Community Reconstruction after the 2004 Indian Ocean Tsunami

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Executive Summary[1]

1 Research Question

This paper explores the reconstruction effort in Aceh following the 2004 Indian Ocean Tsunami. The Indonesian government declared that the goal of the recovery would be to 'build back better' that is, to take advantage of the attention and funds brought about by the catastrophe in a way that would improve the quality of life for Aceh's residents. To evaluate whether reconstruction effectively met this expectation, we observe the recovery's path along three aspects:

i. Community investments in transportation and water/sanitation infrastructure
ii. Rebuilding of housing stock at the community level
iii. Home reconstruction at the household level

The existing disaster aid literature provides some suggestive methods of measuring intervention, but there are no established metrics for evaluating overall success or failure of reconstruction projects, much less full post-disaster recovery efforts. While we cannot specifically determine whether or not Aceh's reconstruction generated more wealth or utility for its residents than was destroyed by the tsunami or could have been generated through other methods, this paper seeks to identify changes in community infrastructure and housing stock that are likely to contribute to individual health and well-being.

2 Background & Context

On December 26, 2004 an earthquake measuring 9.3 on the Richter scale occurred in the Indian Ocean, just off the west coast of Sumatra. A massive tsunami resulted, devastating the province of Aceh, one of Indonesia's least developed regions. The massive rebuilding effort is widely acknowledged to have changed the face of Aceh. Despite the expense and scale of reconstruction, however, there have been few formal efforts to objectively evaluate the recovery in terms of scope and effectiveness.

3 Data and Sample

Our data come from the Study of the Tsunami Aftermath and Recovery (STAR). STAR converted a pre-tsunami socioeconomic survey led by Statistics Indonesia (SUSENAS) into a broad-based panel survey. The 409 enumeration areas and 6,184 households described in this paper were first surveyed by SUSENAS in 2004, and by STAR annually thereafter. By

[1] This student paper was prepared in 2012 as a requirement for the Master of Public Policy program at the Sanford School of Public Policy at Duke University. The research and analysis contained in this paper are the work of the student who authored the document, and do not represent the official or unofficial views of the Sanford School of Public Policy, of Duke University, or of the faculty advisor. Any apparent conclusions reached using the data referenced in this paper are preliminary and are not intended to represent the full scope of available data or methods. Without the specific permission of its author, this paper may not be used or cited for any purpose.

exploiting the pre-tsunami baseline and extensively tracking survivors (93% of which were interviewed face-to-face), STAR provides a unique perspective on the tsunami's effects.

4 Methodology and Results

i. Community-level infrastructure investments

Beginning with transportation infrastructure, we identify the effect of the tsunami on road and bridge damage in Aceh. We then explore correlates of physical recovery and perceived improvements, again comparing communities in heavy damage areas to those relatively less affected by the tsunami. Turning to water and sanitation, we identify trends in access to protected water sources and modern sanitation methods.

ii. Home reconstruction at the community level

Using reported occupancy rates, counts of rebuilt homes, and population estimates, we consider changes in overall housing stock as a possible indicator for overbuilding.

iii. Home reconstruction at the household level

We begin by describing housing quality before the tsunami according to material and construction characteristics, subsequently illustrating how the distribution of these characteristics changed immediately after the tsunami and throughout the recovery. Finally, we explore the possibility of differential aid receipt according to household and community characteristics.

5 Discussion and Conclusions

This paper exploits a panel data set uniquely suited to identifying the impact of one of the costliest disasters in human history on the community and household level.

Our analyses suggest that at the community level, post-tsunami recovery has triggered a development effort much broader than the reach of the tsunami itself. Particularly in the realm of transportation infrastructure, where most communities report improvements over pre-tsunami roads and bridges, much of Aceh finds itself better off today than in 2004. Income and location appear to be important predictors of improvements in water and sanitation, suggesting areas for improved public intervention. We also identify possible evidence of aid dependency in heavily damaged areas.

While analysis does not dismiss the possibility of overbuilding, we generally find that aid agencies accurately replaced the housing destroyed by the tsunami. There is little evidence of differential aid distribution among households experiencing tsunami damage. Although there is some convergence in quality along certain characteristics, it appears that significant differences in overall home quality remain.

Community Reconstruction after the 2004 Indian Ocean Tsunami

1 Research Question

This paper uses data from the Study of the Tsunami Aftermath and Recovery (STAR) to describe the destruction and subsequent rebuilding of housing stock and community infrastructure in Indonesia's Aceh province following the 2004 Indian Ocean tsunami. We develop econometric models for evaluating aid effectiveness, applying these models to STAR data.

Causal links between disaster aid and welfare are beyond this paper's scope. Instead, we will use community- and household-level survey data to measure and describe physical innovations at the community and household level. Specifically, we intend to observe and quantify modifications to Aceh's housing stock and community infrastructure that occurred after the 2004 tsunami in three respects: community-level infrastructure investments, home reconstruction in terms of community-level housing stock, and home reconstruction at the household level.

The trend of aid delivery in the aftermath of natural disasters suggests a pathway between disaster aid and human welfare, but this pathway is not clearly defined in the existing literature. Econometric modeling of the relationship is challenging due to the obvious relationship between damage and aid. Accurate measurement of the effect of aid would require disasters of similar scope in more or less identical places to receive different amounts of aid, and would ultimately require the delivery of disaster aid to be unrelated to the community need. It would be both undesirable and unlikely for aid delivery to be unrelated to damage. However, this pattern of aid delivery generates flow of resources and outcomes uniquely difficult to evaluate.

When measured, the interpretation of aid contributions is also complicated. It is not obvious that the intervention of an aid agency – even when construed alongside a measurable metric like home construction – always or necessarily improves the welfare of its beneficiary. There is a rich literature alternately applauding and critiquing aid delivery of all types, and abundant case studies or anecdotes describing beneficiaries experiencing better or worse outcomes in the presence of aid. It is therefore complicated to argue that even relatively straightforward rebuilding measures in fact improve recipient welfare.

We intend to describe and interpret three specific aspects of reconstruction:

i. *Community-level infrastructure investments:*
With responses from community informants, we describe the transformation of Aceh at the community level, in terms of the rebuilding of roads, bridges, water sources, and sanitation methods after the tsunami. Difference-in-difference estimators identify the effect of the tsunami on infrastructure disruption. Descriptive statistics are used to outline the speed and form of the recovery, and linear probability models further characterize specific community-level predictors of post-tsunami infrastructure investments.

ii. *Home reconstruction at the community level:*
Combining retrospective questions concerning community population and housing with post-disaster data regarding repopulation and rebuilding, we examine whether overbuilding occurred in affected communities.

iii. *Home reconstruction at the household level:*
Using household data, we describe the condition of housing in different damage zones before, in the aftermath of, and in the years following the tsunami. Physical innovations

(such as the transition to metal roofing material, indoor sanitary system, or entirely new home) are presented. Linear probability models test the possibility aid selectivity according to household and community characteristics.

Using this framework, this paper describes the nature and trajectory of post-tsunami recovery in community infrastructure, housing stock, and housing quality.

2 Background & Context

On December 26, 2004 an earthquake measuring 9.3 on the Richter scale occurred in the Indian Ocean, just off the west coast of Sumatra. The quake triggered a massive tsunami. The tsunami devastated the coastline of Sumatra, with the bulk of damage occurring in Aceh, the island's northernmost province.

Damage from the tsunami varied significantly along the coastline. Many coastal communities experienced high levels of damage, resulting in heavy mortality, flooding of agricultural land, and destruction of physical infrastructure. The damage to housing was particularly severe, immediately leaving thousands of families homeless. In the short term, hundreds of domestic and international aid organizations provided tents, barracks, and other temporary housing for the tsunami's living victims. Over the longer term, aid organizations provided permanent homes, in some cases augmenting existing communities, while in other cases rebuilding whole communities from scratch.

Damage to infrastructure and housing was not limited to areas exposed to the tsunami. While the extent of earthquake-induced damage was much less, roads, bridges, and houses miles inland crumbled from the massive quake that triggered the tsunami, as well as numerous aftershocks.

Aceh is generally recognized as one of Indonesia's least developed regions, and for years before the tsunami suffered from grinding guerilla conflict and slow economic growth. The rebuilding effort was of enormous scale, and is widely acknowledged to have changed the face of the province. Yet, despite the massive cost of recovery and near-continuous presence of the world's foremost aid and development agencies, there have been no formal attempts to evaluate objectively the work done in Aceh since the tsunami.

2.1 Disaster Relief

There are interesting and complex questions associated with the usefulness of disaster relief. Domestic governments, international organizations, and independent aid agencies are each concerned to some degree with the rebuilding of communities after disasters, and given the increasing numbers of people affected by disasters, there is reason to be concerned with the effective and efficient delivery of aid (UNEP, 2005).

With regard to effectiveness, there is considerable advocacy for rebuilding efforts to extend beyond the physical act of rebuilding to improvements to recipient well-being.[2] There are also ample opportunities to identify inefficiencies in the allocation of disaster aid, and to aspire for improved delivery mechanisms (Walden, 2005).

[2] See, for example, the discussion in Kennedy et al., 2008.

2.2 Housing in the context of the tsunami

Following the 2004 Indian Ocean earthquake and tsunami, international aid agencies and the Indonesian government coordinated a massive recovery effort in the regions affected by the disaster. The reconstruction effort became the largest ever in the developing world (until the 2010 Haiti earthquake), charged with the task of recovering from an estimated $4.4 billion in direct losses. Housing and shelter is estimated to represent as much as one-third of these losses, and therefore comprised a nontrivial aspect of the recovery (Brown, 2005).

