Regional Differences in Cognitive Dissonance in Evacuation Behavior at the time of the 2011 Japan Earthquake and Tsunami

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Abstract

This paper constructs an evacuation decision-making model that takes cognitive dissonance into consideration. The purpose of this construction is to clarify the psychological mechanism for the evacuation behavior of residents during an emergency, based on Akerlof and Dickens (1982). Specifically, we empirically explore people's psychological mechanism (e.g. cognitive dissonance) for evacuation behavior when a tsunami disaster occurs. As a result, we show that the level of anxiety depends on the area where residents live and that the average anxiety of residents is mostly correlated to the level of damage of past disasters, and that it is affected also by the ages of residents. Since the level of anxiety largely affects an individual's evacuation behavior, this result can indicate for what kinds of people intervention and assistance are required based on the level of anxiety.

Key Words: *Disaster mitigation, Cognitive dissonance, Evacuation behavior*

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1. Introduction

Some natural disasters take many human lives instantly. A tsunami is one such disaster. The Great East Japan Earthquake on March 11, 2011, which recorded a magnitude of 9.0, produced a tsunami that struck a wide area about 32 minutes after the earthquake, and over 18,000 residents lost their lives. The Indian Ocean Earthquake off the coast of Sumatra on December 26, 2004, which recorded a magnitude of 9.1, produced a tsunami that struck many Asian countries, killing approximately 220,000 people. The island of Sumatra, Indonesia was struck by the first wave approximately 15 minutes after the earthquake.

From records of past such disasters, it is well known that achieving early evacuation is effective as a method of minimizing the damage caused by a tsunami, according to the Japanese Central Disaster Management Council (2003). On the other hand, there are many reports that residents often hesitate to evacuate even after the emergency public announcement of the forecast of a big tsunami. So, in order to achieve early evacuation, we need to elucidate the psychological mechanism and then implement disaster prevention policies in accordance with this mechanism.

Up to the present time, a variety of evacuation simulation models have been developed (e.g., Katada et al., 2006; Kaji and Nakahara, 1994; Yokoyama et al., 1995; Hatayama et al., 2010 in Japan). However, none of them modeled the evacuees' psychological mechanism for their evacuation behavior. Indeed, the start point of an individual's evacuation was given by the temporal distribution of starting evacuation based on the past records or the results of surveys conducted after the evacuation. To see the effects of various disaster prevention policies, we have to clarify the psychological mechanism for starting their evacuation.

Various disaster prevention policies can be implemented to achieve the early evacuation of residents (e.g., establishing evacuation routes and raising awareness of evacuation through disaster prevention education). In order to ascertain what policies improve their early evacuation rate, it is essential to understand the decision-making mechanism that expresses how each resident decides whether or not to evacuate.

A logical decision-making model can be considered for evacuation by minimizing costs or maximizing utility in the evacuation. However, people do not necessarily behave logically, and it has been noted that, particularly during a disaster, people hesitate to evacuate due to various irrational factors, one of which is cognitive dissonance (Hirose, 2004). In addition, it is pointed out that they have a normalization bias in which the subjective probability for risk is irrationally low. Cognitive dissonance is the occurrence of dissonance when a person holds multiple cognitions that are inconsistent with each other. When cognitive dissonance occurs, it is thought that it produces the motivation to reduce the cognitive dissonance that causes psychological discomfort.

In the context of tsunami evacuation behavior, after a big earthquake, people have two cognitions: 1) a big tsunami might occur and take their lives, and 2) evacuation might be an overreaction to this earthquake. In this situation, people avoid this cognitive dissonance by supposing that the subjective probability of occurrence of a big tsunami is very low or zero. This conforms with the normalization bias.

There are several approaches to explain this non-evacuation behavior. Applying the prospect theory of Kahneman and Tversky (1979) to this behavior is valid. In their prospect theory, the value function is normally convex when people experience losses. That is why people take risk-seeking actions when experiencing losses. As a result, they choose not to evacuate because staying at home has a higher level of uncertainty. However, this does not explain why people suppose an irrationally low probability of occurrence of tsunami.

The theory of cognitive dissonance proposed by Festinger (1957) is frequently discussed in psychology, while it has been mathematically modeled by Akerlof and Dickens (1982) and Rabin (1994). There have been studies such as Dickens (1986), which modified the model in his previous study and modeled the relationship between the mechanism causing crime to occur and cognitive dissonance, and Balestrino and Ciardi (2008), who modeled the relationship between the timing of marriage and cognitive dissonance. However, these studies, including Akerlof and Dickens (1982), were limited to a qualitative analysis and did not have a quantitative analysis[2].

The current paper, based on a microfounded model basically following Akerlof and Dickens (1982), estimates the psychological parameters of the model, using questionnaires on the actual evacuation behaviors at the time of Japan's 2011 earthquake and tsunami. This approach leads to empirical elucidation of the psychological decision-making mechanisms for evacuation. A quantitative analysis of the mechanisms is indispensable for evaluating evacuation policies. To our knowledge, our analysis is the first quantitative analysis of the Akerlof and Dickens model.

The remainder of the paper is organized as follows. In Section 2, we construct an evacuation behavior model that modifies the model of Akerlof and Dickens (1982). In Section 3, we introduce an evacuation behavior questionnaire and arrange the data used for the

[2] Ida et al. (2015) quantitatively analyze the effect of cognitive dissonance. But their target is not an evacuation behavior. They examined a choice-induced preference change about whether nuclear power generations are appropriate or not, which is captured by the same questionnaire method as in some previous psychological papers (e.g., Brehm, 1956; Steele et al., 1993; Chen and Risen, 2010; Izuma and Murayama, 2013). Ida et al. succeeded in showing the existence of cognitive dissonance in Japanese people's attitude about the trade-off between nuclear power generation and avoiding an increase in electricity rates. However, while they show the difference in people's preference before and after their choice behavior, Ida et al. (2015) do not clarify the micro-founded generation mechanisms of the cognitive dissonance. Our paper targets the behavioral mechanisms in evacuation.

empirical analysis. Section 4 sets the exogenous-cost parameters and estimate the model's parameters. In Section 5, we provide a conclusion.

2. The evacuation behavior selection model

2.1. The Akerlof and Dickens (1982) model and its modifications

Akerlof and Dickens (1982) mathematically explain the phenomenon that workers working in a hazardous environment, in which their lives could be in danger, may underestimate the risk due to cognitive dissonance. The time period in the model consists of two periods; in the first period, the workers cannot avoid the risk of accidents, but in contrast, in the second period, they can avoid this risk by purchasing safety equipment. The workers who correctly estimate the risk of accidents purchase safety equipment, but the workers who underestimate the risk due to cognitive dissonance do not purchase this equipment.

