational Inc. (MI). 2008. *Indonesia Demographic and Health Survey 2007.* Calverton, Maryland: CBS and MI.

Cohan, C.L. & S.W. Cole. (2002). Life Course Transitions and Natural Disaster: Marriage, Birth, and Divorce Following Hurricane Hugo. *Journal of Family Psychology* 16(1): 14-25.

Cohan, C.L. (2010). Family transitions following natural and terrorist disaster: Hurricane Hugo and the September 11 terrorist attack. Pp. 149-164 in *Handbook of Stressful Transitions Across the Lifespan.* (T.W. Miller, ed.). New York: Springer.

Conning, J. & C. Udry. (2007). Rural financial markets in developing countries. Pages 2857-2908 in *Agricultural Development: Farmers, Farm Production and Farm Markets.*

Doocy, Shannon, Yuri Gorokhovich, Gilbert Burnham, Deborah Balk, & Courtland Robinson. (2007). Tsunami Mortality Estimates and Vulnerability Mapping in Aceh, Indonesia. *American Journal of Public Health* 97(S1):S146-S151.

Efron, B. & R.J. Tibshirani. (1994). An Introduction to the Bootstrap. Boca Raton: Taylor and Hall.

Eversley, D.E.C. (1957). A survey of population in an area of Worcestershire from 1660-1850 on the basis of parish records. *Population Studies* 10(3):253-279.

Finlay, J. (2009). Fertility Response to Natural Disasters: The Case of Three High Mortality Earthquakes. Policy Research Working Paper #4338. World Bank.

Frankenberg, E. (1998). The Relationship Between Infant and Child Mortality and Subsequent Fertility in

Indonesia. Pp. 316-338 in *From Death to Birth* (Montgomery and Cohen, eds). Washington DC: National Academy Press.

Frankenberg, E., T. Gillespie, S. Preston, B. Sikoki, & D. Thomas. 2011. Mortality, the Family, and the Indian Ocean Tsunami. *The Economic Journal* 121:F162-182.

Fritsche, I., E. Jonas, P. Fischer, N. Koranyi, N. Berger, B. Fleischmann. (2007). Mortality salience and the desire for offspring. *Journal of Experimental Social Psychology* 43(5):753-762.

Finlay, J.E. (2009). Fertility Response to Natural Disasters: The Case of Three High Mortality Earthquakes. Policy Research Working Paper #4338. World Bank.

Geertz, C. (1968). *Agricultural Involution*. Berkeley: University of California Press.

Gillespie, T., J Chu, E. Frankenberg, & D. Thomas. (2007). Assessment and prediction of natural harzards from satellite imagery. Progress in Physical Geography 31.5:459-70.

Gray, C., E. Frankenberg, T. Gillespie, C. Sumantri, & D. Thomas. (2014). Studying displacement after a disaster using large scale survey methods: Sumatra after the 2004 Tsunami. *Annals of the Association of American Geographers*. 104.3:594-612.

Grimard, F. (1997). Household consumption smoothing through ethnic ties: evidence from Cote d'Ivoire. *Journal of Development Economics* 53(2): 391-422.

Grummer-Strawn, L.M., P. W. Stupp, & Z. Mei. (1998). Effect of a child's death on birth spacing: a cross-national analysis. Pp. 39-73 in *From Death to Birth* (Montgomery and Cohen, eds). Washington DC: National Academy Press.

Guha-Sapir D. & Below R. (2006). Collecting Data on Disaster: Easier Said than Done. Center for Research on the Epidemiology of Disasters Research Paper #221.

Guha-Sapir, D. & P. Hoyois. (2012). Measuring the human and economic impact of disasters. Center for Research on the Epidemiology of Disasters.

Hamoudi, A., E. Frankenberg, C. Sumantri, & D. Thomas. (2014). Impact of the December 2004 Tsunami on Birth Outcomes in Aceh, Indonesia.

Hapsari, E.D., Widyawati, W.A. Nisman, L. Lusmilasari, R. Siswishanto, & H. Matsuo. (2009). "Change in contraceptive methods following the Yogyakarta earthquake and its association with the prevalence of unplanned pregnancy." *Contraception* 79(4): 316-322.

