Migration Response to Tsunami Risk: Evidence from Nankai Trough Earthquake Predictions in Japan[*]

Michio Naoi, Associate Professor, Keio University (corresponding author)
naoi@econ.keio.ac.jp
+81-3-5418-6581
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
Keiichi Sato, Associate Professor, Senshu University
Shingo Nagamatsu, Professor, Kansai University
Hiroaki Matsuura, Provost and Vice President, Shoin University

Abstract

We exploit the release of the Central Disaster Management Council's updated tsunami prediction as a natural experiment, and identify the causal impact of tsunami risk on human migration across municipalities in Japan. Our empirical analysis is based on the municipality-to-municipality migration flows taken from the 2010 and 2015 census of Japan, covering both before and after the release of tsunami predictions. With over 530,000 migration flow observations, we find that higher tsunami predictions can increase the outflow from the municipality and decrease the inflow into the municipality, particularly among younger population. Our empirical findings are robust to the inclusion of various controls such as demographic and socio-economic characteristics, unobserved municipality-level fixed effects, and the impact of 2011 Tohoku earthquake. Further empirical analysis suggests that migration responses are weaker in municipalities by which extensive disaster management and loss prevention activities have already been undertaken in advance.

Keywords: Earthquake, Tsunami, Human migration
JEL codes: Q54, Q58, R23

---

[*] Paper prepared for the International Conference on Sustainable Development. We would like to thank Takaaki Hattori and Yuko Karasawa for their helpful comments and suggestions. We would also like to thank Yozo Tanaka with his help in collecting and constructing the dataset for the empirical analysis. This research was supported by JSPS KAKENHI Grant Number JP17H02072 (Nagamatsu) and the MEXT-supported Program for the Strategic Research Foundation at Private Universities (Naoi).

1 Introduction

Large natural disasters cause catastrophic impacts on affected areas, claiming countless human lives, destroying homes and local infrastructure, and devastating economic activities. In 2011, a magnitude 9.0 earthquake and its subsequent tsunami struck northeastern Japan along the Pacific coast, resulting in a loss of nearly 20,000 human lives. In response to this catastrophic event, the Central Disaster Management Council (CDMC), which is a governmental committee for disaster management planning, released the latest report on the estimated damages from the next Nankai Trough earthquake. The Nankai Trough and its underlying fault are the major source of the future devastating earthquake in Japan. The new report includes the estimated tsunami height for each municipality, which was made public in August 2012 and was updated from the previous one released in 2003.

We exploit the release of the CDMC's updated tsunami predictions as a natural experiment, and identify the causal effect of these updated predictions on human migration across municipalities. Moving to alternative locations is a form of risk mitigation strategies. People can out-migrate from risky areas or in-migrate into safer areas to protect themselves from the potential risks of disasters.

There have been several empirical studies that have explored the migration responses to natural disaster risks. For example, Boustan et al. (2012), using U.S. Census in the 1920s and 1930s, investigate the impact of past disaster experiences—floods, tornadoes, earthquakes and hurricanes—on the regional migration inflows. They find that young men tend to move away from areas hit by tornadoes but are attracted to areas experiencing floods. Fan and Davlasheridze (2016) investigate the effects of community flood risks and flood mitigation policies, which are made available through the NFIP's Community Rating System (CRS) program, on the individual location choices.

Our empirical analysis improves previous literature in a number of ways. First, this paper focuses on disaster risk information rather than the past disaster experiences. Most previous studies use past disaster experiences or frequencies as a measure of potential disaster risk. Recent natural disasters can affect migration patterns through changes in the resident's risk perceptions toward future events. However, they can also affect migration patterns through government's disaster relief activities or their direct impact on labor market and employment conditions, posing significant challenges for the identification of the potential disaster risks on migration. In comparison, our paper examines the impact of updated risk information rather than past experiences of disasters. This enables us to focus exclusively on the informational aspect of future disasters.

Second, the current paper improves identification strategies used in previous literature.[2] We utilize panel data covering the periods both before and after the release of new risk information. This enables us to control for unobserved location factors that are associated with both disaster risks and migration patterns.