The purchasing behavior is expressed by dividing it into three stages. In the first stage, the worker's threshold value of his subjective probability for whether or not to purchase safety equipment is derived. In the second stage, the worker uses the derived threshold value of subjective probability and selects the subjective probability that minimizes costs when purchasing or that when not purchasing the equipment. Finally, in the third stage, the worker compares the costs and decides whether or not to actually purchase the equipment.

Figure 1 shows the behavior-decision process in Akerlof and Dickens (1982). The variables underlined in Figure 1 are the selections at each of the stages and the equation number under the line denotes the corresponding equation in the current paper. In the current paper, in the third stage, "wait" or "evacuate" is chosen instead of "No purchase" or "Purchase" in Akerlof and Dickens (1982).

We will formulate the costs in the events of evacuation and non-evacuation in a situation in which there are fears that a tsunami will strike. Following the sensations of the

tremors from the earthquake and the issuance of a tsunami warning, for the residents in coastal areas where it is thought that a tsunami will strike, residents select 1) the subjective probability of death from the tsunami, and 2) whether or not to evacuate. This setting is essentially the same as that in Akerlof and Dickens (1982), in which workers decide 1) the subjective probability that an accident will occur, and 2) whether or not to purchase safety equipment.

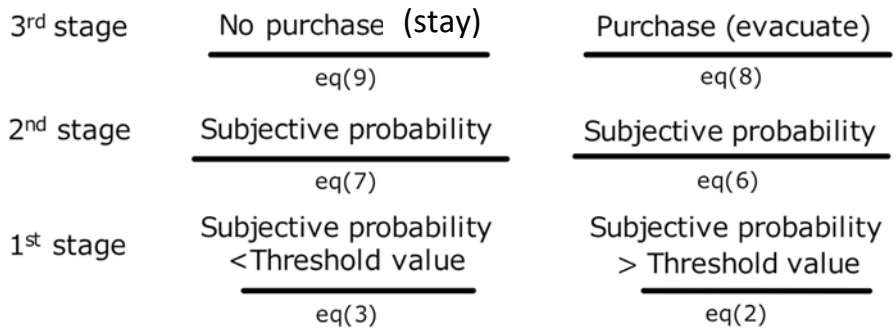

Figure 1: The behavior-decision process

On applying Akerlof and Dickens (1982) to evacuation behavior, we made the following three modifications.

Modification 1: In Akerlof and Dickens (1982), as the results of the modeling, in the event that the worker selects to not purchase safety equipment, the subjective probability=0. This implies that cognitive dissonance results in a complete elimination of the subjective risk. However, this result is an extreme case. So, we introduce a sense of resistance to the divergence between the objective probability and the subjective probability of death from the tsunami to our model. As a result, residents will not completely eliminate subjective risks.

Modification 2: In Akerlof and Dickens (1982), before purchasing safety equipment, in the first period, which corresponds to before the start of the tsunami evacuation in this study, they assume that workers have never encountered risks associated with an accident. However,

in a tsunami disaster in reality, it can be considered that people will have been killed by the tsunami before the start of the evacuation, so we modified the model so that it takes into consideration the possibility of people having died before the start of the evacuation.

Modification 3: In Akerlof and Dickens (1982), while the anxiety cost term is set to be proportional to the subjective probability, the expected cost of death is set to be proportional to only the objective probability, not the subjective probability. This inconsistent treatment seems unrealistic and unnatural. Therefore, in this study, we have modified the model so that both anxiety and the expected cost of death are proportional to the subjective probability.

All parts except for the three modifications follow Akerlof and Dickens (1982). The following expresses our model mathematically. The symbols used for the formulation of costs are as follows; p: subjective probability of death, q: objective probability of death, C_d: cost of death, C_f: cost of anxiety, C_m: cost of moving, $\overline{h}$: the minimum time required to prepare for evacuation, h: the time from the start of the evacuation until the warning is issued (where $h + \overline{h} = 1$ without loss of generality), and γ: the sense-of-resistance parameter.

Figure 2 shows the summary of the model. Residents pay the cost of anxiety and the cost of death until evacuation is completed, also, the cost of moving when evacuating. Meanwhile, residents pay the cost of expected anxiety, the cost of death, and the cost of resistance when not evacuating.

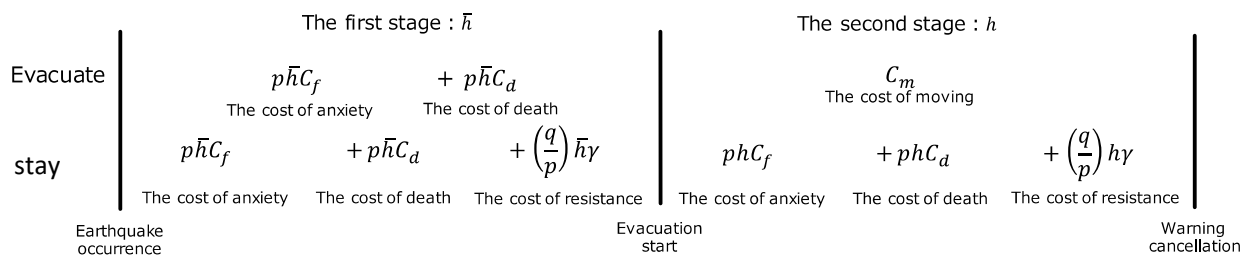

Figure 2: Summary of the model

2.2. Details of each stage

(a) The first stage: determining the threshold value of subjective probability p

Residents compare the total cost of evacuation with that of staying in order to decide whether to evacuate. The costs are composed of the following items: C_m, the cost of moving incurred from the evacuation after the start of the evacuation behavior; phC_d, the cost of expected death incurred when there is no evacuation; phC_f, the cost of expected anxiety; $\gamma h(q/p)$, the cost of resistance. The cost of resistance becomes larger as the subjective probability of death becomes smaller than the objective probability of death, and it expresses the cost of resistance due to fear of misjudgment of the probability of death caused by the tsunami.