Beyond the impressive dollar figure associated with these losses, the destruction of housing stock in in general a common outcome of major natural disasters; the subsequent attempt to restore housing is also major feature of most reconstruction programs. Intuition tells us that home reconstruction is a valuable contribution of disaster relief, and that new homes, if used, are assumed to be good replacements for the old. In the absence of many measureable outcomes, "number of homes rebuilt" is a commonly observed indicator for an agency's contribution to a recovery effort (see for example, USAID, Habitat, and Oxfam project reports from Aceh).

2.3 Aid in general, versus disaster aid

A commonly cited rift in the world of development aid is that between what Banerjee and Duflo (2010) term "supply *wallahs*" (those who see shortfall in the supply of important goods for development, like schools and investment) and "demand *wallahs*" (those who believe that the conditions in developing countries reflect the reality of preferences in those countries). This debate, which in essence questions the value of development aid and guides the flow of funds and nature of interventions, is not commonly applied to the world of disaster aid. To the best of the author's knowledge at the time of writing, there is no meaningful debate concerning the overarching merit of rebuilding after a disaster.

However, the literature lacks any thorough and available evaluations of rebuilding efforts. One reason for this knowledge gap may be the challenge associated with collecting data suitable for analysis. While natural disasters occur widely over space and time, that their timing and precise location is unpredictable makes thorough impact evaluation challenging. After a disaster, collecting representative pre-disaster data is extremely difficult. In very few cases have baseline surveys been converted into panel studies capable of producing in-depth longitudinal analysis; those identified for the purposes of this paper suffer from small sample size and considerable restrictions on generalizability (Lin et al. 2002; Jia et al. 2009). Kelman et al. (2011) point out the need for longitudinal studies, but lacking accurate baseline samples makes this need difficult to address, even when identified.

To add to the challenge of acquiring suitable data, high-profile evaluators (such as the media or the aid agency itself) generally do not operate on timelines as long as recovery can be expected to actually take. The popular media was quick to complain about the slow speed of the recovery, blaming the agencies operating in the area (Barker, 2005). Caught somewhere in the middle, aid agencies are frequently accused of failing to remain for a sufficient length of time to fulfill a comprehensive approach to development, or to evaluate the quality of their work (Steinberg, 2007).[3]

[3] For example, work on the Banda Aceh – Calang road, led by USAID, was unfinished as of the research team's latest visit to the region in July 2011. According to interviews with USAID officials associated with the recovery at the same time, representation had already been withdrawn from the region.

When disaster aid is evaluated, the development agencies delivering the aid commonly evaluate their own work.[4] This leads to further data problems in the instances that comprehensive information is collected. For example, in evaluating a non-random Oxfam survey of home recipients in Aceh, Rand et al. (2011) admit that their data may be biased toward positive responses, with beneficiaries hesitant to criticize the donors responsible for funding and facilitating reconstruction.

In many cases, one may assume that the majority of resources are dedicated to the costs of reconstruction and administration, leaving relatively few resources for proper evaluation. One may further speculate that, with fundraising and mission continuation as a primary goal for aid organizations, illustrating success is in the organization's best interests. While speculative, this interpretation helps describe the tendency of such evaluations to generally follow two predictable forms (again, with overlap).

First, we commonly observe matter-of-fact reports of number of homes rebuilt or individuals "reached", a approach that, while informative as to project scope, does not provide insight as to overall housing quality or resident satisfaction (Oxfam, 2006; USAID, 2008b). Few useful conclusions can be drawn from these reports as to how an intervention may be better implemented in the future. One general impression that might be drawn from this approach is that larger projects are broadly considered to be more successful. This lesson may in fact be distinctly unhelpful when taken in isolation.

Second, we observe case studies highlighting a sequence of events on an individual, household, or community basis. This qualitative analysis is varyingly helpful in drawing useful conclusions. Steinberg & Smidt (2010) provide a nuanced storyline of the ADB-led reconstruction of an Aceh fishing village, with an ultimate conclusion that the village was left "much more beautiful today than before."[5] Oxfam (2006) uses individual and community case studies to describe land rights shortfalls and how Oxfam has overcome them.[6] USAID's final report from Aceh relies heavily on stories of individual perseverance and ultimate recovery, heavily characterizing the demand-side without addressing strengths or weaknesses of the supplier. Finally, any 'lessons learned' are usually positive but often vague and irrelevant to future recovery efforts, such as "disasters can create opportunities for better development" (USAID, 2008a).

2.4 Theoretical Framework

This body of work has produced its own set of recommendations, which will be used in part to inform our method of analysis and hypotheses testing.

Beyond advocating for longitudinal studies, Kelman et al. (2011) use a meta-analysis of housing projects to suggest that housing occupancy rates are a broadly useful measure of rebuilding effectiveness while noting the serious challenges of collecting accurate measures of

[4] In microfinance, Banerjee and Duflo (2011) point out that "there was in fact very little evidence either way on these questions [of the effectiveness of microfinance]. What [the microfinanance institution] called evidence turned out to be case studies, often produced by the [microfinance institutions] themselves."

[5] This conclusion raises two questions in particular: To whom is the fishing village more beautiful, and does "before" refer to pre-tsunami or pre-reconstruction?

[6] Oxfam's critique temporally precedes BAPPENAS' (the National Development Planning Agency's) decision to extend further support to renters, suggesting that Oxfam's critical report may have in fact exerted some influence.

occupancy. This recommendation is reinforced by the findings of Kennedy et al. (2008) in Sri Lanka, where thousands of new homes were left unoccupied.[7]

Duyne Barenstein (2006) and Oxfam (2006) discuss at length the benefits of participatory recovery efforts that seek to include the community in reconstruction. The former uses non-experimental methods suggestive of higher homeowner approval when homeowners themselves drive the recovery process. The latter uses case studies to highlight communities in which the internal planning process was effective. Rand et al. (2011) isolate a contradiction in the literature – while homeowners find participation important, many elect not to be involved. This disparity may in part be explained by the collection of information after the success or failure of a project, rather than objectively tracking beneficiary sentiment over time. Rand et al. (2011) also identify more tangible factors associated with high levels of beneficiary satisfaction, with housing quality and access to sanitation among the most important characteristics in most cases.

Finally, the argument for comprehensive town planning emerges regularly in the literature. ADB reports that "spatial planning" began some time into reconstruction, when the weaknesses of unplanned rebuilding emerged (2010). Johnson (2007) uses case studies to further highlight the benefits of well-planned town rehabilitation projects. Further, USAID (2008) used mapping strategies in a non-random selection of Acehnese villages, using reports of community and homeowner satisfaction as evidence of the strategies' benefits.

Some of these recommendations and findings, such as the value of community planning versus willy-nilly reconstruction, are more or less intuitive. Others, like a homeowner-driven reconstruction process (as opposed to hiring experienced contractors to do the work), are less obvious.

3 Data and Sample

Our data come from the Study of the Tsunami Aftermath and Recovery (STAR). STAR has been conducted since 2004 in the two Indonesian provinces closest the event, Aceh and North Sumatra. The bulk of damage areas are located in Aceh, which also experienced a civil war until soon after the tsunami.

Many disaster-related data collection efforts suffer from selection bias toward survivors and recent arrivals. STAR was designed toward overcoming this limitation by utilizing a pre-tsunami baseline; specifically, a 2004 cross-sectional survey by Statistics Indonesia (SUSENAS), roughly comparable to the U.S. Consumer Expenditure Survey, which was representative of the 2004 population at the district level (Frankenberg et al., 2011). STAR converted SUSENAS into a panel survey, following up annually with over 40,000 respondents since 2005. The first round of post-tsunami interviews were conducted between May 2005 and May 2006. Survival status was ultimately determined for 95% of the study sample.

A major component of STAR is the inclusion of communities from a variety of damage categories, which is necessary to capture differences in the recovery trajectory in a modified treatment versus control framework. Measures of overall damage were assigned to each site using a combination of satellite imagery, informant reports, and surveyor observation. STAR distinguishes between areas of damage in a number of ways, the most straightforward being four categories of damage: none, light, moderate, and heavy. Description will adopt this methodology

[7] Kennedy et al. attributed low occupancy to oversupply. One could also argue that low quality could be a contributing factor.

where helpful, and will otherwise consider communities on a dichotomous basis of limited damage (the first three categories) versus heavy damage. This approach exploits the nature of the event, which exposed a minority of communities to extremely heavy damage while inflicting relatively small amounts of damage on many others.

Information is collected at the household level from each individual in the household, and at the community level from informants within the community, such as village heads, or those intimately involved in the recovery process. In many communities multiple people served as community respondents, and these cases are documented in the surveys.

There are a total of 409 enumeration areas (EAs) located in 18 districts (*kabupaten*) in Aceh and North Sumatra constituting our sample. In addition to seeking out respondents from the initial survey, STAR sought information on and tracked down "split-off" households, or new households formed by panel respondents. In order to compare the same group of households throughout the analysis, we exclude these split-offs and restrict our sample to households identified as the "origin" household. Our sample is 6,184 households, each of which was surveyed by SUSENAS in 2004 and later by STAR multiple (a maximum of 5) times between 2005 and 2010.[8]

4 Methodology and Results

Some of the largest long-term aid projects targeted the improvement of Aceh's transportation infrastructure. Like the USAID-sponsored Banda Aceh - Calang road cited above, the inputs to this form of aid delivery are extremely visible (presumably a benefit for the sponsoring organization). There are also considerable positive externalities associated with functional transportation networks – such as the facilitation of material transport, mobilization of labor supply, and development of new industries. Given the obvious importance of transportation infrastructure in this context, we begin by describing the destruction and subsequent reconstruction of Aceh's roads and bridges.

