Findings

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RESILIENCE FINDINGS

Evacuation Decisions during the Great East Japan Earthquake

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We analyse evacuation decisions with data from a survey among 10,384 survivers of the 2011 Great East Japan earthquake. The decisions of individuals and families to evacuate or stay are influenced by the Tsunami warning system as well as the behaviour of the surrounding population which is modelled as the percentage of persons evacuating from a city. We formulate binary choice models with "field effects" where we try to control for the endogeneity with a 2-stage model approach. Our results quantify the field effect and suggest that with each minute the Tsunami warning arrives later, on average 3% less of the population are evacuating and surviving. We also show the importance of other variables, in particular the preparedness measures such as signage and evacuation drills.

1. Questions

The Great East Japan earthquake was a magnitude 9.0 earthquake off the coast of Japan that occurred at 14:46 JST on March 11th, 2011. It was the most powerful earthquake ever recorded to have hit Japan. The earthquake triggered powerful Tsunami waves that reached heights of up to 40.5 meters in Miyako, Iwate Prefecture and in the Sendai area the Tsunami waves travelled up to 10 km inland.

Soon after the earthquake, Tsunami warnings were issued. Nevertheless, some people decided not to evacuate. We aim to understand factors influencing evacuation decisios. In particular we analyse how relevant the Tsunami warning system was; aiming to expand on results discussed in Yun and Hamada (2015) or Suppasri et al. (2013). Previous research has shown that responses to evacuation orders and warnings differ (Duanmu, Chowdhury, and Taaffe 2011). Our third questions is whether "field effects" are significant, that is, how important the influence of others is on evacuation. Previous literature has shown that following behavior is important for evacuation success but also creates congestion (Slucki and Nielek 2015; Teo et al. 2015). Also, simulation studies related to the Great East Japan earthquake have shown the importane of social network effects in evacuation modelling (Takabatake et al. 2017; Makinoshima, Oishi, and Imamura 2022).

2. Methods

The data used for this research are taken from the Reconstruction Assistance Survey Archive website (RASA 2015) and are based on a survey from the Ministry of Land, Infrastructure and Transport (MLIT) in August 2011. We could utilise 10,603 samples from six prefectures in the hit regions; namely Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba prefecture. After some data cleaning, 10,384 observations and several explanatory variables were extracted. These variables can be grouped into sociodemographic ones (age, gender, occupation), their preparedness for the Tsunami (whether the person knows evacuation routes, knows the shelter location, has participated in Tsunami drills, etc.), whether and when the person has obtained a Tsunami warning, as well as the person's and his family's location during the earthquake.

We firstly employ a standard binary logit choice model with utility function (1).

$$U_{n_m} = V_{n_m}\left(\mathbf{s}_{n_m}; \mathbf{r}_m; \beta\right) + \varepsilon_{n_m} \tag{1}$$

The dependent variable U_{n_m} describes the perceived utility to choose {evacuate} compared to {not evacuate} after the earthquake for person n in city m with an explainable part V_{n_m} and an error term ε_{n_m}. A set of person specific dependent variables $\mathbf{s}_{n_m}$ and city specific dependent variables $\mathbf{r}_m$ are used to explain the differences in evacuation decisions. City specific dependent variables $\mathbf{r}_m$ are Tsunami warning time (measured in minutes after the earthquake occurred) population density, the percentage of area flooded and whether or not the city is a harbour city. The survey respondents come from 41 cities shown in Figure 1. We note that one important limitation of our data is that Tsunami warning time is given by the prefecture so that we do not observe variance in this variable among cities from the same prefecture. Also, percentage road flooded might be more appropriate than area.

To answer our questions whether field effects are significant, we add these variables to our utility function. Not controlling for endogeneity yields

$$U_{n_m} = V\left(\mathbf{s}_{n_m}; \mathbf{r}_m; \beta\right) + \gamma F_m + \varepsilon_{n_m} \tag{2}$$

where F_m describes the percentage of persons choosing to evacuate in city m and γ denotes the field effect parameter. This naïve model ignores that F_m will be correlated with both s_{n_m} and r_m, which is likely to lead to an upward biased estimation of γ and a too low estimate for β. To account for these correlations, following Goetzke and Andrade (2010), we use a 2-stage model. The first step is a binary logit model with

$$d_{n_m} = \theta^T \mathbf{s}_{n_m} + \varepsilon_{n_m} \tag{3}$$

where d_{n_m} takes the value of one if person n in city m decides to evacuate and zero otherwise. The parameters θ^T are used to obtain the fitted field effect for decision {evacuate} as the expected decision by firstly obtaining the estimated aggregate P_n using all person-specific variables. These probabilities are subsequently used to obtain the fitted value of evacuation decisions in city m, $\widehat{F}_m$, as in (4) which is in then inserted in the utility function in (5).