We derive the threshold value of subjective probability. The inequality condition (1) expresses a judgement when a resident selects to evacuate or not. This judgement depends on what level the resident sets his subjective probability, p, at. The threshold p is expressed by inequalities (2) and (3), which are derived from the judgement formula (1).

$$\text{Judgement formula: } C_m < (>) ph\left(C_d + C_f\right) + \gamma h(q/p) \tag{1}$$

$$\text{When evacuating: } p > \frac{C_m \pm \sqrt{{C_m}^2 - 4\gamma q h^2 \left(C_d + C_f\right)}}{2h\left(C_d + C_f\right)} \tag{2}$$

$$\text{When not evacuating: } p < \frac{C_m \pm \sqrt{{C_m}^2 - 4\gamma q h^2 \left(C_d + C_f\right)}}{2h\left(C_d + C_f\right)} \tag{3}$$

(b) The second stage: determining the subjective probability

In the second stage, from the range of the subjective probability selections obtained in the first stage, the subjective probability that minimizes the total cost is selected separately when the resident decides to evacuate and when she/he decides to not evacuate. As a result, the

subjective probability p_1 shown in Formula (6) is selected when evacuating and p_2 in Formula (7) when not evacuating. In Akerlof and Dickens (1982), people chose a subjective probability, corresponding to p_2, of zero. In our model, since we introduce a sense of resistance to the divergence between the objective probability and the subjective probability of death, residents will not completely eliminate subjective risks.

$$\text{Cost of evacuating: } \min_p \left[p\overline{h}\left(C_f + C_d\right) + C_m\right] \tag{4}$$

$$\text{Cost of not evacuating: } \min_p \left[p\left(C_f + C_d\right) + \gamma\frac{q}{p}\right] \tag{5}$$

$$\text{When evacuating: } p_1 = \frac{C_m + \sqrt{C_m^2 - 4\gamma q h^2\left(C_d + C_f\right)}}{2h\left(C_d + C_f\right)} \tag{6}$$

$$\text{When not evacuating: } p_2 = \sqrt{\frac{\gamma q}{\left(C_d + C_f\right)}} \tag{7}$$

(c) The third stage: determining the tsunami evacuation behavior

In the third stage, the selected subjective probability in the second stage is used, both costs across the first and second periods are compared, and whether or not to evacuate is selected. As a result, the cost when evacuating can be expressed by Formula (8), and the cost when not evacuating by Formula (9), and each agent selects the smaller of these costs.

$$\text{Cost of evacuating: } \left(\frac{\overline{h}}{2h}\right)\left(C_m + \sqrt{{C_m}^2 - 4\gamma p_1 h^2\left(C_d + C_f\right)}\right) + C_m \tag{8}$$

$$\text{Cost of not evacuating: } 2\sqrt{\gamma p_2}\sqrt{C_f + C_d} \tag{9}$$

2.3. Comparative statics with respect to parameters

First, in order to analyze the effects that each of the parameters in this model have on evacuation behavior, the evacuation behavior judgment formula f is defined by subtracting

the cost of not evacuating Formula (9), from the cost of evacuating, Formula (8), and this becomes Formula (10). By differentiating Formula (10) with respect to each parameter, we can obtain the changes in the evacuation trends that occur with changes in each parameter.

$$f = \left(\frac{\overline{h}}{2h}\right)\left(C_m + \sqrt{C_m^2 - 4\gamma p_1 h^2\left(C_d + C_f\right)}\right) + C_m - 2\sqrt{\gamma p_2}\sqrt{C_d + C_f} \tag{10}$$

If Formula (10) is negative, “evacuate” is selected, and if Formula (10) is positive, “do not evacuate” is selected. Therefore, by differentiating Formula (10) with each parameter and finding out its functional form, we can obtain the tendency of evacuating or not evacuating. Each parameter shall be within the following range from what is realistically valid.

$$C_m > 0, C_d > 0, C_f > 0, p > 0, \gamma > 0 \tag{11}$$

Consequently, Formulas (12) to (15) below are obtained. We understand that evacuation becomes difficult as the cost of moving C_m increases, and that evacuation becomes more likely as the cost of death C_d, the cost of anxiety C_f, and the objective probability p increase, confirming that an evacuation tendency conforming to actual evacuation behavior was appropriately expressed.

$$\frac{\partial f}{\partial C_m} = \frac{\overline{h}}{2h} + \frac{2\overline{h}C_m}{4h\sqrt{{C_m}^2 - 4\gamma q h^2\left(C_d + C_f\right)}} + 1 > 0 \tag{12}$$

$$\frac{\partial f}{\partial C_d} = \frac{-4\gamma q h^2}{4h\sqrt{{C_m}^2 - 4\gamma q h^2\left(C_d + C_f\right)}} - 2\sqrt{\gamma q}\frac{1}{2\sqrt{C_f + C_d}} < 0 \tag{13}$$

$$\frac{\partial f}{\partial C_f} = \frac{-4\gamma q h^2}{4h\sqrt{{C_m}^2 - 4\gamma q h^2\left(C_d + C_f\right)}} - 2\sqrt{\gamma q}\frac{1}{2\sqrt{C_f + C_d}} < 0 \tag{14}$$

$$\frac{\partial f}{\partial q} = \frac{-4\gamma h^2\left(C_d + C_f\right)}{4h\sqrt{{C_m}^2 - 4\gamma q h^2\left(C_d + C_f\right)}} - \frac{\sqrt{\gamma}}{\sqrt{q}}\sqrt{C_d + C_f} < 0 \tag{15}$$

3. The disaster case and the evacuation behavior questionnaire

3.1. Introduction

The 2011 Japan Earthquake which recorded a magnitude of 9.0 occurred at 14:46 (Japan time) on March 11 at the east and southeast off the coast of the Oshika Peninsula, Miyagi Prefecture. The evacuation alert information was given as follows. First, at 14:49 on March 11, the Meteorological Agency issued a tsunami warning (forecasted height, 3 meters) in Iwate Prefecture, Miyagi Prefecture, and Fukushima Prefecture. After that, the level of the forecasted tsunami was increased at 15:14 on March 11. The arrival of the tsunami was observed from 15:20 this day.

In order to estimate the parameters, we employ the evacuation behavior questionnaires performed by the City Bureau of the Ministry of Land, Infrastructure and Transport, Japan. The questionnaire, “Digital Archive of the Great East Japan Earthquake and Tsunami Disaster Recovery Support Survey of Damaged Cities” was carried out for 49 municipalities in 6 prefectures. In this survey, personal attribute data of 10,240 samples and a total of 24 items such as evacuation place, route, flooded area and so on are collected.

3.2. Samples used for analysis

In this research, since it is necessary to secure a certain number of samples for analysis for each municipality, we target 22 municipalities that have more than 100 samples (total number of samples: 8369). Table 1 shows the municipalities used for analysis, the number of samples and the evacuation rate. The municipalities are listed downwards in terms of evacuation rates.

The highest evacuation rate was about 92% in Oduchi, and the lowest evacuation rate was 48% in Asahi.