Third, our migration data is based on the most detailed and reliable source of the population inflows and outflows across municipalities. Our dataset covers migration flows

---

[2] In a related but different strand of the literature, several empirical studies use hedonic approach to explore the impact of natural disaster risks (Brookshire et al., 1985; Troy and Romm, 2004; Naoi et al. 2009; Nakanishi, 2016; Votsis and Perrels, 2016).

between all possible pairs of origin and destination municipalities. This data structure allows us to separately identify the impact of tsunami prediction in the place of origin as well as that in the place of destination. Updated tsunami predictions can influence both population outflows and inflows. People tend to move away from risky areas (the impact of predictions at the origin) and to choose safer areas (the impact of predictions at the destination).

Our empirical analysis shows that higher tsunami predictions can increase the outflow from the municipality and decrease the inflow into the municipality, particularly among younger population. Our empirical findings are robust to the inclusion of various controls such as demographic and socio-economic characteristics, unobserved municipality-level fixed effects, and the impact of 2011 Tohoku earthquake. Further empirical analysis suggests that migration responses are weaker in municipalities by which extensive disaster prevention activities have already been undertaken in advance.

Organization of the rest of the paper is as follows. Section 2 describes the dataset and variables. Section 3 sets out our empirical model and provides empirical results. Finally, section 4 concludes

2 Data and Variables

2.1 Migration

Our measure of migration is based on a question in the Japanese census that asks respondents where they lived five years before. The Japanese census is conducted every five years and we utilize the 2010 and 2015 censuses to calculate the migration flow between all pairs of origin and destination municipalities. The implied five-year migration rate from municipality i (origin) to municipality j (destination) is defined as

$$y_{ijt} = \frac{M_{ijt}}{N_{i,t-5}}, \tag{1}$$

where t indexes the survey years ($t = 2010, 2015$), M_{ijt} is migration outflow (i.e., number of migrants) from municipality i to municipality j, and $N_{i,t-5}$ is the population size of municipality i in the base period (i.e., five years prior to the census survey year). We also define the age-specific migration rates based on the migrant's ages and age-specific base-year population.[3]

In the following regression analysis, we use the log of five-year migration rates as our dependent variable. As mentioned earlier, the CDMC released the updated tsunami predictions in August 2012. Therefore, five-year migration rates between 2010-2015 are subject to this updated predictions, whereas those between 2005-2010 are presumably unrelated to these updates (but are subject to previous ones released in 2003).

---

[3] For expositional purposes, age-specific migration rates are calculated for three age categories—ages 20-39, 40-59 and 60 and over.
For base-year populations,

2.2 Tsunami Predictions of the Nankai Trough Earthquake

As mentioned earlier, the new report released by the CDMC estimated the possible tsunami height for each municipality, which were updated from the previous ones released in 2003. The new report conveys updated information on tsunami damages to the current and future local residents.

The original analysis of the report simulates the possible tsunami height for each 10m grid cell all over Japan. Based on these simulations, the report provides two distinct measures of tsunami predictions. The first one is the average tsunami height, which is the average value of the predicted heights over all the 10m grid cells within each municipality.[4] The second one is the maximum tsunami height, which is the maximum value of the predicted heights over all the grid cells within municipality. Upon their release, these two predictions are extensively covered by the media including nationwide newspapers and major TV news programs, thereby widely recognized by the general public.

In the following analysis, we use these average and maximum tsunami predictions as our measure of updated tsunami risk information. As for the maximum prediction, we use the changes in its value from the previous 2003 report in order to capture the additional informational content conveyed by the 2012 report. As for the average prediction, the same information is not available in the 2003 report. We therefore assume that average values themselves are the new information to the local residents and use them as our measure of updated risk information.

(Table 1 around here)

Table 1 shows the distribution of municipalities in terms of the average tsunami predictions and the changes in maximum predictions between 2003 and 2012. Of all 1,741 municipalities in Japan, tsunami events are anticipated in 376 municipalities. Most of these municipalities are from coastal areas in the Disaster Management Zone (DMZ), which is the government designated area where significant damage from the Nankai Trough earthquake is expected and various disaster management regulations are enforced.