Heuveline, P. (2008). 'Between one and three million': Toward demographic reconstruction of a decade of Cambodian history (1970-79). *Population Studies* 52(1):49-65.

Heuveline, P. & B. Poch (2007). The Phoenix Population: Demographic Crisis and Rebound in Cambodia. *Demography* 44(2): 405-426.

Hill, K. (2004). *War, Humanitarian Crises, Population Displacement, and Fertility: A Review of Evidence*. Washington D.C.: National Resource Council.

Hossain, M.B., J.F. Phillips, & T.K. LeGrand. (2007). The Impact of Childhood Mortality on Fertility in Six Rural Thanas of Bangladesh. *Demography* 44(4):771-784.

Hosseini-Chavoshi, M. & M.J. Abbasi-Shavazi. (2013). Demographic consequences of the 2003 Bam earthquake. International Conference on the Demography of Disasters. Australian National University.

Huber, P. (1967). The Behavior of Maximum Likelihood Estimates under Nonstandard Conditions. *Proceedings of the Firth Berkeley Symposium on Mathematical Statistics and Probability*, 1:221-33.

Jansen, S. & E. Helms. (2009). The White Plague: National-Demographic Rhetoric and its Resonance after the Yugoslav Wars. Pp 219-244 in *Gender Dynamics and Post-Conflict Reconstruction* (Eifler and Seifert, eds). Frankfurt: Peter Land.

Kuate Defo, B. (1998). Fertility Response to Infant and Child Mortality in Africa with Special Reference to Cameroon. Pp 254-315 in *From Death to Birth* (Montgomery and Cohen, eds). Washington DC: National Academy Press.

Lee, R. (1997). Population dynamics: Equilibrium, disequilibrium, and consequences of fluctuations in M. R. Rosenzweig and O. Stark (eds), *Handbook of Population Economics* Volume 1B, Cap 19, 1063-115. Amsterdam: North Holland.

LeGrand, T., T. Koppenhaver, N. Mondain, & S. Randall. (2003). Reassessing the Insurance Effect: A Qualitative Analysis of Fertility Behavior in Senegal and Zimbabwe. *Population and Development Review.* 29(3):375-403.

Lindstrom, D. P. & B. Berhanu. (1999). The Impact of War, Famine, and Economic Decline of Marital Fertility in Ethiopia. *Demography* 36(2):247-261.

Lindstrom, D. P. & Kiros, G-E. (2007). The Impact of Infant and Child Death on Subsequent Fertility in Ethiopia. *Population Research and Policy Review* 26:31-49.

Marshall, B.K. & J.S. Picou. (2008). Postnormal science, precautionary principle, and worst cases: the challenge of twenty-first century catastrophes. *Sociological Inquiry* 78(2):230-247.

Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, & Monson ML. (2003). Births: Final Data for 2002. *National Vital Statistics Report* 52(10). National Center for Health Statistics.

McAdoo, B.G., N. Richardson, & J. Borrero. (2007). Inundation Distances and Run-Up Measurements from ASTER, QuickBird and SRTM Data, Aceh Coast, Indonesia."*International Journal of Remote Sensing* 28(13-14, July 2007):2961-2975.

Montgomery, M. R. & Cohen B., eds. (1998). *From Death to Birth: Mortality Decline and Reproductive Change*. Washington DC: National Academy Press.

Montgomery, M. (2000). Perceiving mortality decline. *Population and Development Review* 26(4):695-819.

Morin, R. (2002). "A 9/11 Baby Boom?" *The Washington Post* 31 March.

Nakamura, K., S. Sheps, & P.C. Arck. (2008). Stress and reproductive failure: past notions, present insights, and future directions. *Journal of Assisted Reproduction and Genetics* 25(2-3):47-62.

Nakonezny, P.A., Reddick, R., & Rodgers, J.L. (2004). Did Divorces Decline After the Oklahoma City Bombing? *Journal of Marriage and Family* 66(1):90-100.