Table 1: Number of samples and evacuation rate

Number	Municipality	Number of samples	Number of evacuees	Evacuation rate (%)
1	Otsuchi	224	207	92.41
2	Yamada	221	203	91.86
3	Kamaishi	292	254	86.99
4	Ofunato	483	414	85.71
5	Onagawa	163	139	85.28
6	Miyako	349	297	85.10
7	Kesennuma	817	688	84.21
8	Kuji	166	139	83.73
9	Shiogama	164	137	83.54
10	Minamisanriku	393	322	81.93
11	Rikuzentakata	479	388	81.00
12	Ishinomaki	1558	1212	77.79
13	Sendai	181	130	71.82
14	Souma	240	165	68.75
15	Yamamoto	205	137	66.83
16	Watari	259	171	66.02
17	Iwaki	702	460	65.53
18	Iwanuma	168	108	64.29
19	Natori	349	210	60.17
20	Higashimatushima	313	178	56.87
21	Minamisouma	333	178	53.45
22	Asahi	310	148	47.74

Considering that the characteristics of people's evacuation behavior are likely to be affected by their age, we set three population categories: $Age\ Group\ 1$ (49 years old or younger), $Age\ Group\ 2$ (50 to 69 years old), $Age\ Group\ 3$ (over 70 years old). We estimate the parameters of evacuation decision by age group.

The number of samples and the evacuation rate of these three categories are shown in Figure 3 and Figure 4 below. In these classifications, the evacuation rates are in the range between 70% and 78%, depending on the gender and the age. The minimum rate is about 71% in the case of males in age group 1, while the maximum rate is about 78% in the case of females in age group 2.

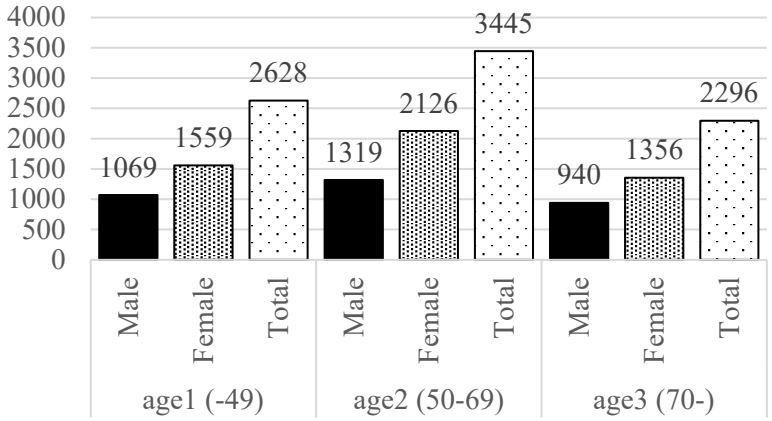

Figure 3: Number of samples by age group

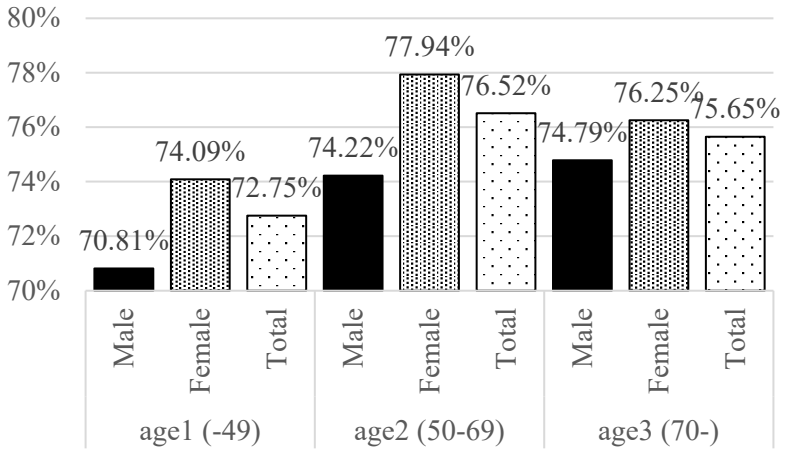

Figure 4: Evacuation rate by age group

4. Setting values and estimating parameters

4.1. Introduction

We will show the policy for the setting of the parameters. We formulized the evacuation decision-making model shown by Formula (10) using the objective probability of death from the tsunami q, cost of death C_d, cost of moving C_m, cost of anxiety C_f, time ratio from the start of the evacuation action to the end of the evacuation action h, the shortest preparation time required for the evacuation behavior from the occurrence of the disaster $\overline{h}$, and the sense-of-resistance parameter γ.

The exogenous cost parameters other than the cost of anxiety can be calculated from the previous studies. Based on these exogenous parameters, we estimate the cost-of-anxiety parameter. We divide the setting of the parameters in the evacuation decision-making model into two stages: 1) setting the exogenous costs and the various parameters, and 2) using the non-aggregated questionnaire data to estimate the distribution of the cost-of-anxiety parameter.

4.2. Setting the exogenous cost parameters

First, in order to set the exogenous costs and various parameters, we referred to previous research involving cost-benefit calculations, and studies of the statistical values of life based on the willingness to pay for the objective probability of death from a tsunami p, the cost of death C_d, the cost of moving C_m, evacuation preparation time, the estimated evacuation time, and the sense-of-resistance parameter. We will explain the parameters one by one as follows.

(a) The objective probability of death q

The objective probability of death of an individual from the tsunami, q, is calculated by dividing the total deceased and missing people in the 2011 Japan Earthquake and Tsunami by the daytime population municipality by municipality. The number of the daytime population,

the total number of deceased and missing people and the objective probability are shown for each municipality in Table 2 below.

Table 2: The objective probability of death

Number	Municipality	Daytime population	Deceased and missing	Probability (%)
1	Otsuchi	4247	1277	30.068
2	Yamada	6131	835	13.619
3	Kamaishi	10692	1145	10.709
4	Ofunato	13351	498	3.730
5	Onagawa	3633	872	24.002
6	Miyako	12081	568	4.702
7	Kesennuma	24307	1434	5.900
8	Kuji	9346	5	0.053
9	Shiogama	6231	42	0.674
10	Minamisanriku	6300	832	13.206
11	Rikuzentakata	5928	1807	30.482
12	Ishinomaki	40897	3975	9.720
13	Sendai	13469	950	7.053
14	Souma	4065	486	11.956
15	Yamamoto	3438	717	20.855
16	Watari	4749	287	6.043
17	Iwaki	72509	461	0.636
18	Iwanuma	3438	187	5.439
19	Natori	5306	993	18.715
20	Higashimatushima	7493	1152	15.374
21	Minamisouma	12758	1121	8.787
22	Asahi	15439	16	0.104

(b) The cost of death C_d

We calculated the cost of death C_d. In this study, the cost of death C_d is the value of the lives of the residents themselves that are lost when they die in the tsunami. In this study, this

cost is set as the willingness to pay for avoiding the risk of death. We set this with reference to the survey-research report on an economic analysis of damages and loss from traffic accidents (2012) by the Director General for Economic and Fiscal Management, the Cabinet Office, who statistically estimates the value of life (and who is responsible for the policies for a cohesive society) (Itaoka et al. (2005)). In the survey-research report on an economic analysis of damages and loss from traffic accidents (2012), the statistical value of life was calculated based on the willingness to pay for the risk of dying in a traffic accident.