4.1 Transportation infrastructure

Extent of damage to roads and bridges

Table 1 illustrates the scope of damage inflicted by the tsunami, and the proportion of communities that benefited from repairs in the two years following the event (conditional on experiencing damage). The scope of damage to roads and bridges was most dramatic in heavy damage zones, but the disparity is narrower in the case of bridges – 86% of heavily damaged communities reported damaged roads, 46% reported damaged bridges. Part of this may be explained simply by scale: fewer communities have bridges than roads. In any case, the destruction of bridges appears less correlated with a unique community's tsunami exposure than that of roads. Therefore, we explore road destruction as a more highly correlated outcome of tsunami exposure.

Even before the 2004 tsunami, Aceh was one of Indonesia's least developed provinces, with a sprawling, rural population base. It is reasonable to expect some level of underlying road damage that is not attributable to the disaster itself. Column 1, Table 1 presents the underlying

[8] Typically the origin household is that which contains the largest number of original household members, but the assignment rule has some elements of arbitrariness.

road damage (in terms of months main roads were impassable) as described by community respondents. Pre-tsunami, the average community experienced roughly one month of impassable roads (or slightly less in heavy damage zones). Post-tsunami (Column 3), this amount of time more than doubled in heavy damage zones, while it remained the same or declined elsewhere.

To account for pre-tsunami differences and a subsequent time trend, we model the tsunami's effect on road transportation networks in a difference-in-difference framework, comparing the time (in months) that each community reported main roads to be impassable:

$$(1) \qquad \theta_{ct} = \alpha_c + \beta_1 * \text{Damage}_c + \beta_2 * \text{Time} + \beta_3 (D_c * T) + \gamma X_c + \epsilon_{ct}$$

Where θ is the amount of time a community's main roads are reported impassable, α is the amount of time an eventually unexposed community experienced damaged roads over the year prior to the tsunami; β_1 is the difference associated with future heavy exposure to tsunami damage; β_2 the difference one year after the tsunami; and β_3 the tsunami impact on heavily damaged communities. A vector of community-level controls a (distance from urban centers, distance from coast, elevation, pre-tsunami population, and per-capita expenditure) are contained in γ, and ϵ is an error term which is assumed to vary randomly across village and time.[9] Results are presented in Table 2; the first column contains results inclusive of all communities providing responses. Communities exposed to heavy damage experienced on average 1.4 months of impassable roads over and above what they experienced before the tsunami. Distance from an urban center predicts duration of impassability: communities less than 25 miles (omitted from the regression) or more than 100 miles from Meulaboh in the south or Banda Aceh in the north (two important cities along the affected coastline) experienced the longest period of road impassability, while those between 25 and 75 miles from either urban area experienced roughly two-thirds of a month less impassable roads. On average, higher earning communities (expressed through mean log per-capita expenditure within a community) experienced shorter duration of impassable roads. An added interaction term between heavy damage and log expenditure shows that this effect does not pertain to damage zones, however. This coefficient suggests that while communities accustomed to road damage (due to mud or inaccessibility, or other non- tsunami factors) could mobilize community resources to repair infrastructure, poor and rich communities most profoundly affected by the tsunami had access to similar resources regardless of pre-tsunami economic standing. Communities at higher elevation – generally more rural, less developed, and less economically connected to urban centers, were likely to experience longer durations of impassable roads. Most major roads in Aceh run along the coastline, and this finding provides evidence that repair priority was related to overall interconnectivity versus meeting individual community needs.

[9] Unless otherwise indicated, "distance from urban centers" is modeled as a set of mutually exclusive dummy variables representing <25, <50, <100, and >100 miles from Banda Aceh or Meulaboh, the two large cities located at the northern tip and southern mid-point of the southwest-facing coast, respectively; distance from coast using log transformation of the meter distance from the coast; elevation using quartic roots of meter elevation; mean per-capita expenditure is taken as the mean of log per-capita expenditure, measured at the household level, and averaged across the community.

Table 1: Proportion of communities reporting infrastructure damage & improvement

	A: Roads						B: Bridges			
	1	2	3	4	5	6	7	8	9	10
Damage level	**Pre-tsunami**	**Damage from tsunami**	**Post-tsunami**	**Repair (if damaged)**		**Improvement**	**Damage from tsunami**	**Repair (if damaged)**		**Improvement**
N	# months impassable		# months impassable	2005-2006 interview	2006-2007 interview	2009-2010 interview		2005-2006 interview	2006-2007 interview	2009-2010 interview
Heavy	0.77	86.0%	2.09	38.8%	80.0%	61.3%	13.0%	40.0%	80.0%	61.1%
90	(0.275)	(.036)	(0.391)	(.055)	(.045)	(.051)	(.039)	(0.163)	(.163)	(.067)
Moderate	1.49	59.6%	1.49	24.5%	45.3%	65.2%	21.4%	50.0%	66.7%	40.7%
86	(0.419)	(.052)	(0.401)	(.060)	(.069)	(.051)	(.039)	(.104)	(.098)	(.065)
Low	0.55	13.4%	0.27	26.7%	40.0%	59.8%	48.3%	41.9%	55.8%	38.8%
112	(0.236)	(.032)	(0.161)	(.118)	(.131)	(.047)	(.053)	(.076)	(077)	(.055)
None	1.01	6.5%	0.78	40.0%	80.0%	64.9%	46.2%	37.2%	55.8%	42.4%
77	(0.375)	(.028)	(0.339)	(0.245)	(.200)	(.055)	(.052)	(.075)	(.077)	(.065)
Total	0.92	41.2%	1.12	32.7%	64.1%	62.5%	32.3%	41.7%	58.3%	44.8%
365	(0.160)	(.026)	(0.166)	(.038)	(.039)	(.025)	(.024)	(.045)	(.045)	(.031)

Table 2: Reported time of road damage (in months)

VARIABLES	(1) Full sample	(2) Limited sample
Heavy damage	-19.47**	-10.08
	(8.38)	(10.63)
Time	-0.19	-0.25
	(0.27)	(0.54)
Damage*time	1.42**	1.49**
	(0.57)	(0.74)
<25 miles	[omitted]	[omitted]
<50 miles	-0.65**	-0.80
	(0.33)	(0.50)
<100 miles	-0.69*	-0.56
	(0.36)	(0.67)
>100 miles	-0.18	-0.91
	(0.41)	(0.61)
Coastal dist.	-0.15	-0.34*
	(0.10)	(0.20)
Elevation	0.56***	0.50*
	(0.18)	(0.28)
Population	-0.20	-0.20
	(0.12)	(0.15)
Expenditure	-1.35***	-0.67
	(0.34)	(0.62)
Damage*Exp.	1.54**	0.76
	(0.66)	(0.84)
Constant	19.53***	13.05
	(4.64)	(8.69)
Observations[10]	665	298
R-squared	0.0709	0.0599
F-test	4.014	2.017

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

One shortcoming of this model is that many communities relegated to the control group did experience some extent of damage. Bearing in mind that limited resources would have been designated to reconstruction, it is reasonable to expect that resources dedicated to addressing road damage in one area would to some extent limit those allocated to another. The second column restricts the sample to heavy damage (treatment) and no damage (control), so that the control group will be less affected by reconstruction activities. The interaction term of interest

[10] Total number of observations is n(total communities)*2, given two years of observations. Odd numbers are the result of community response in only one year. Missing observations due to non-response. Non-response was tested using LPM with identical covariates to Model 1. Results are not included, but heavy damage zones were more likely than non-damage zones to respond; poorer communities more likely than richer to respond (except in heavy damage zones).

(heavy damage*time), remains the same. However, previously important distance indicators become insignificant at 10%, though the effects of distance from urban centers remain negative (distance from urban centers reduces road impassability). Average community expenditure also no longer predicts duration of impassability. While both elevation and distance are marginally significant, their effects counter one another. In each regression, a test for significance indicates that the joint effects of these two variables are not different than zero (p=.09,.34, respectively).

However, the low R^2 on the results from this model (from .06-.07) suggests that much of the variation in reported road damage is attributable to factors not included in the regression. Particularly when taking into consideration the considerable level of variation in areas of limited damage, there are clearly many possible factors at play influencing road quality that are not captured by this model.

Time patterns of aid delivery

The model described above provides some evidence of the characteristics leading to the mitigation of road damage across Aceh. We can also construct a linear probability model to test specific characteristics contributing to faster recovery for communities experiencing damaged roads or bridges.

$$(2) \qquad \Pr(y_i=1 \mid x_i) = \alpha + \beta_1 * \text{Damage}_c + \beta_2(\text{Year}^{\alpha} * D_{ct}) + \beta_3(\text{Year}^{\alpha} * TVC_{ct}) + \gamma X_c + \epsilon_{ct}$$

In Model 2, the outcome measure of interest is whether repairs have been made to tsunami- or earthquake-damaged infrastructure, conditional upon damage in December 2004. β_1 reflects exposure to heavy damage, β_2 is the interaction of year indicator terms with damage exposure (in order to test the possibility of time variation in response), β_3 is an interaction of year indicators with independent variables hypothesized to influence reconstruction differently over time (log expenditure, population, and distance from urban centers). Community controls not presumed to contain varying time effects are contained in γ.

The results in Table 3 suggest that, in the case of road reconstruction, the first year after the tsunami emphasized rebuilding in heavy damage areas (β=.33, se=.12) with lower socioeconomic standing (a one unit increase in mean log per-capita expenditure reduced odds of road repair by about a quarter, significant at 10%). Controlling for elevation and distance from the coast, communities more distant from urban areas were also favored.

During the second year after the tsunami, road rebuilding appears to have refocused away from areas of heavy damage (β(2006*damage)=-.37, se=.13), basically counterbalancing the coefficient on 2005 damage). Expenditure is no longer a significant predictor of recovery. The distance trends observed in 2005 are reversed; communities less than 25 miles from urban centers are more likely than more distant locations to experience road repairs in 2006.