As for the maximum tsunami height, more than half of DMZ municipalities in our sample (N = 419) did not have any changes in their tsunami predictions, most of which are from inland municipalities (N = 383) where no tsunami damages are predicted both in 2003 and 2012 reports.[5] Changes in predicted tsunami height vary substantially among coastal areas. While small number of coastal municipalities (N = 30) did not have any changes in their tsunami predictions, changes in tsunami height are as high as 25m in some municipalities.[6]

---

[4] More specifically, the original CDMC's analysis conducted separate simulations based on eleven different seismic scenarios, where each scenario assumes movement of different segment of underlying faults. Our average measure is the maximum value of the averages under these eleven different scenarios.

[5] There is only one inland municipality that have non-zero predicted tsunami height. Excluding this municipality from our sample does not change our empirical results.

[6] There is six municipalities that have lower tsunami prediction in the 2012 report than in 2003 report. All of these municipalities experienced less than one meter decrease in the predicted tsunami height.

2.3 Data

We compiled the longitudinal data covering the period 2008-2015. Our observation unit is pair of origin and destination municipalities. In 2010, there are total of 633,020 origin-destination municipality pairs for which at least one person migrates between these pairs of municipalities. In 2015, total number of municipality pairs used in our empirical analysis is 610,798.

In the following analysis, we will use various subsamples in order to estimate the causal impact of tsunami predictions on migration patterns. We will return to the detailed discussion about our subsample definitions in the next section.

Our first subsample focuses on outmigrations from areas that are likely to be affected by the Nankai Trough earthquake. We restrict our sample to migrations away from DMZ municipalities or from coastal municipalities that have non-zero tsunami predictions. We will test whether updated risk information would have any impacts on population outflow from these potentially risky areas. Our second subsample looks at migration into areas that are likely to be affected the Nankai Trough earthquake. In this case, the destination can either be municipalities in the DMZ or coastal municipalities with non-zero tsunami predictions. This enables us to test whether updated risk information would have any impacts on population inflow into these areas. Figure 1 illustrates the location of municipalities used in the following analysis.

(Figure 1 around here)

3 Empirical Analysis

3.1 Empirical Model

Our benchmark regression model is given as follows:

$$\ln(y_{ijt}) = \beta_0(d_t \times h_i) + \beta_1(d_t \times h_j) + x'_{i,t-5}\gamma_0 + x'_{j,t-5}\gamma_1 + z'_{ij}\theta + u_{ijt}, \qquad (2)$$

where subscript i and j denote origin and destination municipalities, respectively, and t denotes survey year. $\ln(y_{ijt})$ is the five-year migration rate from municipality i to municipality j in year t.

The impact of updated risk information can be evaluated by the coefficients β_0 and β_1. The two interaction terms, $(d_t \times h_i)$ and $(d_t \times h_j)$, represent the updated risk information by the CDMC's new report, where d_t is a dummy variable for the period after the release of the 2012 report (i.e., $d_t = 1$ if $t = 2015$), and h_i and h_j represent tsunami predictions at origin and destination municipalities, respectively. As mentioned earlier, we use two different measures for h_i and h_j—the average tsunami height and the changes in maximum predictions from the 2003 report.

In addition to tsunami predictions, we also control for a number of municipality-level characteristics that can influence the migration patterns. These control variables include: income per capita, population size, population density, population share of selected age groups (by ten-year age intervals), and share of workers who live and work in the same municipality. We control for characteristics of origin municipalities $(x_{i,t-5})$ as well as destination municipalities $(x_{j,t-5})$, both measured at the base year (i.e., five years prior to the census survey year). Furthermore, since inter-regional mobility is closely related to the distance between origin and destination places, we also control for the distance between municipality i and municipality (z_{ij}). In order to deal with possible nonlinearity, we include up to third order polynomial terms for distance variable.

There are several empirical challenges in identifying the causal effects of updated risk information on migration patterns based on Equation (2). First, omitted municipality characteristics that are related to both tsunami predictions and migration patterns can bias our estimates from Equation (2).[7] In order to cope with potential omitted variables problem, we exploit the panel structure of our dataset and control for fixed effects for origin and destination municipalities.[8] Specifically, we model the error term in Equation (2) as follows:

$$u_{ijt} = \eta_i + \xi_j + \phi_t + \varepsilon_{ijt}, \tag{3}$$

where η_i and ξ_j represent unobserved, time-invariant fixed effects for origin and destination municipalities, respectively. In addition, our specification in Equation (3) accounts time effects, ϕ_t.