Neria Y, Nandi A, Galea S. 2008. "Post-traumatic Stress Disorder Following Disasters: A Systematic Review." *Psychological Medicine* 38:467-480.

Norris. F.H., M.J. Friedman, P.J. Watson, C.M. Byrne, E. Diaz, & K. Kaniasty (2002). 60,000 Disaster Victims Speak: Part I. An Empirical Review of the Empirical Literature, 1981–2001. *Psychiatry* 65(3):207–39.

Olsen, R.J. (1980). Estimating the Effect of Child Mortality on the Number of Births. *Demography* 17(4):429-443.

Palloni, A. & Rafalimanana, H. (1999). The Effects of Infant Mortality on Fertility Revisited: New Evidence from Latin America. *Demography* 36(1):41-58.

Palloni, A. & Tienda, M. (1986). The Effects of Breastfeeding and Pace of Fertility on Mortality at Early Ages. *Demography* 23(1):31-52.

Parker, V. J. & A. J. Douglas (2010). Stress in early pregnancy: Maternal neuro-endocrine-immune responses and effects. *Journal of Reproductive Immunology 85*(2010), 86–92.

Pinghui, Z. (2013). New births help Sichuan quake victims overcome loss of children. *South China Morning Post.* 7 May.

Portner, C. (2007). Gone with the Wind? Hurricane Risk, Fertility and Education, mimeo.

Preston, S. H. (1978). *The Effects of Infant and Child Mortality on Fertility*. New York: Academic Press.

Qin, L., S. Luo, X. Li, Y. Wang. & S. Li. (2009). Fertility assistance program following the Sichuan earthquake in China. *International Journal of Gynecology & Obstetrics* 104(3):182-183.

Ramakrishnan, D., S. Ghosh, V. Raja, R. Chandran, & A. Jeyram. (2005). Trails of the killer tsunami: a preliminary assessment using satellite remote sensing technique. *Current Science* 88(5):709-711.

Rindfuss, R.R. & Sweet, J.A. (1978). The Pervasiveness of Postwar Fertility Trends in the United States. In K.E. Taeuber, L.L. Bumpass, and J.A. Sweet, (eds): *Social Demography*. New York: Academic Press, 1978.

Rodgers, J.L., C.A. St. John, & R. Coleman. 2005. "Did Fertility Go up after the Oklahoma City Bombing? An Analysis of Births in Metropolitan Counties in Oklahoma. *Demography* 42(4):675-692.

Rosenzweig, M. R. and T. P. Schultz. (1983). Consumer Demand and Household Production: The Relationship between Fertility and Child Mortality. *American Economic Review*, 73.2:38-42.

Rosero-Bixby, L. (1998). Child mortality and the fertility transition: aggregated and multilevel evidence from Costa Rica. Pp. 384-410 in *From Death to Birth* (Montgomery and Cohen, eds). Washington DC: National Academy Press.

Sandberg, J. (2006). Infant mortality, social networks, and subsequent fertility. *American Sociological Review* 71(2):288-309.

Segraves RT. 1998. "Psychiatric Illness and Sexual Function." *International Journal of Impotence Research* 10: S131-33.

Scelfo, J. 2002 "A 9-11 Baby Boomlet." *Newsweek.* 3 June.

Smith, S.K. & C. McCarty. 1996. Demographic Effects of Natural Disasters: A Case Study of Hurricane Andrew. *Demography* 33(2):265-275.

Solomon, S., J. Greenberg, & T. Pyszczynski. 2000. Pride and Prejudice: Fear of Death and Social Behavior. *Current Directions in Psychological Research* 9:200-204.

Stein, Z. & M. Susser. (1975). Fertility, fecundity, famine: food rations in the Dutch Famine 1944/5 have a causal relation to fertility, and probably to fecundity. *Human Biology* 47(1):131-154.

Suri, T. (2003). "Spillovers in village consumption: Testing the extent of partial insurance", Department of Economics, Yale University.

Townsend, R.M. (1994). Risk and Insurance in Village India. *Econometrica* 62(3): 539-591.

Trinitapoli, J. & S. Yeatman. (2011). Uncertainty and fertility in a generalized AIDS epidemic. *American Sociological Review* 76(7):935-954.