According to this report, the per-capita loss from death is 213 million yen. Also, in the study of Itaoka et al. (2005), they estimated the willingness-to-pay amount for four age categories (40 to 49 years, 50 to 59 years, 60 to 69 years, and 70 years and over), calculated the statistical value of life in each category, and showed that the statistical value of life for people aged 70 years and above tends to be smaller than that of people aged under 70 years. For the cost of death used in this study, we set the cost for people under 70 years old as 213 million yen, and the cost for people aged 70 years and over as 77 million yen, which was calculated in the study of Itaoka et al. (2005). Table 3 shows the cost of death.

Table 3: The objective probability of death

Under 70 years old	213,000,000 [yen]
70 years and over	77,000,000 [yen]

(c) The cost of moving C_m

For the cost of moving C_m, the time value and the mental and physical burden incurred when moving from the evacuation starting point to the evacuation site are calculated in monetary values. The cost of moving C_m is obtained by multiplying the cost of moving per unit of time C_m^{unit} by the evacuation time. The cost of moving per unit of time C_m^{unit} is defined by Formula (16).

$$C_m^{unit} = C_{time}^i + C_{physical+mental}^i \quad (16)$$

C_{time}^i signifies the opportunity cost of the evacuation behavior, and the time value is calculated using the income approach method. For the average annual income and actual working hours used for the calculations, we used the values from the salary census of 2010. C_{time}^i is defined by Formula (17).

$$C_{time}^i = \frac{\text{Average annual salary in category } i}{Actual\ w\text{orking hours per month} \times 12(\text{months}) \times 60(\text{minutes})} \quad (17)$$

$C_{physical+mental}^i$ signifies the mental and physical costs incurred from the evacuation behavior. This cost is set based on previous studies. Although there has been no research that attempted to measure $C_{physical+mental}^i$ as the mental and physical costs resulting from the evacuation behavior, Sato et al. (2002) converted into monetary values the mental and physical costs of transfer (between trains) behavior in the process of quantifying resistance to transfer behavior at stations as a generalized transfer cost.

In this study, $C_{physical+mental}^i$, the mental and physical costs that are incurred during evacuation behavior, is set to be the energy value and the mental burden in the generalized transfer cost of Sato et al. Sato et al. calculated the total cost of energy value and the mental burden for the elderly aged 70 years and over to be $74.01\ [yen/min]$, and the value for other pedestrians to be $26.26[yen/min]$. We use these values. The cost of moving per unit of time C_m^{unit} calculated from the above-described sequence is shown in Table 4.

Table 4: The cost of moving per unit of time

	Age	C_{time}^{i} [yen/min]	$C_{phys+mental}^{i}$ [yen/min]	C_{m}^{unit} [yen/min]
Male	20-49	36.802	26.260	63.062
	50-69	41.301		67.561
	70-	22.154	74.010	96.164
Female	20-49	25.097	26.260	51.357
	50-69	26.231		52.491
	70-	14.127	74.010	88.137

The final cost of moving is obtained from Formula (18), from the moving time of each resident until arriving at the evacuation site, using the cost of moving per unit of time C_{m}^{unit}.

$$C_m = (\text{evacuation distance} / \text{moving speed}) \times C_{m}^{unit} + T_{evacuate} \times C_{m}^{unit} \quad (18)$$

In this study, based on the results of a survey of actual conditions of natural walking conducted by Akutsu (1975), the walking speed was set by gender and age category. We use his result as the walking speeds to calculate the cost of moving. Table 5 shows walking speeds for each citizen category. Additionally, moving speed of cars and bicycles were set based on the walking speed as shown in Table 6 below.

Table 5: The walking speeds of each citizen category

Age	Male [m/s]	Female [m/s]
20-49	1.444	1.228
50-69	1.190	1.041
70-	0.983	0.899

Table 6: The moving speed of cars and bicycles

Mode of transportation	Speed condition	Attribute	Speed [m/s]
Bicycle	3 x walking speed	Male Age Group 1	4.332
		Male Age2	3.57
		Male Age3	2.949
		Female Age1	3.684
		Females Age2	3.123
		Females Age3	2.697
Motor bike Car	Uniformly 30km/hour	Males Age1	8.33
		Males Age2	
		Males Age3	
		Females Age1	
		Females Age2	
		Females Age3	

(d) Evacuation preparation time $T_{prepare}$ and evacuation time $T_{evacuate}$

We use the evacuation preparation time $T_{prepare}$ and evacuation time $T_{evacuate}$ to calculate h, which is the time ratio from the start of the evacuation behavior until the time when the danger of a tsunami has passed (i.e., residents stops feeling anxiety); $\overline{h}$, which is the time ratio of the preparation time required for the evacuation behavior; and the cost of moving C_m. Evacuation preparation time $T_{prepare}$ is the shortest time required for evacuating. In this study, we suppose $T_{prepare} = 35\ minute$s, referring to the evacuation starting times of residents who responded to the questionnaire. Regarding the evacuation time $T_{evacuate}$, we suppose $T_{prepare} = 120\ minute$s. These settings are summarized in Table 7.

Table 7: Evacuation preparation time and evacuation time

$T_{prepare}$	35 $minutes$
$T_{evacuate}$	120 $minutes$
$\bar{h} = \frac{T_{prepare}}{T_{prepare} + T_{evacuate}}$	0.226
$h = \frac{T_{evacuate}}{T_{prepare} + T_{evacuate}}$	0.774

(e) Sense-of-resistance parameter γ

The sense-of-resistance parameter γ determines the difference between the subjective probability perceived by each resident and the objective probability. This parameter should be set so that the cost of anxiety threshold value is non-negative for all the samples analyzed (number of samples, n=8,369). We assume that $\gamma = 0.1$.

4.3. Estimating the distribution of the cost of anxiety

By rearranging the evacuation behavior judgment formula $f = 0$ shown in Formula (10) with regards to individual i's cost of anxiety C_f^i, the cost of anxiety threshold value C_{fc}^i shown in Formula (19) is obtained as

$$C_{fc}^i = -\frac{\left\{\begin{matrix}\gamma {C_m}^2(-2+h-4h^2+h^3)q+\gamma^2 C_d h^2(5-2h+h^2)^2q^2 \\ -2\sqrt{-\gamma^2 {C_m}^4(-1+h)^3(1+h)^2q^2}\end{matrix}\right\}}{\gamma^2 h^2(5-2h+h^2)^2q^2}. \quad (19)$$

Individual i evacuates when his or her anxiety C_f^i is greater than the anxiety threshold value C_{fc}^i $\left(C_f^i > C_{fc}^i\right)$. In other words, the probability that individual i will evacuate is expressed by the cumulative probability to the right of C_{fc}^i in the probability density function, as shown in Figure 5. Therefore, if we assume that the cost of anxiety

follows a certain probabilistic distribution, we can estimate the distribution, using the non-aggregated data from the results of the evacuation behavior questionnaire and the cost of anxiety threshold value C_{fc}^{i} of individual i.