Second, the 2011 Tohoku earthquake can affect the migration patterns in coastal areas. A powerful tsunami triggered by the 2011 earthquake caused enormous devastation across the northeastern coastal areas of Japan. The devastating impact of this tsunami event might change the migration patterns in a way that people move away from the coastal areas and choose inland areas instead. This can also bias our estimates based on Equation (2). The changes in migration patterns described above can increase the outmigration from coastal areas where mostly non-zero tsunami predictions are observed. Similarly, inland municipalities can attract more inmigration. As a result, regression analysis based on Equation (2) using both coastal and inland municipalities as a regression sample can yield spurious correlation between tsunami predictions and migration rates. In order to address this issue, we will use subsamples in which origin or destination is restricted to coastal municipalities. In these subsamples, we will only exploit variations in predicted tsunami height within coastal municipalities to see the impact of updated risk information.

3.2 Benchmark Results

Our benchmark regression results are presented in Table 2. All estimations include standard control variables and municipality and year fixed effects, but the coefficient

---

[7] Sample selection bias can also be an issue because our dataset only includes origin-destination municipality pairs with positive migration flows $(y_{ijt} \neq 0)$. In addition, log-linearized gravity models as in Equation (2) can yield biased elasticity estimates in the presence of heteroscedasticity. A detailed discussion of this issue can be found in Santos Silva and Tenreyro (2006).

[8] In order to check the robustness of our results, we also estimate the models which control for the fixed effects of possible municipality OD "pairs." This does not change our main empirical findings. Results are available upon request.

estimates of these control variables and fixed effects are not reported in the table. In the following analysis, we present the heteroscedasticity robust standard errors.[9]

(Table 2 around here)

The first two columns in Table 2 show our regression results using subsample in which origins are DMZ municipalities or are coastal municipalities in the DMZ. Overall, these results indicate that people tend to move away from municipalities with higher tsunami predictions, and are less likely to move into municipalities with higher predictions.

As for the effect of tsunami predictions at the origin municipalities, the size of coefficient estimates is relatively small and are not significant when we use the DMZ municipalities (which include both inland and coastal municipalities). As discussed earlier, the 2011 Tohoku earthquake can change the migration patterns in a way that people tend to move away from coastal areas and are attracted to inland ones. As a result, our coefficient estimates can be biased upward when we use both coastal and inland municipalities as a regression sample. Our regression results presented in columns [1] and [2], however, indicate that this is in fact not the case. Coefficient estimates for the tsunami predictions at the origin municipalities are not only larger but also statistically significant when we restrict our sample to coastal municipalities.

Our results indicate that tsunami predictions at the destination municipalities also matter for explaining the migration between the specific pair of municipalities. A higher tsunami prediction at the destination is significantly and negatively related to the migration rate.

Columns [3] and [4] present our regression results using subsample in which destinations are DMZ municipalities or are coastal municipalities in the DMZ. In this case, the coefficient on tsunami predictions at origin municipalities cannot be estimated because we choose non-DMZ municipalities (where no tsunami events are anticipated) as an origin of migration. Our results indicate that, regardless of the choice of tsunami prediction measures (average/maximum) and subsample definitions, tsunami predictions at the destination municipalities are always significantly and negatively associated with migration rate.

3.3 Age-Specific Migration Rates

In this subsection, we compare migration responses between different age groups. Specifically, we use age-specific migration rates as our dependent variable and run the same regression models as Equation (2). We have three age categories for this analysis: migration rates for people aged between 20-39, aged between 40-59, and aged 60 and older.

Regression results are presented in Tables 3 and 4. Table 3 presents regression results using sample of municipality pairs where origin municipalities are in the DMZ or are coastal ones in the DMZ. The results indicate that, for tsunami predictions at origin municipalities, statistically significant and positive effect can be found only for the sample of young population (i.e., aged between 20-39) and for the case when we use maximum predictions

---

[9] To check the robustness of our results, we also compute the standard errors clustered by municipality OD pairs. This, however, does not change our main findings.

as a risk measure. This has the following two implications. First, higher tsunami predictions will increase the likelihood of outmigration only for the young population, but are generally unrelated to migration patterns of older population. This observation is consistent with the previous finding by Boustan et al. (2012). Second, migration patterns among young population is significantly associated with the changes in maximum predictions, but not with average predictions. This implies that the former measure conveys new information to local residents while the latter does not.