Umitsu, Masatomo, Charlchai Tanavud, & Boonrak Patanakanog. (2007). Effects of Landforms on Tsunami Flow in the Plains of Banda Aceh, Indonesia, and Nam Khem, Thailand. *Marine Geology* 242(2007):141-153.

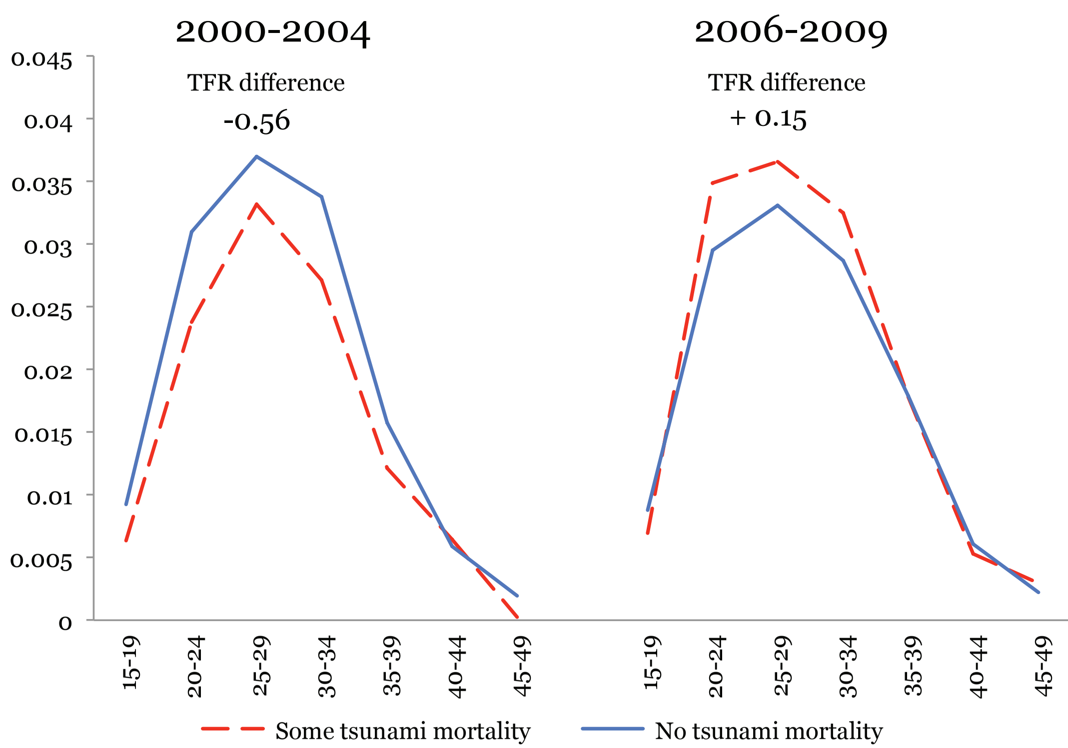
Umitsu, M. (2011). The geoenvironment and the giant tsunami disaster in the Northern part of Sumatra Island, Indonesia. Pp 51-64 in *The Indian Ocean Tsunami* (P.P.Karan & S.P.Subbiah, Eds). Lexington: University Press of Kentucky.

Vail, K.E., Juhl, J., Arndt, J., Vess, M., Routledge, C., Rutjens, B.T. (2012). When Death is Good for Life: Considering the Positive Trajectories of Terror Management. *Personality and Social Psychology Review* 16(4):303-329.

Vos, Femke, Jose Rodriguez, Regina Below, & D. Guha-Supir. (2010). Annual Disaster Statistical Review 2009". Centre for Research on the Epidemiology of Disasters (CRED).

Watkins, S. & J. Menken. (1985). Famines in historical perspective. *Population and Development Review* 11(4):647-675.