A relatively straightforward interpretation of these results is a story of saturation. Road rebuilding appears to have taken on more challenging projects first – that is, the more devastated, distant, and poor communities received attention in the tsunami's aftermath. Once initial needs in these areas were met, the focus readjusted to more urban or proximate and relatively less damaged communities.

Table 3: Factors contributing to infrastructure recovery

VARIABLES	(1) Roads	(2) Bridges
Heavy damage from tsunami	0.33***	-0.18
	(0.12)	(0.12)
2006	-1.17	0.96
	(1.78)	(1.77)
2006*Damage	-0.37***	-
	(0.13)	
Coastal dist.	-0.04	-0.03
	(0.04)	(0.04)
Elevation	-0.04	-0.08
	(0.05)	(0.05)
Expenditure	-0.27*	0.00
	(0.14)	(0.14)
2006*Expenditure	0.19	-0.07
	(0.14)	(0.14)
Population	0.05	-0.05
	(0.06)	(0.06)
2006*Population	-0.05	0.08
	(0.06)	(0.07)
<25 miles	[omitted]	[omitted]
<50 miles	0.29*	0.36**
	(0.15)	(0.15)
<100 miles	0.27*	-0.11
	(0.14)	(0.22)
>100 miles	0.24*	0.11
	(0.14)	(0.15)
2006 *<25 miles	[omitted]	[omitted]
2006* <50 miles	-0.32**	-0.35**
	(0.15)	(0.17)
2006* <100 miles	-0.36**	0.01
	(0.15)	(0.22)
2006* >100 miles	-0.32**	-0.23
	(0.15)	(0.17)
Constant	3.63**	1.15
	(1.83)	(1.77)
Observations	134	112
R-squared	0.384	0.276
F-test	7.789	9.726

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

There are no obvious patterns in bridge reconstruction, with the exception of communities between 25 and 50 miles being the most likely to benefit from bridge reconstruction in either year. This may support the hypothesis of bridges serving as shared access points for several communities. But based upon this evidence, it does not appear that heavy damage zones benefited disproportionately in terms of the construction of new bridges.

Table 4: Correlates of Transportation Infrastructure Improvement

	Roads		Bridges	
	(1)	(2)	(3)	(4)
VARIABLES	Full	Limited^	Full	Limited^
Damage	-0.03	-0.06	0.27***	0.12
	(0.07)	(0.13)	(0.09)	(0.15)
Expenditure	-0.11	0.07	-0.18**	0.04
	(0.07)	(0.10)	(0.08)	(0.13)
Population	0.04	0.02	-0.01	0.03
	(0.03)	(0.04)	(0.03)	(0.05)
<25 miles	[omitted]	[omitted]	[omitted]	[omitted]
<50 miles	-0.12	-0.06	-0.12	-0.13
	(0.08)	(0.11)	(0.10)	(0.16)
<100 miles	-0.14*	-0.04	-0.02	-0.11
	(0.08)	(0.14)	(0.10)	(0.17)
>100 miles	-0.04	0.06	0.00	0.05
	(0.07)	(0.12)	(0.10)	(0.15)
Coastal dist.	-0.00	0.02	0.01	-0.03
	(0.02)	(0.05)	(0.03)	(0.06)
Elevation	0.00	-0.03	-0.04	0.01
	(0.03)	(0.05)	(0.04)	(0.06)
Constant	1.82**	-0.43	2.71**	0.00
	(0.90)	(1.29)	(1.13)	(1.84)
Observations	337	151	237	102
R-squared	0.0285	0.0202	0.0671	0.0672
F-test	1.191	0.386	2.267	0.903

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
^Excludes communities exposed to intermediate levels of damage.

Built back better?

Finally, we use a simple model to explore whether Aceh's communities indeed have better roads and bridges at the time of the most recent survey wave as compared to immediately before the tsunami. Using unaffected and marginally affected communities as a control group and controlling for community characteristics should provide some evidence as to whether the tsunami provided impetus for infrastructure improvement specifically in affected areas, or whether the disaster resulted in a broader recovery effort. Again, the two samples are tested in order to account for contamination of the comparison group through limited damage, with the model:

$$(3) \qquad \Pr(y_i=1 \mid x_i) = \beta * \text{Damage}_v + \gamma X_v + \epsilon_v$$

Where β contains the effect of exposure to the tsunami in 2004, and γ a vector of community characteristics hypothetically related to infrastructure development.

Overall, the very low R^2 and test statistics on these results (contained in Table 4) suggest that exposure to damage and the chosen community controls do not explain a large proportion of reported transportation improvements. Reassuringly, 63% of communities report road

improvements since the tsunami (Table 1; the comparable number with regard to bridges is 45%). Taken together, this information suggests that such improvements were not limited to damage areas, and that in fact a broader recovery effort has improved transportation infrastructure around Aceh regardless of damage exposure.

Regression results indicate no obvious relationship between exposure to heavy damage and reported improvements in road quality. The same is not true for bridges, but β is significant and positive only in the full sample, which makes the simplest interpretation of Column (3) results impossible. Taken together, the results from (3) and (4) suggest that reported improvement is contingent upon exposure to heavy damage when these communities are compared to those in areas of more moderate damage, but not compared to those experiencing none at all. Again, these results suggest a general recovery and development effort not completely dependent upon heavy damage exposure.

4.2 Water & Sanitation

Access to clean water remains an issue in many parts of Aceh today, as does the disposal of sewage waste. In 2005, 90% of communities reported their main water source to come from sources listed in the survey, including tap water, protected well, protected spring (together considered "protected sources"), pump, unprotected well, unprotected spring, river, and rain water (together considered "unprotected sources"), and bottled water. Methods of sewage disposal range from septic tanks (relatively uncommon around the time the tsunami struck, but increasingly common since) to agricultural ponds or fields, shores or open fields, or bodies of water (rivers, lakes, oceans). In this section we observe transitions in water and sanitation trends since the tsunami.

Water contamination & transition to protected sources

Table 5 shows the effect of the tsunami on water contamination within STAR communities. Contamination is heavily concentrated in areas exposed to the most damage, and water sources in these areas were not returned to their previous status for a reported average of five months after the tsunami (Columns 1 & 2). This trend is also evident in Column 3 by the proportion of communities reporting main water sources as protected (using retrospective question for before/immediately after the tsunami); we also observe that communities in heavy damage zones enjoyed a significantly higher proportion of protected water sources at the baseline. As illustrated in Figure 1, over time levels of access converge and remain roughly similar to date. The years since the tsunami are associated with major improvements in access to safe water, even for communities not exposed to tsunami damage.

Table 5: Water and Sanitation

	A: Contamination and main source of water					B: Sewage disposal^	
	1	2	3	4	5	6	7
Damage level	**Contamination**	**Duration***	**Pre-tsunami**	**Post-tsunami**	**2009-2010**	**2005-2006**	**2008-2009**
N	from tsunami	Months	% protected sources	% protected sources	% protected sources	% using septic tanks	
Heavy	83.9%	5	41%	10.8%	55.9%	17%	27%
93	(.038)	(.670)	(.051)	(.032)	(.052)	(.039)	(.046)
Moderate	36.0%	2.613	17%	16.9%	58.4%	10%	17%
89	(.051)	(.618)	(.040)	(.040)	(.052)	(.032)	-0.041
Light	2.7%	0.158	31%	29.5%	79.5%	10%	18%
112	(.015)	(.092)	(.044)	(.043)	(.038)	(.028)	(.036)
None	2.6%	1.5	34%	36.4%	76.6%	12%	28%
77	(.018)	(0.5)	(.054)	(.055)	(0.049)	(.037)	(.052)
Total	31.0%	4.08	31%	23.2%	67.9%	12%	22%
371	(.024)	(.498)	(.024)	(.022)	(.024)	(.017)	(.022)

*Conditional on reporting contamination.

^Since these questions were asked differently, we do not attempt to reconstruct a baseline, instead showing improvement from after the tsunami until 2009.

2010 data on septic tank use was not prepared for analysis at the time of writing.

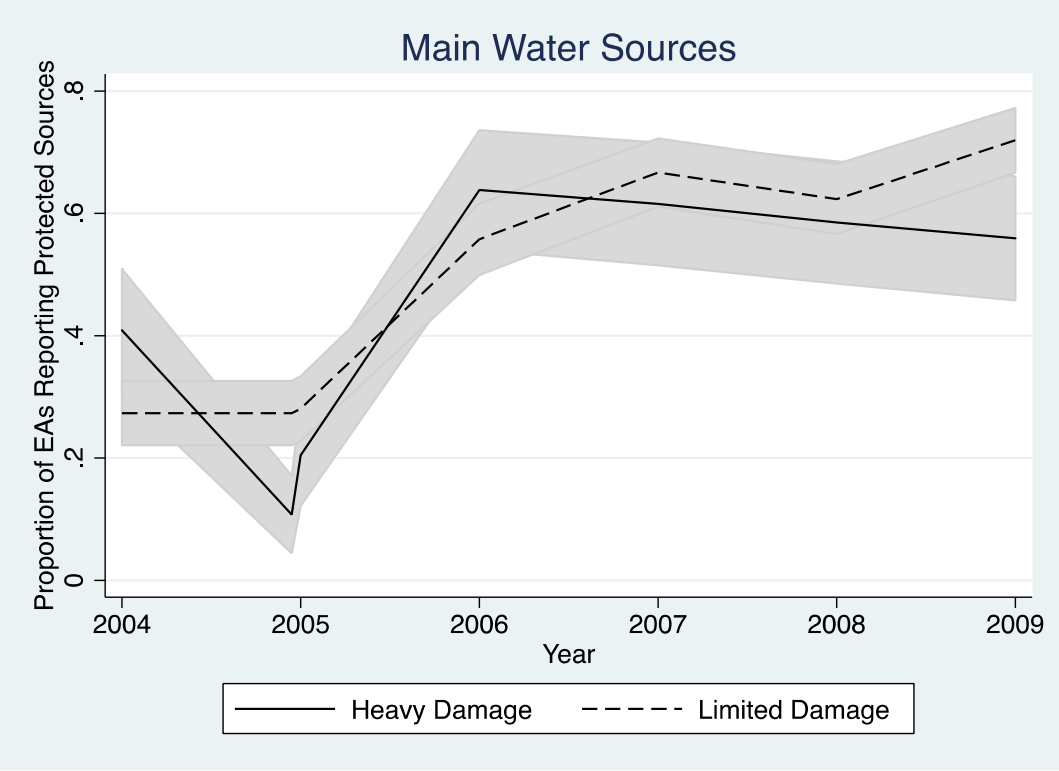


Figure 1: Primary water source for a community, by damage zone. 95% confidence intervals in gray.