(Table 3 around here)

On the other hand, for tsunami predictions at destination municipalities, statistically significant and negative effects can be found for migration rates of people aged between 20-29 and those between 40-59. Again, migration patterns of relatively older population (aged 60 and older) are not significantly associated with updated risk information.

(Table 4 around here)

In Table 4, we examine the impact of updated tsunami predictions in DMZ municipalities on the migration inflow into these municipalities. The results indicate that an increase in predicted tsunami height will reduce the migration inflows into the municipality in question, and this can be observed only for relatively younger populations.

In summary, our regression results for age-specific migration rates indicate that the CDMC's updated tsunami predictions increased the net outmigration among younger population, whereas they did not generally affect migration patterns among elderly.

Our empirical results above have particularly important implications for disaster policy and planning. It is well-known that the elderly population are disproportionately vulnerable to natural disasters (Cutter et al., 2003). In fact, the 2011 earthquake and its subsequent tsunami took the heaviest toll on the elderly, about 65% of the earthquake and tsunami-related deaths were people aged 60 and older, which was far larger than the elderly population share of about 30% in the affected areas (Cabinet Office, 2011). Our results that elderly population are less likely to respond to updated hazard information suggest that the dissemination of hazard information cannot reduce, or might even increase, the social vulnerability at the local level.

3.4 Past Disaster Management Program

Given the historic regularity of the Nankai Trough earthquakes, the Japanese government has been putting an enormous effort into disaster management and loss prevention programs targeting areas likely to be affected by this specific earthquake.[10] In this subsection, we examine whether migration responses to the updated tsunami predictions are different depending on the government's past disaster management program.

In 1979, the Japanese government first designated 96 municipalities as an area where extensive disaster management and loss prevention activities are required against the

---

[10] There are a number of scientific studies showing that the earthquakes along the Nankai megathrust have occurred repeatedly in the past, with a return period of approximately 90 to 200 years.

Tokai earthquake.[11] The designated municipalities are expanded in 2002 when 61 municipalities are additionally designated. These designated municipalities can receive additional funding from the central government for the specific disaster management and loss prevention programs. The municipalities are also required to formulate a disaster management plans at the local level.

(Table 5 around here)

In Table 5, we compare the migration responses to the updated tsunami predictions in municipalities that are designated as a Tokai earthquake disaster management area with those in non-designated municipalities. Columns [1] and [2] give the results for non-designated municipalities, columns [3] and [4] are for municipalities that were designated in 2002, and columns [5] and [6] are for those designated in 1979. In all estimations, sample is restricted to pairs of municipalities where destination is in the DMZ (or is coastal municipality in the DMZ).

The results indicate that the updated tsunami predictions are significantly related to migration rates only when the origin municipalities are not designated as the Tokai earthquake disaster management area. In comparison, updated predictions are in most cases not related to the outmigration from municipalities that have already been designated (either in 1979 or in 2002). These results suggest that, since extensive disaster management and loss prevention activities have been undertaken in designated municipalities, migration responses to the CDMC's updated risk information are weaker in these municipalities.

4 Conclusion

In this paper, we examined the effect of the dissemination of updated hazard information on inter-municipal human migration. We exploited the release of the CDMC's updated tsunami prediction as a natural experiment, and estimated the causal effect of tsunami risk on migration rates across municipalities in Japan. Our empirical analysis is based on the municipality-to-municipality migration flows taken from the 2010 and 2015 census of Japan, covering both before and after the release of tsunami predictions.

We found that higher tsunami predictions can increase the outflow from the municipality and decrease the inflow into the municipality, particularly among younger population. Our empirical findings are robust to the inclusion of various controls such as demographic and socio-economic characteristics, unobserved municipality-level fixed effects, and the impact of 2011 Tohoku earthquake. Further empirical analysis suggests that migration responses are weaker in municipalities by which extensive disaster prevention activities have already been undertaken in advance.