Figure 1. ASFR and TFR Differences by Period and Presence of Tsunami Mortality in the Community



Mortality in community:	Some	None	Difference
TFR			
2000-2004	2.18	2.74	-0.56
2006-2009	2.67	2.52	0.15
Difference	0.49	-0.22	0.71
ASFR (post- minus pre-tsunami)			
15-19	0.001	0.000	0.001
20-24	0.011	-0.001	0.013
25-34	0.004	-0.004	0.009
35-49	0.002	0.001	0.002
No. of communities	92	191	

Notes: Average quarter-year age-specific probabilities of live birth presented for the pre-tsunami period: 1 January 2000—31 December 2004, and the post-tsunami period: 1 January 2006—31 December 2009, for women in 283 communities. In each quarter-year, women from the baseline survey who are alive and aged 15-49 contribute an observation. Pooled data contain 176,862 observations for 6,363 women. Average annual total fertility rates estimated as TFR = 5 x 4 x $\Sigma_i(ASFR_i)$, where i indexes 5-year age intervals.

Table 1. Tsunami Impacts by whether the Community was Mortality-Affected

	Mortality Zone	
	Community affected by tsunami mortality	Community not affected by tsunami mortality
A. % dead as a result of the tsunami		
All ages	29.0%	0.5%
Children less than 5	33.0%	1.0%
Children 5-14	30.0%	0.4%
Women 15-49	33.0%	0.7%
Men 15-19	19.0%	0.3%
B. Measures of physical damage		
Satellite-based: number of pixels indicating a post-tsunami change to bare earth (mean, range 0-9)	5.1	0.8
Village leader reports:		
Water contaminated	69%	12%
Damage to roads	68%	21%
Problem with debris	69%	13%
C. Subjective measures of tsunami impacts		
Village leader reports that life in the community changed for the worse	73%	34%
Reported reasons		
Loss of population	21%	1%
Increases in price of rice	41%	30%
Increases in other food prices	50%	39%
Fewer business opportunities	43%	26%
Fewer jobs	45%	26%
Number of communities	96	195

Table 2. Sample characteristics of mothers at time of tsunami and all women age 15-49

	Mothers at time of tsunami				All women age 15-49			
	Mean	Std Err	Difference: Mother experienced child death - did not		Mean	Std Err	Difference: Mortality affected - other communities	
			Diff	Std Err			Diff	Std Err
Tsunami-related deaths								
% mothers lost ≥1 child in tsunami	5.5	0.47						
Number of children died | ≥1 died	1.4	0.06						
% community population died					4.2	0.19		
% died in mortality-affected communities					14.7	0.67		
Tsunami-exposure: saw waves	10.4	0.64	43.0	5.8	11.0	0.50	22.5	3.1
Post- tsunami fertility								
% women had birth post tsunami	27.1	0.93	7.1	5.1	31.2	0.74	4.5	2.3
Characteristics of women: Pre-tsunami								
Number of children born pre-tsunami	2.8	0.03	0.2	0.2	1.6	0.03	-0.1	0.1
% who lost ≥1 child pre-tsunami	7.4	0.54	-3.1	1.8	6.7	0.49	-4.4	1.4
Characteristics of women at time of tsunami								
Age	34.4	0.16	0.9	1.0	29.2	0.15	-0.6	0.4
Education - % completed								
< high school	13.4	0.71	8.7	5.3	9.3	0.46	-3.0	2.0
some high school	49.6	1.04	-0.1	6.3	53.0	0.80	-7.2	3.2
> high school	37.0	1.01	-8.6	6.3	37.7	0.77	10.2	4.0
Sample size	2301				3936			

Table 3. Effect of death of own child in tsunami on subsequent birth probabilities
Dependent variable: Indicator variable for birth post-tsunami