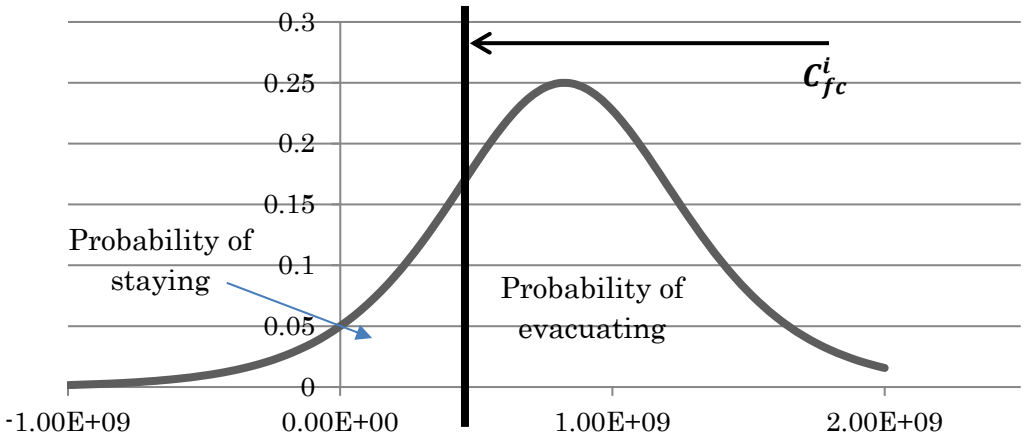

Figure 5. The relationship between the cost of anxiety threshold value and probability

We set a logistic distribution as the probabilistic distribution in the following manner. The average and variance of residents' anxiety are thought to differ according to age, gender, and whether or not they heard a tsunami alert, checked the hazard map, and participated in a local evacuation drill. Therefore in this study, we take these factors into account as "categories".

Anxiety C_f of residents in category *k*, as in Formula (20) below, is assumed to be the sum of the average value of the residents' anxiety in each category $\widehat{C_f^k}$ and the variable term. The variable term is expressed as the product of the scale parameter δ^k that represents the variance of the probability and the probability term ε_i expressing the logistic distribution of parameters $(\eta, \omega) = (0,1)$. In other words, among residents who belong to a certain category, there will be variations in the cost-of-anxiety parameter between them as individuals, but as a whole, the value of C_f will follow a logistic distribution. The probability density function of

the logistic distribution and the probability function can be expressed by Formula (21) using the average parameter η and the variance parameter ω.

$$C_f^i = \widehat{C_f^k} + \delta^k \varepsilon_i \tag{20}$$

$$f(x;\eta,\omega) = \frac{exp\left(-\frac{x-\eta}{\omega}\right)}{\omega\left\{1+exp\left(-\frac{x-\eta}{\omega}\right)\right\}^2} \quad \text{and} \quad F(x;\,\eta,\omega) = P_s = \frac{1}{1+\exp\left(-\frac{x-\eta}{\omega}\right)} \tag{21}$$

One problem with using a logistic distribution is that the area of the distribution on the left side of the y-axis has negative values of cost of anxiety (see Fig. 5). Negative cost of anxiety is difficult to interpret. However, if we assume that these negative values are all zero cost of anxiety, there will be no problem, noting that C_f^i is positive. In other words, the negative areas can be used only for conveniently calculating the probability.

As individual i evacuates when his or her anxiety C_f^i is greater than the anxiety threshold value $C_{fc}^i\left(C_f^i > C_{fc}^i\right)$, the probability of evacuation can be expressed by the Formula (22).

$$\begin{aligned} P_E = P\left(C_f^i > C_{fc}^i\right) &= P\left(\widehat{C_f^k} + \delta^k \varepsilon_i > C_{fc}^i\right) = P\left(\varepsilon_i > \frac{1}{\delta^k}\left(C_{fc}^i - \widehat{C_f^k}\right) = \frac{C_{fc}^i}{\delta^k} - \frac{\widehat{C_f^k}}{\delta^k}\right) \\ &= 1 - \frac{1}{1 + exp\left(-\frac{1}{\delta^k}\left(C_{fc}^i - \widehat{C_f^k}\right)\right)} = 1 - \frac{1}{1+exp(-\alpha)} \end{aligned} \tag{22}$$

$$\text{where } \alpha = \frac{1}{\delta^k}\left(C_{fc}^i - \widehat{C_f^k}\right)$$

As the last line of Eq. (22) shows, function α is composed of two terms: the term mainly determining the variance of the cost of anxiety, $(1/\delta^k)C_{fc}^i$, and the term including the

average value $\widehat{C_f^k}$, $\widehat{C_f^k}/\delta^k$. Since the average and variance of residents' anxiety are thought to differ according to age, gender, and whether or not they heard a tsunami alert, checked the hazard map, and participated in a local evacuation drill, both terms can be expressed as the function of these attributes. So, we set Formulas (23) and (24) using dummy variables.

The dummy variables within Formulas (23) and (24) are shown as x_{sex}: sex dummy ($x = 1$ when individual i is male; $x = 0$, female), x_{age1}: young aged dummy ($x = 1$ when individual i is age group 1; $x = 0$, others), x_{age2}: middle aged dummy ($x = 1$ when individual i is in age group 2; $x = 0$, others), x_{alert}: alert dummy ($x = 1$ when individual i heard a tsunami alert or call for evacuation; $x = 0, \text{others}$), x_{sign}: sign dummy ($x = 1$ when individual i had seen a sign marking previous tsunamis; $x = 0$, others), x_{map} : map dummy ($x = 1$ when individual i checked the tsunami hazard map; $x = 0$, others), x_{drill}: drill dummy ($x = 1$ when individual i participated in a local evacuation drill; $x = 0, \text{others}$), $x_{municipal\,n}$: municipal dummy ($x = 1$: When individual i lives in municipality n; $x = 0$, others).

$$-\widehat{C_f^k}/\delta^k = \begin{matrix}\beta_0 + \beta_1 x_{sex} + \beta_2 x_{age1} + \beta_3 x_{age2} + \beta_4 x_{alert} \\ +\beta_5 x_{sign} + \beta_6 x_{map} + \beta_7 x_{drill} + \beta_n x_{municipal\,n} (n = 1\sim22)\end{matrix} \tag{23}$$

$$1/\delta^k = \begin{matrix}\lambda_0 + \lambda_1 x_{sex} + \lambda_2 x_{age1} + \lambda_3 x_{age2} + \lambda_4 x_{alert} \\ +\lambda_5 x_{sign} + \lambda_6 x_{map} + \lambda_7 x_{drill} + \lambda_n x_{municipal\,n} (n = 1\sim22)\end{matrix} \tag{24}$$