---

[11] The Tokai earthquake is the one that occurs by the rupture of the northeastern segment of the Nankai megathrust. Hence, it can be thought of as a part of the Nankai Trough earthquake.

References

Boustan, L.P., M.E. Kahn and P.W. Rhode (2012) “Moving to Higher Ground: Migration Response to Natural Disasters in the Early Twentieth Century,” *American Economic Review*, 102(3), 238-244.

Brookshire, D.S., M.A. Thayer, J. Tschirhart and W.D. Schulze (1985) “A Test of the Expected Utility Model: Evidence from Earthquake Risks,” *Journal of Political Economy*, 93(2), 369-389.

Cabinet Office (2011) *White Paper on Disaster Prevention 2011 (Bosai Hakusho)*, Printing Bureau, Ministry of Finance.

Cutter, S.L., B.J. Boruff and W.L. Shirley (2003) “Social Vulnerability to Environmental Hazards,” *Social Science Quarterly*, 84(2), 242-261.

Fan, Q. and M. Davlasheridze (2016) “Flood Risk, Flood Mitigation, and Location Choice: Evaluating the National Flood Insurance Program’s Community Rating System,” *Risk Analysis*, 36(6), 1125-1147.

Nakanishi H. (2016) “How the Change of Risk Announcement on Catastrophic Disaster Affects Property Prices?,” in Chichilnisky G. and A. Rezai (eds) *The Economics of the Global Environment, Studies in Economic Theory*, 29, 577-595, Springer: Cham.

Naoi, M., M. Seko and K. Sumita (2009) “Earthquake Risk and Housing Prices in Japan: Evidence before and after Massive Earthquakes,” *Regional Science and Urban Economics*, 39(6), 658-669.

Santos Silva, J.M.C. and S. Tenreyro (2006) “The Log of Gravity,” *Review of Economics and Statistics*, 88(4), 641-658.

Troy, A. and J. Romm (2004) “Assessing the Price Effects of Flood Hazard Disclosure under the California Natural Hazard Disclosure Law (AB 1195),” *Journal of Environmental Planning and Management*, 47(1), 137-162.

Votsis, A. and A. Perrels (2016) “Housing Prices and the Public Disclosure of Flood Risk: A Difference-in-Differences Analysis in Finland,” *Journal of Real Estate Finance and Economics*, 53(4), 450-471.

Figure 1: Location of municipalities in the estimation sample

Table 1: Tsunami Height Predictions and Distribution of Municipalities

Average Predictions	All Municipalities		Municipalities in Disaster Management Zone	
	# of muni.	(%)	# of muni.	(%)
No predictions	1,365	(78.33)	384	(54.31)
Average ≥ 1m	376	(21.67)	323	(45.69)
2m	42	(2.42)	14	(1.98)
3m	117	(6.74)	92	(13.01)
4m	75	(4.32)	75	(10.61)
5m	23	(1.33)	23	(3.25)
6m	22	(1.27)	22	(3.11)
7m	17	(0.98)	17	(2.40)
8m	15	(0.86)	15	(2.12)
9m	12	(0.69)	12	(1.70)
10m	10	(0.58)	10	(1.41)
11m	9	(0.52)	9	(1.27)
12m	10	(0.58)	10	(1.41)
13m	11	(0.63)	11	(1.56)
14m+	13	(0.75)	13	(1.84)

ΔMaximum Predictions	All Municipalities		Municipalities in Disaster Management Zone	
	# of muni.	(%)	# of muni.	(%)
No predictions/updates	1,402	(80.53)	419	(59.26)
Δmax pred. ≥ 1m	339	(19.47)	288	(40.74)
1m	79	(4.54)	63	(8.91)
2m	46	(2.64)	44	(6.22)
3m	56	(3.22)	27	(3.82)
4m	48	(2.76)	44	(6.22)
5m	16	(0.92)	16	(2.26)
6m	17	(0.98)	17	(2.40)
7m	14	(0.80)	14	(1.98)
8m	12	(0.69)	12	(1.70)
9m	11	(0.63)	11	(1.56)
10m	13	(0.75)	13	(1.84)
11-13m	11	(0.63)	11	(1.56)
14m+	16	(0.92)	16	(2.26)
Total	1,741		707	

Notes : "No predictions" includes municipalities that are not covered by the CDMC's report. For the changes in maximum preditions, municipalities with lower predictions in 2012 than in 2003 (N = 6) are included in "No predictions/updates" category.