We can also model the characteristics associated with acquiring access to protected water sources using the same linear probability model described in (3):

(3) $\Pr(y_i=1 \mid x_i) = \beta * \text{Damage}_c + \gamma X_c + \epsilon_c$ (copied from above)

Where β shows the effect of community exposure to heavy damage and γ contains the same set of community controls. In column 1 of Table 6, we model access before the tsunami in terms of geographic location, mean log per-capita expenditure, and log population. Expenditure and population are both positive predictors of access to protected water sources. Exposure to heavy damage should be insignificant in this regression since the tsunami had not yet occurred, and is included to test this hypothesis; we observe no predictive power associated with exposure for the pre-tsunami model.

Using the same covariates, we consider in column 2 the same outcome for 2009-2010 (5-6 years after the tsunami). Pre-tsunami population is not predictive of access to protected sources, but wealthier communities continue to have significantly better access. Distance from the coast is also associated with a lower probability of access to protected water sources. Perhaps most surprising, though, is the strong negative relationship between exposure to heavy damage and primary access to protected water sources in 2009-2010. One possible explanation for this outcome is the introduction of bottled water to exposed communities in the tsunami's immediate aftermath: it is possible that in some cases bottled water has replaced other water sources, whether due to continued provision, or persistent damage to protected water sources. By

including an indicator for bottled water within the same regression framework (column 3), we observe that the effect of heavy damage disappears and that the negative relationship seen in column 2 is likely to reflect the widespread use of bottled water instead of developing protected water sources.

One could reasonably speculate that this relationship is lingering aid reliance. Many exposed communities benefitted from bottled water delivery after the tsunami, and bottled water as a primary source is relatively unusual. Considering all communities in the sample, it is clear that there has been a broad improvement in access to protected water sources (and clean water in general, considering the bottled water trend in heavy damage communities). The strong, positive coefficient on log expenditure (in all three regressions tested) suggests that wealthier communities have in general benefited disproportionately from this transition (although it likely that the pathway not unidirectional, since improved water and sanitation measures are likely to contribute to economic growth).

Table 6: Community-level determinants of water and sanitation methods

		Water		Sanitation	
	(1)	(2)	(3)	(4)	(5)
VARIABLES	2004	2009-10	2009-10	2005-06	2008-09
Damage	-0.01	-0.23***	0.01	-0.08*	0.00
	(0.07)	(0.07)	(0.06)	(0.05)	(0.06)
Expenditure	0.18***	0.17**	0.22***	0.21***	0.23***
	(0.06)	(0.07)	(0.05)	(0.05)	(0.05)
Population	0.11***	-0.00	0.00	0.07***	0.04*
	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
<25 miles	[omitted]	[omitted]	[omitted]	[omitted]	[omitted]
<50 miles	0.05	0.03	0.08	-0.07**	0.04
	(0.07)	(0.08)	(0.06)	(0.03)	(0.06)
<100 miles	0.12	0.10	0.11*	-0.08*	-0.07
	(0.08)	(0.07)	(0.06)	(0.05)	(0.06)
>100 miles	-0.03	-0.07	-0.12*	0.02	0.25***
	(0.06)	(0.08)	(0.07)	(0.05)	(0.07)
Coastal dist.	-0.02	-0.05**	-0.04*	-0.03	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Elevation	-0.00	0.03	0.01	-0.01	-0.05**
	(0.03)	(0.03)	(0.02)	(0.01)	(0.02)
Bottled water			-0.86***		
			(0.04)		
Constant	-2.61***	-1.08	-1.74**	-2.72***	-3.02***
	(0.78)	(0.93)	(0.69)	(0.64)	(0.67)
Observations	337	337	337	337	337
R-squared	0.150	0.0867	0.35	0.24	0.18
F-test	8.591	3.781	114.8	6.446	8.905

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Sewage disposal

While the survey permits the reporting of a variety of methods of sewage disposal, the two general options are open disposal (in a field, body of water, or hole in the ground, for example), or use of a septic tank. The former is much more common, but responses from 2005-2008 suggest a general increase in septic tank use (Table 5).[11] Even lacking pre-tsunami retrospective responses, it is possible to assume from the 2005 responses that, once again, those communities to be hardest hit by the tsunami had somewhat higher rates of septic tank use.

Using a linear probability model (Table 6, Column 4) we test the same basic community features as predictors of using septic tanks for waste disposal, finding a strong positive relationship between mean log per capita expenditure and septic tank use. In terms of geography, the indicator for >100 miles from an urban center is also highly significant and positive, while elevation has a small but significant negative effect.

While the meaning of the sign and magnitude of some geographic characteristics is not entirely obvious, ultimately these results suggest that community wealth is the most important and consistent predictor of the acquisition of modern water and sanitation methods. This may be unsurprising if these improvement efforts are locally funded, but is perhaps more alarming in consideration of massive government involvement in the years since the tsunami struck. These results suggest that in terms of water and sanitation – an area in which governments and donors frequently choose to intervene in the interest of public health equity – a gap between richer and poorer communities in clean water access and sanitary waste disposal may be well-established, and that the tsunami recovery has not propagated a centralized effort for improved water and sanitation measures.

4.3 Housing Stock

Considering overbuilding

The reconstruction literature frequently speculates on overbuilding after disasters, perhaps in part because empty homes are obvious and contribute to vivid narratives. Overbuilding may reflect a variety of factors, such as overambitious aid organizations, inaccurate mortality estimates, or unpredictable migration patterns. Although there are no precise occupancy records in the data, it is possible to generate some estimates based upon direct and indirect questions asked in the community-level survey.

In STAR, community informants report the estimated occupancy rates of homes rebuilt by aid agencies after the tsunami. Table 7 presents the percentage of communities, by damage zone, reporting damaged housing stock, the breadth of subsequent rebuilding conditional experiencing damage, and the mean occupancy rates of these homes in the years that have passed since the tsunami (Columns 1-3). There is wide variation in reported occupancy, but it appears that mean aid home occupancy is roughly two-thirds to three-fourths of newly built aid-sponsored homes.

[11] Although data on sewage disposal continue until the fifth survey round of STAR in 2009-2010, data from this final round on this topic had not been confirmed

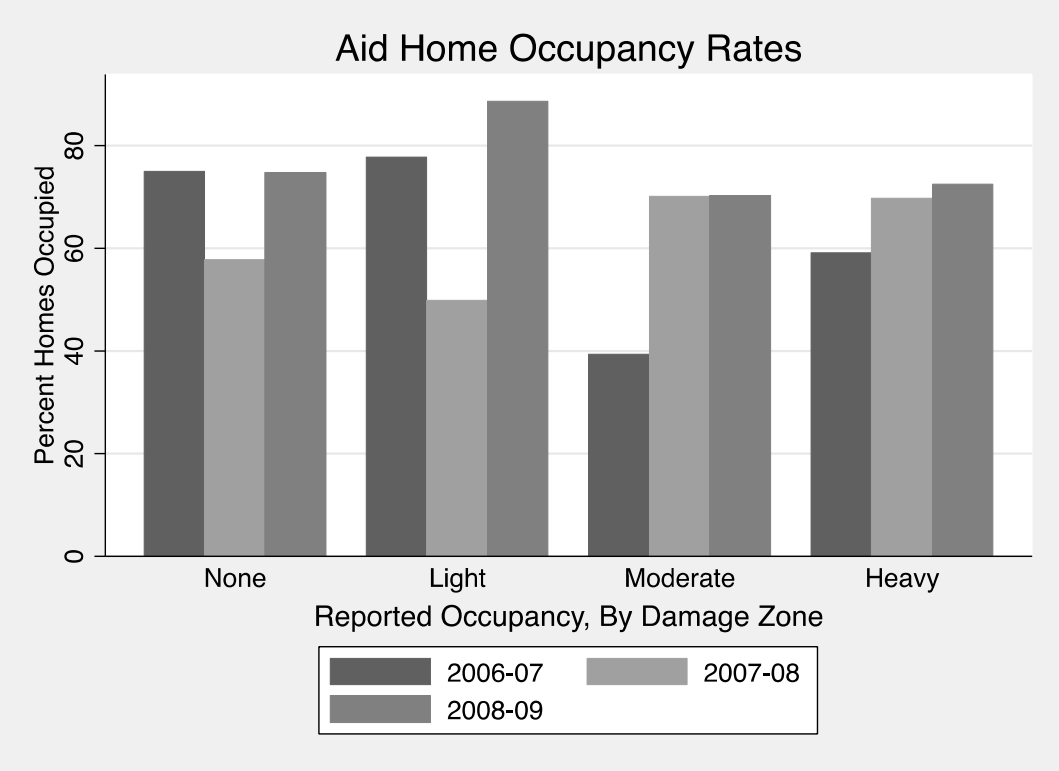


Figure 2: Occupancy rates of homes built in response to the 2004 tsunami.