Based on this setting, the likelihood function is set as in Formula (25) and estimated using the maximum likelihood method.

$$L\left(\theta \middle| C_f^i\right) = \prod_{i=1}^{n} \delta_i P_s \cdot (1-\delta_i) P_E$$
$$\begin{cases} \delta_i = 1 \; stay \\ \delta_i = 0 \; evacuate \end{cases} \tag{25}$$

$$P_E = 1 - \frac{1}{1 + exp(-\alpha)}, P_S = \frac{1}{1 + exp(-\alpha)} \tag{26}$$

We will explain the results of the method of regression method within Formulas (23) and (24) and the examination of validity. We performed this regression analysis using statistical analysis software, namely the "multiple logistic regression analysis" tool in Excel Statistics 2010. To investigate the goodness of fit of the model, we used McFadden's pseudo-decision coefficients R^2 and AIC, and the hit rate as the indicators. We judged the validity of the parameters using the significance of the regression coefficients and the validity of the signs.

We estimated all the combinations of dummy variables, and we adopted the best combination that has the highest AIC, likelihood ratio, and hit rate. Formula (27) shows the regression equation with only significant parameters. Table 6 shows the regression coefficients of Formula (27).

$$\begin{aligned} \alpha &= \frac{1}{\delta^k}\left(C_{fc}^i - \widehat{C_f^k}\right) = \frac{1}{\delta^k} C_{fc}^i - \frac{\widehat{C_f^k}}{\delta^k} \\ &= \left(\lambda_0 + \lambda_1 x_{sex} + \lambda_2 x_{age1} + \lambda_3 x_{age2}\right) C_{fc}^i \\ &+ \begin{pmatrix} \beta_0 + \beta_{sex} x_{sex} + \beta_{age1} x_{age1} + \beta_{age2} x_{age2} + \beta_{alert} x_{alert} \\ +\beta_{sign} x_{sign} + \beta_{map} x_{map} + \beta_{drill} x_{drill} \\ +\beta_{area1} x_{area1} + \cdots + \beta_{area21} x_{area21} \end{pmatrix} \end{aligned} \tag{27}$$

Table 8: coefficient and statistical indices of formula (27)

$Coefficient$	$p\ value$	$Coefficient$	$p\ value$
$\lambda_0 = 8.98E-13$	0.482	$\lambda_{sex} = -7.96E-13$	0.258
$\lambda_{age1} = 9.18E-13$	0.556	$\lambda_{age2} = -8.64E-14$	0.953
$\beta_0 = -1.2279$	0.000	$\beta_{sex} = 0.1699$	0.003
$\beta_{age1} = 0.1640$	0.028	$\beta_{age2} = 0.0173$	0.807
$\beta_{alert} = -0.1679$	0.002	$\beta_{sign} = -0.0952$	0.147
$\beta_{map} = 0.0085$	0.932	$\beta_{drill} = -0.1005$	0.176
$\beta_{Ofunato} = -0.4771$	0.001	$\beta_{Miyako} = -0.4604$	0.005
$\beta_{Oduchi} = -1.2547$	0.000	$\beta_{Yamada} = -1.1721$	0.000
$\beta_{Kuji} = -0.6717$	0.431	$\beta_{Kamaishi} = -0.5983$	0.002
$\beta_{Rikuzentakata} = -0.1526$	0.261	$\beta_{Asahi} = 1.1120$	0.014
$\beta_{Iwaki} = 0.5110$	0.000	$\beta_{Minamisouma} = 1.0450$	0.000
$\beta_{Souma} = 0.3480$	0.024	$\beta_{Kesennuma} = -0.3616$	0.002
$\beta_{Minamisanriku} = -0.1702$	0.258	$\beta_{Natori} = 0.7921$	0.000
$\beta_{Higashimatushima} = 0.9354$	0.000	$\beta_{Sendai} = 0.3229$	0.070
$\beta_{Watari} = 0.6265$	0.000	$\beta_{Yamamoto} = 0.5145$	0.001
$\beta_{Onagawa} = -0.5228$	0.023	$\beta_{Iwanuma} = 0.6058$	0.001
$\beta_{Shiogama} = -0.3998$	0.080		
AIC		8840.67	
$coefficient\ of\ determination$		0.0659	
$hit\ rate$		75.29%	

4.4. Considering the estimation

There are two kinds of coefficients: coefficients related to average β and coefficients related to variance λ. Looking at Table 8, we can see that the coefficients related to variance do not satisfy the significance level for the p-value and we cannot grasp the difference by attribute. However, the coefficients related to average satisfy the significance level for the p-value and we can grasp the difference by attribute. Therefore, we examine the difference in average anxiety.

First, we consider the difference in average by area. Figure 6 shows the average anxiety level by area. Average anxiety level shows average anxiety in each area with the anxiety of Ishinomaki as numeraire =1. Figure 7 shows the relationship between the maximum runup height of the Sanriku earthquake tsunami or the Chile earthquake tsunami and the average anxiety level estimated in the current paper.

The top 8 regions with shaded bars in Figure 6 is the area which suffered flood damage by either the 1960 Chile earthquake tsunami or the Sanriku earthquake tsunami. As shown in Figure 6 and Figure 7, the average anxiety of a resident who lives in the areas which suffered flood damage by a large-scale past disaster is large. Moreover, average anxiety of residents is roughly correlated to the damage of past disasters.