$$\widehat{F}_m = \sum_{n \in m} P_n \left(\{evacuate\} \middle| \theta^T \right) \tag{4}$$

$$U_{n_m} = V\left(\mathbf{s}_{n_m}; \mathbf{r}_m; \beta\right) + \gamma \widehat{F}_m + \varepsilon_{n_m} \tag{5}$$

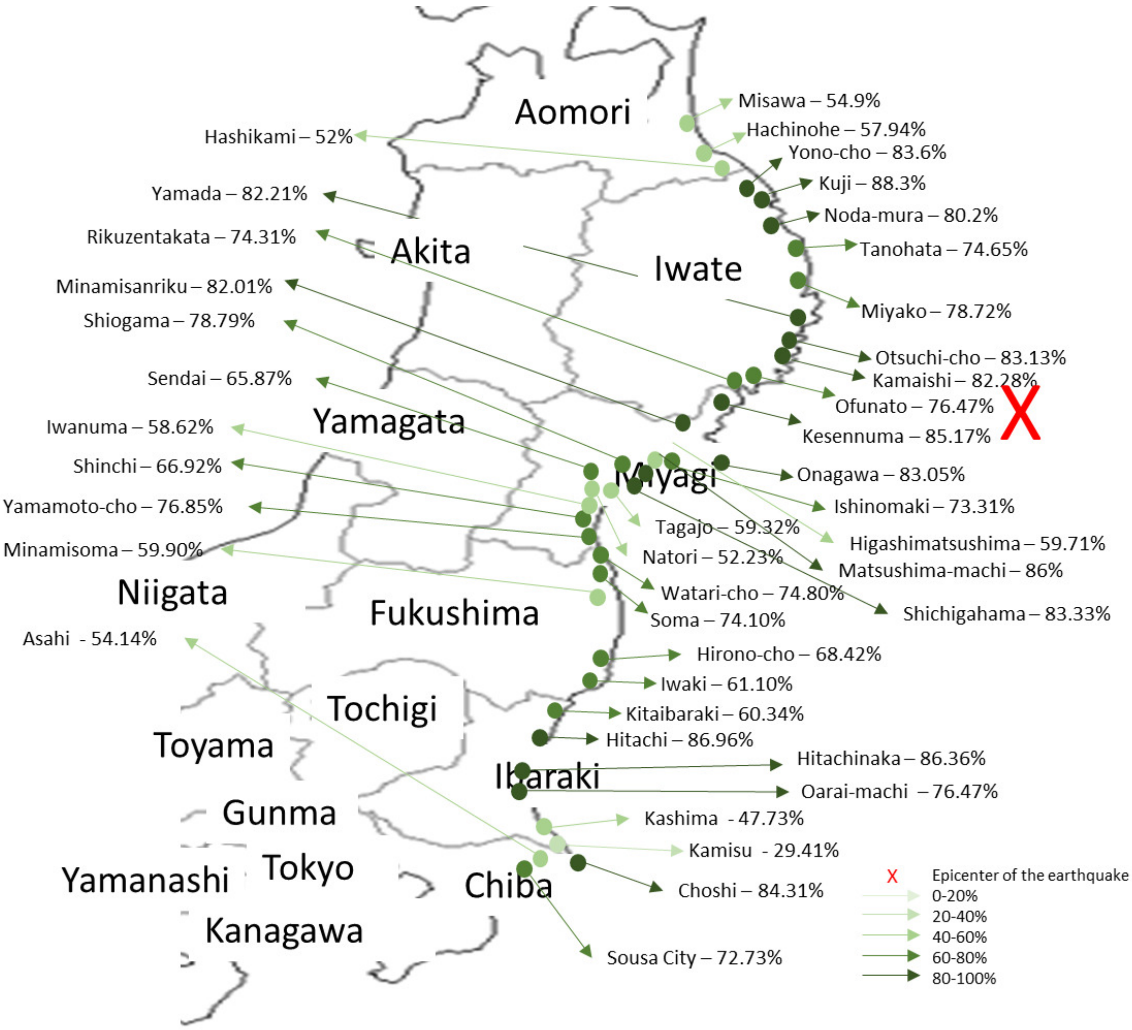

Figure 1. Proportion of population evacuating in each city.