Table 7: Changes in housing stock

	1	2	3	4	5	6
Damage Levels	**Reported Housing Damage**	**Aid homes built**	**Mean occupancy**	**Housing difference**	**Population Change**	
N	*(% Communities)*	*(% Communities)*	*(% Homes)*	*Rebuilt - destroyed*	*2005 - 2004 pop*	*2009 - 2004 pop*
Heavy	84.62	97.4	66.89	96.33	-43.18	2499.17
91	(0.038)	(0.018)	(3.51)	(33.90)	(21.78)	(639.77)
Moderate	69.66	87.1	71.86	-54.71	0.02	2387.32
89	(0.049)	(0.043)	(4.59)	(22.97)	(25.49)	(640.77)
Light	18.69	86.96	61.38	16.06	21.47	1013.96
123	(0.035)	(0.043)	(5.79)	(9.06)	(23.53)	(126.72)
None	10.67	87.5	66.87	3.74	-0.62	1240.5
75	(0.036)	(0.13)	(8.98)	(3.76)	(2.19)	(209.36)
Total	44.97	91.76	67	14.71	-4.7	1734.974
378	(0.026)	(0.021)	(2.47)	(10.17)	(10.79)	223.812

Another method of evaluating overbuilding is to compare the number of homes destroyed to the number rebuilt. It would be logical for aid efforts to focus on replacing homes destroyed by the tsunami, where possible taking into consideration population-reducing mortality. In absolute terms, home rebuilding appears to have exceeded destruction by the most in heavy damage zones. On average, roughly 100 extra homes were built by aid agencies since the tsunami. Average community populations increased by approximately 2,500 over the same time period (Table 7, Columns 4-6). The average Indonesian household has roughly 4.5 members. Even ignoring the possibility of non-tsunami related housing being built in these same communities, we can reasonably expect some of this housing to remain vacant. Conversely, areas of moderate damage experienced (on average) a net loss of homes while experiencing similar absolute population gain. This suggests that targeting may have led to overcompensation in heavy damage zones, while underproviding new homes in areas less affected but still in need.

Unfortunately, it is not straightforward to account for some factors that would profoundly impact housing stock. For example, there is anecdotal evidence of quick degeneration of aid homes built by certain agencies and the substitution of new aid homes for existing homes. Furthermore, differential mortality resulting from the tsunami almost certainly impacted living situations and created new housing demands. In consideration of these possible factors and others, these results can be merely suggestive.

There is, however, some evidence of overbuilding in the aftermath of the tsunami: namely, an overemphasis on rebuilding in heavily damaged areas that were the least likely, in consideration of mortality, to benefit from increased housing stock. Ultimately, the areas exposed to the most damage lost the most people but gained the most homes. This dynamic is not surprising, since the most exposed communities are not only the likeliest to suffer high mortality, but also receive the most attention from aid organizations. As unsurprising as it may be, however, it is also reasonably counterintuitive. Still, in the face of evidence of overbuilding in heavy damage zones, the overall trend in rebuilding is quite close to simply matching the number of homes destroyed by the disaster – that is, the overall gain or loss of housing stock is closer to zero than many critiques of aid delivery may lead one to expect.

4.4 Housing Quality & Aid Targeting

Turning to housing from the perspective of households rather than communities, we use STAR household data to observe the physical characteristics of Indonesian homes prior to the tsunami, the extent of destruction when the disaster struck in 2004, and the patterns associated with reconstruction.

Baseline characteristics

The household questionnaire provides a collection of indicators pertaining to home characteristics, including: building quality (new, refurbished, or old), roof type (concrete, tile, iron, leaves, sugar palm, or asbestos), floor quality (not dirt, or dirt), and toilet type (squatter, raised seat, or dry latrine). It is not possible to make welfare claims based upon a particular characteristic, but in some cases it is clear that some characteristics are more frequently associated with a modern, functional structure. In other cases, a change from one characteristic to another can be considered a "household innovation", or a modification that can broadly be considered desirable (from the viewpoint of either the household or the providing entity).

Characteristics are categorized according to the following order: new or refurbished builds versus old: concrete, tile or iron roofs versus roofs of asbestos, leaves, or palm; non-dirt floors versus dirt floors; and squat/raised seat toilets versus dry latrines or uncategorized. When stratifying by the four categories of damage, there are baseline differences in every category. In general, households located in the area of heaviest damage before the tsunami are associated with better housing characteristics in these four categories (see Table 8, Columns 1-6). This is likely to be a function of wealth, since coastal communities (those most likely to be exposed to tsunami damage) are generally better off than those more protected (i.e. further inland and less accessible).

Independence of destruction

Table 8, Column 7 reports rates of damage for homes that are owned by respondents. Homeownership is broadly similar across damage zones, but damage to respondent homes was roughly twice as common in heavy damage zones than overall. And while 77% of damaged homes in heavy damage zones received aid, only between 34 and 40% benefited elsewhere (Column 8).

Using model (3), we substitute tsunami damage to the home as the outcome measure and include the characteristics described in Table 9 to observe correlations between observed household characteristics and tsunami damage.

With respect to the homes damaged by the tsunami, none of the characteristics are highly predictive of damage. The first (full sample, including renters) and second (homeowner sample) columns of Table 9 show regression results for a linear probability model testing the association between the four household characteristics outlined above, expenditure, and damage to household (when including community fixed effects).[12] Of the independent variables, only "new/refurbished home" approaches standard levels of statistical significance (t=1.92) in column 1, and per-capita expenditure (t=1.72). Insured households were no more or less likely to experience damage.[13]

[12] A large number of homes (n=957) did not report presence or absence of damage. The same model can be used to test whether nonresponse is predicted by any obvious characteristics, or whether it is more or less random. Columns 3 and 4 suggest that log per-capita expenditure is strongly predictive of non-response (β=.04, se=.01). Superior roof type is negatively associated with non-response, an uninformative relationship given the lack of other characteristic-based relationships, but reinforcing of the previous result that better-off households were less likely to report on damage. Again, insurance is not an important predictor of the outcome. These results, while informative in providing information on which households were least likely to report, are ambiguous as to the ultimate outcome in which we are interested. The survey is structured to only ask homeowners whether or not their house was damaged by the tsunami. However, a reasonably large proportion of non-homeowners (~16% overall) still reported property damage. This analysis assumes that damage was reported if it occurred. In the worst-case scenario, results will only be representative of homeowners (80% of the selected sample). All relevant regressions are run twice: once with just homeowners, and once with the full populations; when necessary, differences between the two regressions are reported.

[13] Further regressions explore the relationship between homeownership and home quality (results not included). We find that log per-capita expenditure and new/refurbished home are positively associated with home ownership (t=1.94, 5.25, respectively). Overall, homeowners in 2004 are better off, and occupy more modern buildings, than non-homeowners.