Table 2: Migration Responses to Updated Tsunami Predictions

	Outmigration from Tsunami Areas		Inmigration into Tsunami Areas	
	[1]	[2]	[3]	[4]
(a) Average Tsunami Predictions (m)				
Origin	0.0007	0.0024 *	(Omitted)	(Omitted)
	(0.0008)	(0.0013)		
Destination	-0.0044 ***	-0.0039 ***	-0.0032 ***	-0.0058 ***
	(0.0010)	(0.0015)	(0.0011)	(0.0018)
Adj. R^2	0.6435	0.6772	0.6638	0.6834
N	530,974	320,521	233,813	151,721
(b) Changes in Maximum Tsunami Predictions (m)				
Origin	0.0008	0.0018 *	(Omitted)	(Omitted)
	(0.0009)	(0.0011)		
Destination	-0.0051 ***	-0.0048 ***	-0.0029 ***	-0.0033 **
	(0.0011)	(0.0016)	(0.0011)	(0.0014)
Adj. R^2	0.6435	0.6772	0.6638	0.6834
N	530,974	320,521	233,813	151,721
Sample municipalities				
Origin	DMZ	DMZ Coastal	Non-DMZ	Non-DMZ
Destination	All	All	DMZ	DMZ Coastal

Notes: ***, ** and * indicate that estimated coefficients are significant at 1, 5, and 10% levels, respectively. Heteroscedasticity-robust standard errors are presented in the parentheses. "DMZ Coastal" municipalities are those in the Disaster Management Zone with positive tsunami predictions in the 2012 report. "Non-DMZ" municipalities are those outside of the DMZ and without positive tsunami height predictions. All estimations include following control variables: income per capita, population size, population density, population share of selected age groups (by ten-year age intervals), and share of workers who live and work in the same municipality. Origin and destination municipality fixed effects, and year fixed effects are also controlled.

Table 3: Age-Specific Migration Responses to Updated Tsunami Predictions (Outmigration from Tsunami Areas)

	20~39		40~59		60+	
	[1]	[2]	[3]	[4]	[5]	[6]
(a) Average Tsunami Predictions (m)						
Origin	0.0008	0.0024	0.0027 **	0.0019	0.0023	0.0014
	(0.0010)	(0.0016)	(0.0012)	(0.0019)	(0.0015)	(0.0023)
Destination	-0.0028 **	-0.0029 *	-0.0030 **	-0.0035 *	-0.0004	0.0000
	(0.0012)	(0.0016)	(0.0013)	(0.0018)	(0.0018)	(0.0023)
Adj. R^2	0.6785	0.7114	0.6840	0.7047	0.7218	0.7327
N	373,515	228,034	224,028	145,546	137,578	92,837
(b) Changes in Maximum Tsunami Predictions (m)						
Origin	0.0017 *	0.0026 **	0.0019	0.0003	0.0025 *	0.0025
	(0.0010)	(0.0013)	(0.0012)	(0.0015)	(0.0015)	(0.0018)
Destination	-0.0037 ***	-0.0035 **	-0.0031 **	-0.0037 **	-0.0016	-0.0009
	(0.0013)	(0.0017)	(0.0014)	(0.0019)	(0.0019)	(0.0025)
Adj. R^2	0.6785	0.7114	0.6840	0.7047	0.7218	0.7327
N	373,515	228,034	224,028	145,546	137,578	92,837
Sample municipalities						
Origin	DMZ	DMZ Coastal	DMZ	DMZ Coastal	DMZ	DMZ Coastal
Destination	All	All	All	All	All	All

Notes: ***, ** and * indicate that estimated coefficients are significant at 1, 5, and 10% levels, respectively. Heteroscedasticity-robust standard errors are presented in the parentheses. "DMZ Coastal" municipalities are those in the Disaster Management Zone with positive tsunami predictions in the 2012 report. All estimations include following control variables: income per capita, population size, population density, population share of selected age groups (by ten-year age intervals), and share of workers who live and work in the same municipality. Origin and destination municipality fixed effects, and year fixed effects are also controlled.