3. Findings

The model results are shown in Table 1. The low R^2 value is suggesting that our independent variables have only limited explanatory power. An important reason for this is that we do not have more detailed information on the person's location than the city in which s/he is living. Nevertheless, we observe that the estimated parameters are mostly significant.

Parameter estimates show that Tsunami warning has a positive significant impact on evacuation decisions, which means that people who heard the Tsunami warning are more likely to evacuate. People who have family at home are also more likely to evacuate, especially compared to those who have family at work. Gender is only significant at the 10% level where men are less likely to evacuate. That women are more likely to evacuate is in line with findings discussed in e.g. Murray-Tuite and Wolshon (2013). Further, living near the harbour, having prepared for a Tsunami and having seen signboard information also have positive significant impacts on evacuation decisions. The Tsunami warning time has a negative significant parameter estimate. This indicates that the quicker people obtain the warning from government after the earthquake the more likely a person is to evacuate.

We add the fully standardized parameters in order to allow for a comparison in magnitude. These highlight the importance of the Tsunami warning for evacuation decisions. The warning is even more important than locational variables such as whether the person is living near the harbour or not. We note though one tragic bias in our data, in that obviously surveys are not obtained from those perishing during the disaster. Therefore, in fact our results should be interpreted as factors determining "evacuating and surviving". Given this bias we can interpret the standardized value as follows: With the increase in one standard deviation of Tsunami warning time, which is 7 minutes, people are 21% less likely to evacuate. In other words, each minute the Tsunami warning time arrives later, means that on average 3% less of the population are evacuating and surviving. The variable with the second largest standaridized effect is the preparedness of individuals. We hence find strong evidence that indeed Tsunami warning drills, distribution of shelter information and general campaigns encouraging residents to consider actions to be taken in case of a Tsuanmi have indeed an effect on the evacuation behaviour.

The result for the naïve model suggests that the field effect has a positive significant impact on evacuation decisions, in line with our hypothesis. Living near the harbour and the Tsunami warning time become insignificant. Generally, though the effect of other variables remains largely the same as in our base model. Considering the standardized values, we observe that the field effect variable is of similar importance to evacuation as to whether the person has heard the Tsunami warning.

Table 1. Model Results

	Base Model		Naïve Model		2-Stage Model		
					Step 1	Step 2	
	Estimate	Stdz. Est.	Estimate	Stdz. Est.	Estimate	Estimate	Stdz.
ASC	**1.26**		**-1.01**		**1.17**	**1.10**	
Person specific							
Male	*-0.05*	*-0.11*	*-0.05*	*-0.11*	**-0.05**	*-0.04*	*-0.10*
Heard Tsunami Warning	**0.39**	**0.86**	**0.35**	**0.77**	**0.37**	**0.39**	**0.87**
Family at home	**0.13**	**0.15**	**0.12**	**0.13**	**0.13**	**0.14**	**0.16**
Family at work	**-0.11**	**-0.13**	*-0.09*	*-0.10*	**-0.11**	**-0.10**	**-0.12**
Family at kindergarten	*0.19*	*0.11*	**0.22**	**0.12**	*0.20*	*0.21*	*0.12*
Live near harbour	**0.24**	**0.29**	0.04	0.05	**0.28**	**0.26**	**0.31**
Preparation	**0.28**	**0.67**	**0.28**	**0.65**	**0.30**	**0.27**	**0.65**
Seen sign	**0.10**	**0.23**	*0.06*	*0.14*	**0.10**	**0.10**	**0.23**
City specific							
Tsunami warning time	**-0.01**	**-0.21**	0.00	0.04		**-0.01**	**-0.16**
Population density	*-0.01*	*-0.11*	0.00	0.01		0.00	-0.07
Flooded area density	*0.01*	*0.12*	0.00	-0.02		*0.01*	*0.13*
Harbor city [dummy]	0.00	0.09	0.00	0.04		0.00	-0.13
Field effect							
Fitted evacuation (sum in city)			**3.14**	**0.78**		**0.21**	**0.30**
Sample Size N	10384						
AIC (Pseudo R2)	10620 (0.05)		10532 (0.06)		10678 (0.05)	10651 (0.05)	

Note: Bold p value<0.05; Italic p value <0.1; Stdz: standardized value

Compared to the naïve model, signage information and flooded area density become significant in the 2-SLS model because the endogeneity problem is corrected to some extent. That is, here $\widehat{F}_m$ might be interpreted as the "expected evacuations independent of the geographic characteristics of the city".

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