Table 8: Household characteristics pre-tsunami & subsequent destruction

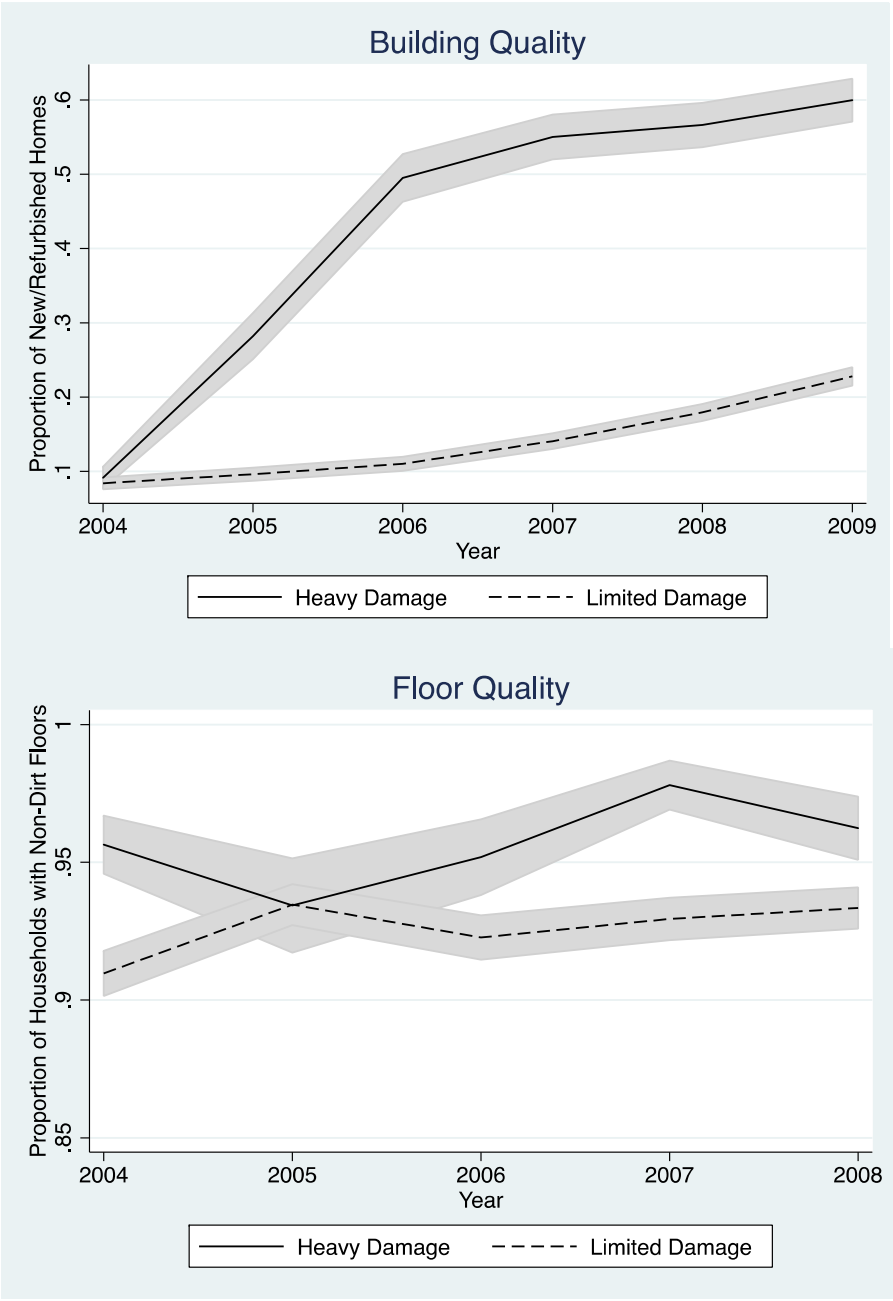
A: Baseline home characteristics

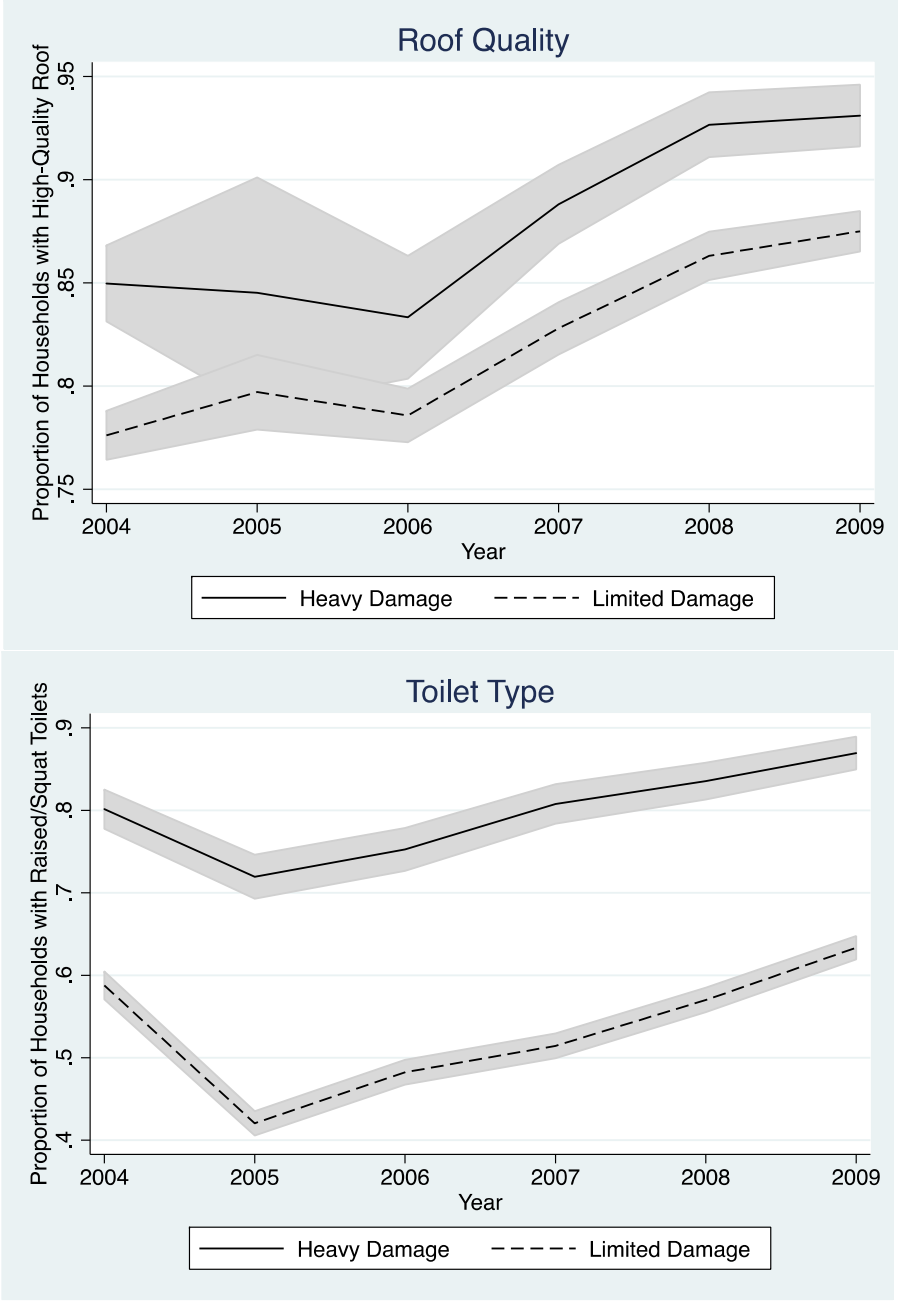
	1	2	3	4	5	6
Damage level	**Ownership**	**Log per-capita expenditure**	**Building**	**Roof**	**Floor**	**Toilet**
# households			*New/refurbished*	*Concrete/tile/iron*	*Not Dirt*	*Sitting/squatting*
Heavy	0.816	12.86	0.091	0.85	0.956	0.603
1444	(.011)	(0.015)	(.008)	(.009)	(.005)	(.013)
Moderate	0.77	12.63	0.082	0.71	0.905	0.403
1490	(.010)	(0.017)	(.007)	(.012)	(.008)	(.013)
Light	0.813	12.64	0.084	0.775	0.911	0.398
1964	(.010)	(0.012)	(.006)	(.009)	(.006)	(.011)
None	0.74	12.63	0.09	0.854	0.913	0.429
1285	(.012)	(0.015)	(.008)	(.010)	(.008)	(.014)
Total	0.783	12.69	0.086	0.793	0.921	0.454
6183	(.005)	(0.007)	(.004)	(.005)	(.003)	(.006)

B: Tsunami damage and reconstruction

	7	8	9	10	11	12
Damage level	**Damage***	**Aid receipt**	**Improvement to new or refurbished home (conditional on experiencing tsunami damage)**			
# households		2009-2010	2006-07	2007-08	2008-09	2009-10
Heavy	0.624	0.771	0.555	0.553	0.68	0.743
1444	(.015)	(.016)	(.019)	(.019)	(.018)	(.016)
Moderate	0.375	0.392	0.136	0.243	0.313	0.369
1490	(.014)	(.022)	(.016)	(.019)	(.021)	(.021)
Light	0.155	0.369	0.112	0.214	0.281	0.367
1964	(.009)	(.030)	(.018)	(.024)	(.026)	(.028)
None	0.088	0.34	0.117	0.245	0.32	0.346
1285	(.008)	(.048)	(.032)	(.043)	(.046)	(.047)
Total	0.292	0.553	0.316	0.37	0.467	0.531
6183	(.006)	(.013)	(.011)	(.012)	(.012)	(.012)

*Conditional on home ownership. This survey question was aimed at homeowners as a measure of asset damage.





Figures 5-8: Household characteristics, by damage zone. Including 95% confidence intervals (in gray). For floor quality, 2009 was omitted due to data concerns.

Table 9: Determinants of household damage

	Destruction	
	(1)	(2)
VARIABLES	All households	Homeowners
Expenditure	-0.00705	0.0249*
	(0.0122)	(0.0145)
Insurance?	-0.0302	-0.0335
	(0.0427)	(0.0555)
New/refurbished home?	0.0347*	0.00643
	(0.0181)	(0.0199)
Roof quality	0.00553	-0.0165
	(0.0148)	(0.0162)
Floor quality	0.00454	0.00987
	(0.0207)	(0.0223)
Toilet type	-0.0101	-0.0230
	(0.0147)	(0.0170)
Constant	0.375**	0.0362
	(0.154)	(0.182)
Observations	5222	3881
R-squared	0.525	0.602
F-test	0.527	0.478

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Trajectory of recovery: Household innovations

In order to observe changes in the household characteristics of interest, we use the more restrictive division of heavy versus limited damage. Figures 6-8 illustrate changes in building, roof, floor, and toilet quality between 2004 and 2010.

Building quality in heavy damage zones jumps after the tsunami, from less than 10% new/refurbished buildings in 2004 to roughly 50% in 2006. The trend toward building improvement is positive but slower thereafter. This sudden shift almost certainly reflects rebuilding after the event. In limited damage zones, a slight upward trend from 2004-2005 accelerates thereafter, but a large gap between areas of heavy and limited damage remains; based upon the post-tsunami jump in new/refurbished housing, this is likely to be the unsurprising function of the significant housing stock destroyed and subsequently replaced.

Columns 9-12 of Table 8 provide a more detailed view of the transition of homes reported damaged after the tsunami. We observe the proportions of homes self-identifying as refurbished or new for each subsequent year. While the shift is relatively fast in heavy damage zones, damaged homes in less exposed communities wait longer to experience repairs.

Of course, the quality of new housing stock is uncertain and, based upon observation and interviews, highly variable. The remaining characteristics help describe the nature of rebuilt homes. While the surge in new/refurbished homes began immediately after the tsunami, noticeable changes in roof quality (from asbestos/plant material to concrete, steel or tile) did not begin until roughly 2006, perhaps corresponding with shifts from semi-permanent to permanent housing stock. Heavy/limited damage zones increase proportions high quality roofing material at a similar rate from 2006 to 2009, but with heavy damage zones maintaining a distinctly higher

level of high quality roofs throughout the time period. Between 2006 and 2009, there is a 10-percentage point increase in the use of modern roofing materials independent of damage zone.

The impact of the tsunami is much clearer in the case of floor quality. While heavy damage zones begin with a distinctly higher proportion of non-dirt floors relative to limited damage zones, there is convergence in the aftermath of the tsunami. From 2006 to 2007, heavy damage zones show a clear increase, but the pattern after 2007 shows a diminishing proportion of non-dirt floors. Limited damage communities remain roughly stable after 2005.[14]

There is a declining proportion of households with raised/squat toilets between 2004 and 2005, and the decline is somewhat sharper in areas of limited damage. Toilet type is linked not only to household quality but community infrastructure, and this may serve as substantiating evidence of reports of otherwise unexposed communities being cut off from intra-community infrastructure as a result of the tsunami. In any case, there is an upward trend in raised/squat toilets from 2005 onward, at roughly the same rate across damage zones, with heavy damage zones enjoying roughly one-quarter higher prevalence (87% versus 63%).