Table 4: Age-Specific Migration Responses to Updated Hazard Information

	20~39		40~59		60+	
	[1]	[2]	[3]	[4]	[5]	[6]
(a) Average Tsunami Predictions (m)						
Destination	-0.0028 **	-0.0063 ***	0.0003	0.0000	-0.0002	0.0029
	(0.0012)	(0.0020)	(0.0015)	(0.0024)	(0.0019)	(0.0030)
Adj. R^2	0.7193	0.7127	0.7172	0.6844	0.7695	0.7209
N	158,301	106,750	88,009	64,513	47,281	37,193
(b) Changes in Maximum Tsunami Predictions (m)						
Destination	-0.0022 *	-0.0036 **	0.0004	0.0005	-0.0020	-0.0003
	(0.0012)	(0.0015)	(0.0014)	(0.0017)	(0.0018)	(0.0023)
Adj. R^2	0.7193	0.7127	0.7172	0.6844	0.7695	0.7209
N	158,301	106,750	88,009	64,513	47,281	37,193
Sample municipalities						
Origin	Non-DMZ	Non-DMZ	Non-DMZ	Non-DMZ	Non-DMZ	Non-DMZ
Destination	DMZ	DMZ Coastal	DMZ	DMZ Coastal	DMZ	DMZ Coastal

Notes : ***, ** and * indicate that estimated coefficients are significant at 1, 5, and 10% levels, respectively. Heteroscedasticity-robust standard errors are presented in the parentheses. "DMZ Coastal" municipalities are those in the Disaster Management Zone with positive tsunami predictions in the 2012 report. "Non-DMZ" municipalities are those outside of the DMZ and without positive tsunami height predictions. All estimations include following control variables: income per capita, population size, population density, population share of selected age groups (by ten-year age intervals), and share of workers who live and work in the same municipality. Origin and destination municipality fixed effects, and year fixed effects are also controlled.

Table 5: Disaster Management Program and Migration Responses to Updated Tsunami Predictions

	Tokai Earthquake Disaster Management Reinforcement Area					
	Not Designated		Designated in 2002		Designated in 1979	
	[1]	[2]	[3]	[4]	[5]	[6]
(a) Average Tsunami Predictions (m)						
Origin	0.0004	0.0030 *	0.0029	0.0093	-0.0005	-0.0065
	(0.0010)	(0.0017)	(0.0038)	(0.0087)	(0.0018)	(0.0073)
Destination	-0.0049 ***	-0.0049 ***	-0.0049 *	-0.0003	-0.0028	-0.0077
	(0.0012)	(0.0016)	(0.0029)	(0.0041)	(0.0029)	(0.0048)
Adj. R^2	0.6513	0.6852	0.7246	0.7433	0.6889	0.7425
N	402,754	264,402	52,362	27,462	75,858	28,657
(b) Changes in Maximum Tsunami Predictions (m)						
Origin	0.0012	0.0031 **	-0.0006	-0.0009	-0.0004	-0.0040
	(0.0011)	(0.0014)	(0.0024)	(0.0034)	(0.0018)	(0.0036)
Destination	-0.0056 ***	-0.0056 ***	-0.0063 *	-0.0028	-0.0033	-0.0088 *
	(0.0013)	(0.0017)	(0.0033)	(0.0047)	(0.0029)	(0.0050)
Adj. R^2	0.6513	0.6852	0.7246	0.7432	0.6889	0.7425
N	402,754	264,402	52,362	27,462	75,858	28,657
Sample municipalities						
Origin	DMZ	DMZ Coastal	DMZ	DMZ Coastal	DMZ	DMZ Coastal
Destination	All	All	All	All	All	All

Notes : ***, ** and * indicate that estimated coefficients are significant at 1, 5, and 10% levels, respectively. Heteroscedasticity-robust standard errors are presented in the parentheses. "DMZ Coastal" municipalities are those in the Disaster Management Zone with positive tsunami predictions in the 2012 report. All estimations include following control variables: income per capita, population size, population density, population share of selected age groups (by ten-year age intervals), and share of workers who live and work in the same municipality. Origin and destination municipality fixed effects, and year fixed effects are also controlled.