Model:	Child died		# children	Child died interacted with		
Covariates	OLS	FE	died	Child age	Parity	Education
	[1]	[2]	[3]	[4]	[5]	[6]
Mother lost ≥1 child in tsunami	0.050	0.099				
	[0.031]	[0.036]				
Number of children lost in tsunami			0.069			
			[0.023]			
(1) if mother lost ≥1 child interacted with						
age of children at tsunami						
all age >2				0.098		
				[0.045]		
some <2				0.094		
				[0.231]		
mother parity at tsunami						
< 3					0.114	
					[0.044]	
≥3					0.066	
					[0.056]	
mother completed high school?						
yes						0.086
						[0.037]
no						0.153
						[0.103]
Mother's parity at tsunami	-0.001	-0.009	-0.010	-0.010	-0.014	-0.009
	[0.005]	[0.006]	[0.006]	[0.006]	[0.009]	[0.006]
Mother parity ≥3 at tsunami					0.024	
					[0.028]	
Mother exposed to tsunami waves	0.016	0.065	0.065	0.065	0.064	0.063
	[0.024]	[0.032]	[0.032]	[0.033]	[0.032]	[0.031]
Mother completed junior high	0.030	0.037	0.037	0.035	0.038	0.037
	[0.019]	[0.024]	[0.024]	[0.025]	[0.024]	[0.024]
Mother completed high school	0.062	0.073	0.072	0.070	0.074	0.070
	[0.025]	[0.034]	[0.034]	[0.034]	[0.034]	[0.034]
Sample size	2301	2301	2301	2301	2301	2301
R^2	0.21	0.22	0.22	0.22	0.22	0.22
Community fixed effects	No	Yes	Yes	Yes	Yes	Yes
Number of communities	276	276	276	276	276	276

Notes: Linear probability models for all mothers at time of tsunami living in mortality-affected districts.
Community fixed effects measured for community of residence at time of pre-tsunami survey.
All models include controls for age of mother splines, ln(per capita expenditure), indicator variables for household ownership of land and ownership of house, all measured prior to the tsunami.
Standard errors take into account clustering at the community level and robust to heteroskedasticity.
Difference between OLS and FE estimate of impact of child death = 0.049 (s.e.=0.020).

Table 4: Effect of community mortality on probabiliy of a post-tsunami birth

	Fraction of total population in community that died						Fraction of children that died
Woman's characteristics at time of tsunami		Parity		Age	Completed high school		
		≤3	>3	25-34	No	Yes	
Covariates	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Fraction died in tsunami interacted with							
A. Mother lost at least one child	0.460	0.578	0.056	0.279	0.204	1.077	0.315
	[0.184]	[0.231]	[0.325]	[0.372]	[0.220]	[0.311]	[0.146]
B. Woman childless pre-tsunami	0.468	0.488	.	1.238	0.400	0.565	0.341
	[0.181]	[0.190]		[0.421]	[0.231]	[0.345]	[0.153]
Mother lost ≥1 child in tsunami	0.012	0.004	0.088	0.204	0.029	-0.024	0.026
	[0.043]	[0.053]	[0.077]	[0.106]	[0.046]	[0.110]	[0.041]
Woman childless pre-tsunami	-0.150	-0.167	.	-0.224	-0.155	-0.153	-0.146
	[0.025]	[0.030]		[0.051]	[0.032]	[0.046]	[0.025]
Woman's parity at tsunami	-0.008	-0.022	0.013	-0.008	-0.010	-0.001	-0.008
	[0.005]	[0.011]	[0.012]	[0.016]	[0.006]	[0.013]	[0.005]
Woman exposed to tsunami waves	0.028	0.026	-0.022	-0.013	0.023	0.049	0.028
	[0.026]	[0.029]	[0.039]	[0.062]	[0.033]	[0.043]	[0.026]
Woman completed junior high	0.029	0.021	0.071	0.118	0.034	.	0.028
	[0.023]	[0.029]	[0.044]	[0.077]	[0.024]		[0.023]
Woman completed high school	0.092	0.091	0.112	0.162	.	.	0.090
	[0.028]	[0.034]	[0.067]	[0.080]			[0.028]
Sample size	3,936	3347	589	1264	2675	1261	3931
Number of communities	283	283	226	268	272	233	280
R^2	0.16	0.13	0.19	0.07	0.15	0.17	0.16
F test (p value)							
Row *A* = Row *B*	0.970	0.707		0.020	0.489	0.193	0.882
Rows *A* and *B* = 0	0.008	0.010	0.863	0.011	0.191	0.002	0.025

Notes: Linear probability models with community fixed effects for all women age 15-49 and living in mortality-affected districts at time of tsunami. See notes to Table 3.