There is an apparent higher quality of homes in the areas more exposed to tsunami damage, but this must be considered in light of the massive destruction that took place in December 2004 and the subsequent construction of many modern housing units designed to replace those destroyed. With the possible exception of floor quality, it does not appear that tsunami reconstruction has served to expand the prevalence of certain household-level innovations – such as improved building materials and interior conveniences – from more to less damaged communities of Aceh. However, the utility generated from the household innovations that accompany newer construction is not necessarily obvious.

Determinants of aid receipt

While the utility generated from the delivery of disaster aid for the recipient is arguable, it is almost certainly positive compared to the utility generated by non-delivery. As such, there is considerable interest in the nature of aid recipients. In particular, we may be interested in whether aid distribution serves to reinforce the existing social structure, which may be of interest to those in positions of authority over aid distribution itself (particularly that emanating from the government, or foreign aid organizations enlisting local assistance). Alternately, aid may to some extent level the playing field: if abundant wealth was destroyed when the tsunami struck and subsequent inflows of wealth are distributed without regard to pre-tsunami status, previously poorer households may benefit at the expense of those formerly better off.

In order to test for differential aid receipt at the household level, we use a linear probability model to predict aid (specifically, housing materials or grants for home construction or renovation) as a function of household and community characteristics, allowing for variation over the four periods in which respondents were specifically asked if, to date, money or materials for the purposes of home purchase or improvement were received:[15]

$$(5) \qquad \Pr(y_i=1 \mid x_i) = \beta_1 \text{Year} + \beta_2 \text{Damage} + \beta_3 V_h + \beta_4 Z_b + \gamma X_c + \epsilon_{ct}$$

[14] 2009-2010 data on the prevalence of dirt floors are under review at the time of writing.

[15] Home loans are indistinguishable from grants in the questionnaire, and as such are excluded in this analysis. The same regressions were also run with grant/loan information, and results are robust to the changes, with three exceptions: the relationship with *widow* is positive but statistically insignificant; *property disputes* is stronger and statistically significant in the full sample regressions (represented by Columns 3 and 4 in Table 10), and increased distance from urban centers does not consistently predict decreased probability of aid receipt (as observed in Table 10).

Table 10: Determinants of aid receipt among households

	Conditional on damage		Full Sample		Conditional on homeownership	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	EA FE	EA controls	EA FE	EA controls	EA FE	EA controls
2007	-0.00637	0.0128	-0.000734	0.0156	-0.00729	0.0194
	(0.0220)	(0.0185)	(0.0149)	(0.0129)	(0.0173)	(0.0146)
2008	0.00706	0.0121	0.0139	0.0189	-0.00232	0.0218
	(0.0264)	(0.0244)	(0.0172)	(0.0162)	(0.0198)	(0.0182)
2009	-0.835***	-0.880***	-0.889***	-0.914***	-0.899***	-0.906***
	(0.0196)	(0.0146)	(0.0120)	(0.00975)	(0.0141)	(0.0110)
Experienced damage?			0.0225***	0.0462***	0.0208**	0.0449***
			(0.00810)	(0.00692)	(0.00937)	(0.00775)
Own home?	-0.000617	0.00282	-0.00267	0.000756		
	(0.0180)	(0.0162)	(0.00723)	(0.00637)		
Expenditure	-0.00308	-0.00489	0.00776	-0.00641	0.0159**	-0.000506
	(0.0150)	(0.0102)	(0.00656)	(0.00463)	(0.00780)	(0.00536)
Insurance?	-0.0356	-0.0602	-0.0184	-0.0327	-0.0251	-0.0421
	(0.0533)	(0.0522)	(0.0252)	(0.0245)	(0.0331)	(0.0312)
Widow?	0.0187	0.0146	0.0241	0.0201	0.0200	0.0179
	(0.0340)	(0.0325)	(0.0166)	(0.0165)	(0.0182)	(0.0178)
New/refurbished home?	0.0342	0.0559***	0.00485	0.0183**	0.00120	0.0178*
(in 2004)	(0.0210)	(0.0191)	(0.00965)	(0.00920)	(0.0110)	(0.0102)
Elevation		-0.00363		-0.000392		-0.000408
		(0.00404)		(0.00124)		(0.00135)
Property disputes in EA		0.0257*		0.00608		0.0109
		(0.0141)		(0.00635)		(0.00727)
>50% homes damaged		0.0243**		0.0223***		0.0335***
		(0.0124)		(0.00784)		(0.00910)
<25 miles	[omitted]	[omitted]	[omitted]	[omitted]	[omitted]	[omitted]
<50 miles		-0.00135		-0.0129		-0.0136
		(0.0181)		(0.00815)		(0.00912)
<100 miles		-0.0188		-0.0254***		-0.0250***
		(0.0210)		(0.00772)		(0.00879)
>100 miles		-0.0161		-0.0192***		-0.0190**
		(0.0156)		(0.00709)		(0.00818)
Constant	0.987***	1.018***	0.819***	1.017***	0.729***	0.936***
	(0.194)	(0.137)	(0.0854)	(0.0636)	(0.101)	(0.0721)
Observations	1,472	1,472	4,798	4,798	3,739	3,739
R-squared	0.873	0.821	0.859	0.828	0.863	0.829
F-test	329.8	476.4	1086	1531	886.5	1286

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Where β_1 represents the effect of a particular year; β_2 the effect of a household experiencing damage from the tsunami; β_3 a set of household characteristics (including basic characteristics like log per-capita expenditure, and more complicated-to-interpret features like home insurance and widowhood status; β_4 features of the physical building, and γ a set of community characteristics. We alternately explore an identical model substituting μ_c, EA fixed effects, for γ.

For robustness, the model was used on three overlapping samples: all homes in the sample, exclusively those experiencing damage, and exclusively homeowners. In the first regression, EA fixed effects were absorbed into the regression; in the second, a set of community-level independent variables are instead used. Similar results are obtained, but the fixed effects version consistently produces a higher R^2, although the community characteristics chosen seem to do a reasonably good job of predicting aid flows.

Using a set of year indicators, we observe aid flowing at a constant pattern until year 5 (2009), which experienced a sharp drop-off (almost certainly attributable in part to saturation, with at that point roughly three-quarters of damaged homes in heavy damage areas already having received aid). Home ownership is not a predictor of aid receipt in these models, contrary to the arguments that homeowners received preferential treatment.[16] Households in which the head is a tsunami widow did not receive preferential treatment overall, and insured households were no more or less likely to receive aid. Log expenditure is also insignificant in all but one regression. Households in communities in which greater than 50% of homes were damaged were somewhat more likely to receive aid, and communities situated further (starting at 50 miles and moving out) were less likely to receive aid. Unsurprisingly, actual damage is an important indicator when the sample is not restricted to households with damaged homes. Finally, property disputes in the EA are positively correlated with aid receipt. Since it is difficult to imagine that being a less cohesive community would for any reason positively influence aid receipt, it is much more likely that increased aid receipt in certain communities generated conflict. There are no consistent patterns suggestive of discrimination or preference in aid distribution.

5 Discussion and Conclusions

The 2004 Indian Ocean tsunami was among the deadliest disasters ever recorded, and one of the largest earthquakes to register on the Richter scale to date. In addition to massive mortality, the direct economic costs of the subsequent tsunami were estimated at over $4 billion, with much more spent in subsequent reconstruction efforts. STAR data make it possible to draw a uniquely detailed picture of Aceh after the tsunami, and the way that reconstruction has remade communities throughout the province, including the many locations and households unaffected by the tsunami itself.

At the community level, the recovery of transportation infrastructure was apparently not isolated to areas most damaged by the tsunami. Instead, poorer and more rural communities seem to have experienced some of the same benefits as those better off and more exposed to damage. The same does not seem to be true for water and sanitation, where improvements appear more contingent on income and location. There is interesting evidence of aid dependency in terms of heavy damage communities continuing to utilize bottled water instead of central, protected sources, but this could also be argued to be a function of wealth, and may be health improving.

[16] Home ownership was also interacted with *year* indicators (results not shown) and found to be an insignificant predictor of aid receipt in any particular year.

Without a clearer approach it is difficult to conceptualize what actually constitutes overbuilding, and therefore to address that specific concern. However, it does appear that on average, reconstruction agencies did a remarkably accurate job of replacing housing destroyed by the tsunami. Where overbuilding may have taken place, it may be attributable to a failure to account for substantial mortality, the specifics of which were unlikely to be fully understood by the aid agencies operating throughout Aceh in the tsunami's immediate aftermath.

Evidence of household assistance receipt suggests that aid was distributed fairly independently of household characteristics. The majority of those homes experiencing home damage received aid, and conditional on damage, it does not appear that homeownership led to preferential treatment. Our main findings are robust to the inclusion of grants and loans, indicative of a broad-based distribution effort that suggests parity over reinforcement.

Future research would do well to uncover the work of particular types of organizations that operated in Aceh after the tsunami, the political economy of the recovery, and the household-level utility benefits of aid receipt. Higher order household effects of this global event – such as modified credit constraints, the impact of transformed household composition, or changes in educational and employment expectations – are of potentially high interest to future disaster response and development efforts.

The line between recovery from the tsunami and a remarkable development effort across Aceh is extremely blurry. This broader development – a result of not just massive aid flows, but the end of guerilla conflict and a united political front, among other things – emerges as the silver lining of the catastrophe experienced in 2004.

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