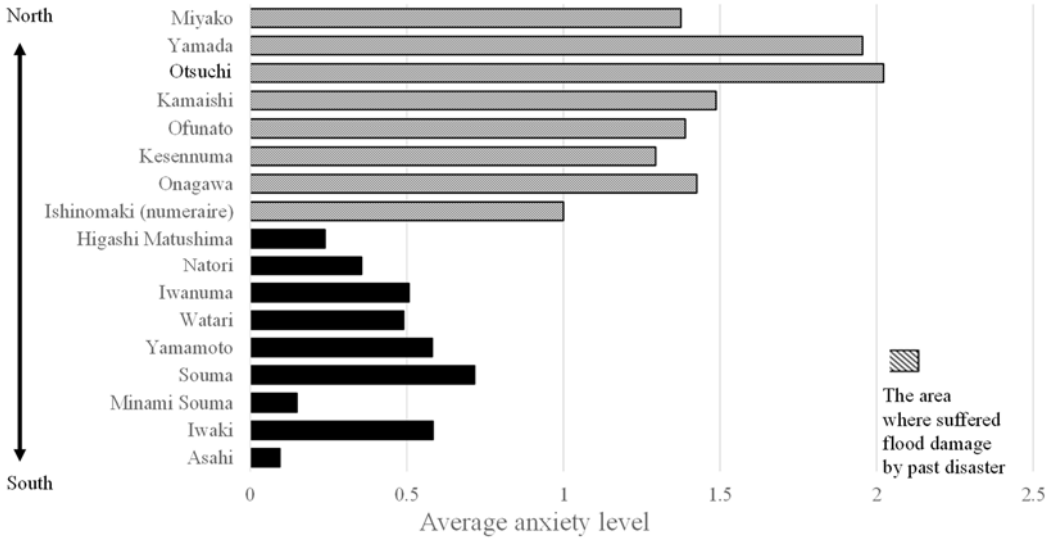

Figure 6: Average anxiety level by area

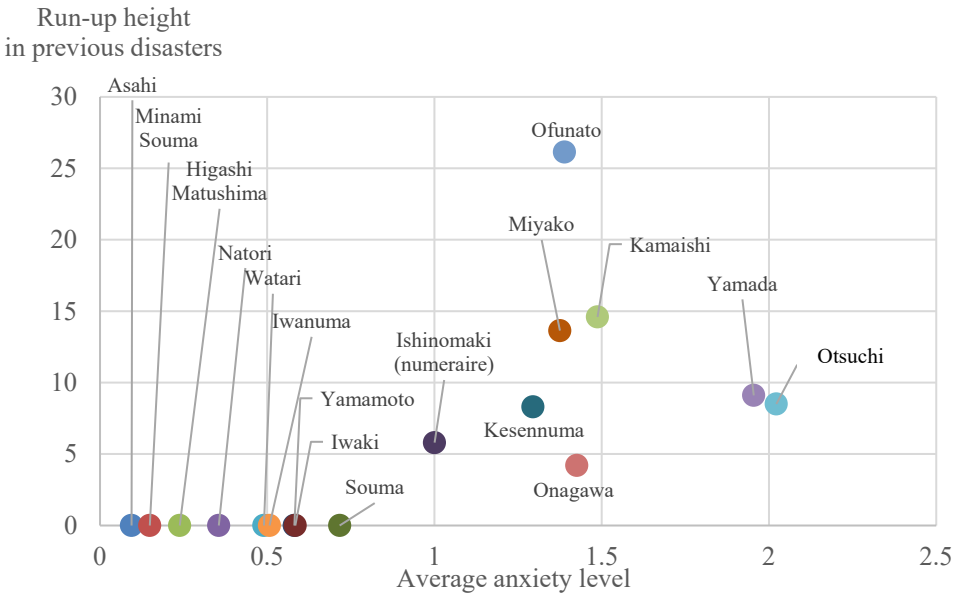

Figure 7: Relationship between maximum run-up height and average anxiety level

Next, we explore the difference in average anxiety level by sex, age and whether they heard an alert or not. In order to see what level of evacuation rate corresponds to the difference in anxiety, we consider three comparisons.

Comparison 1: A comparison of the evacuation rates between the cases when all residents have a ‘female” level of anxiety that the female has and the case when all residents have a ‘male” level of anxiety.

Comparison 2: A comparison of the evacuation rates between the case when all residents have the anxiety level of Age group 3 and the case when all residents have the anxiety level of Age group 1.

Comparison 3: A comparison of the evacuation rates between the case when all residents have the anxiety level of people who heard an alert and the case when all residents have the anxiety level of people who did not hear an alert.

Table 9 summarizes the three comparisons in terms of average evacuation rates. As shown in Table 9, the anxiety felt by females is larger than that by males and the difference in anxiety by gender is equivalent to the difference in the evacuation rate 2.546% (comparison 1). The difference by gender category may be caused by a difference in the role in the family during evacuation. The anxiety of Age group 3 is larger than that of Age group 1, and the difference in anxiety is equivalent to the difference in evacuation rate 3.278% (comparison 2). The difference by age category may be caused by their past disaster experience. Anxiety of residents who heard an alert is larger than that of residents who did not hear an alert. This difference in anxiety is equivalent to the difference in the evacuation rate 2.926% (comparison 3). This result shows that it is effective to issue an alert for achieving early evacuation.

Table 9: Relationship between anxiety and evacuation rate

		Anxiety	Evacuation rate (%)	Difference in anxiety	Difference in evacuation rate (%)
Comparison 1	Female	1.000	76.061	0.138	2.546
	Male	0.862	73.515		
Comparison 2	Age group 3	1.000	76.127	0.134	3.278
	Age group 1	0.866	72.849		
Comparison 3	No Alert	1.000	73.415	0.137	2.926
	Alert	1.137	76.341		

5. Conclusion

In the current study, we modeled tsunami evacuation behavior while taking cognitive dissonance into consideration. Applying the model to the data of the evacuation behavior at the time of the 2011 Japan Earthquake and Tsunami, we quantitatively estimated the anxiety of 22 municipalities from evacuation behavior by the cross attributes of gender, age, and whether or not they heard a tsunami alert, and whether or not they have cheked a hazard map, and whether or not they participated in local evacuation drill as “categories”.

As a result, we mainly obtained the following four results. 1) We show that anxiety varies largely across residential locations. 2) The average anxiety of residents is roughly correlated to the damage in the past disasters. 3) Anxiety of females is larger than that of males, and the anxiety of Age group 3 is larger than that of Age group 1. 4) Tsunami alert affects the anxiety and increases the evacuation rate. Additionally, the provision of a hazard map and participation in evacuation drills might affect the improvement of the anxiety and the evacuation rate. However, these effects do not satisfy significance levels.

Future research can combine this evacuation model with a dynamic tsunami evacuation simulation and explore some policies related to evacuation routes.

Appendix

A.1. Confirmation of robustness

We use the data from the questionnaire conducted in disaster area of the 2011 Japan Earthquake and Tsunami. Accordingly, we cannot capture the attributes and behaviors of residents who died due to the tsunami because the questionnaire was carried out after the disaster occurrence. So, if those who died had different preferences from the respondents to the questionnaire, there is a possibility that the estimation result does not represent the total group. In order to explore this bias, we estimated coefficients with the data excluding the

samples in the areas with high death rates. The exclusion areas are four areas (Otsuchi, Onagawa, Rikuzentakata, Yamamoto) which had death rates of more than 20%.

Figures 10-1 and 10-2 show the comparison of the results when we use the total samples and when we exclude four areas. The difference in anxiety level from the original evacuation model is only 0.03 in the area with the maximum difference. Therefore, we can suppose that the influence of residents who died will not be so large and there is robustness in our estimation.

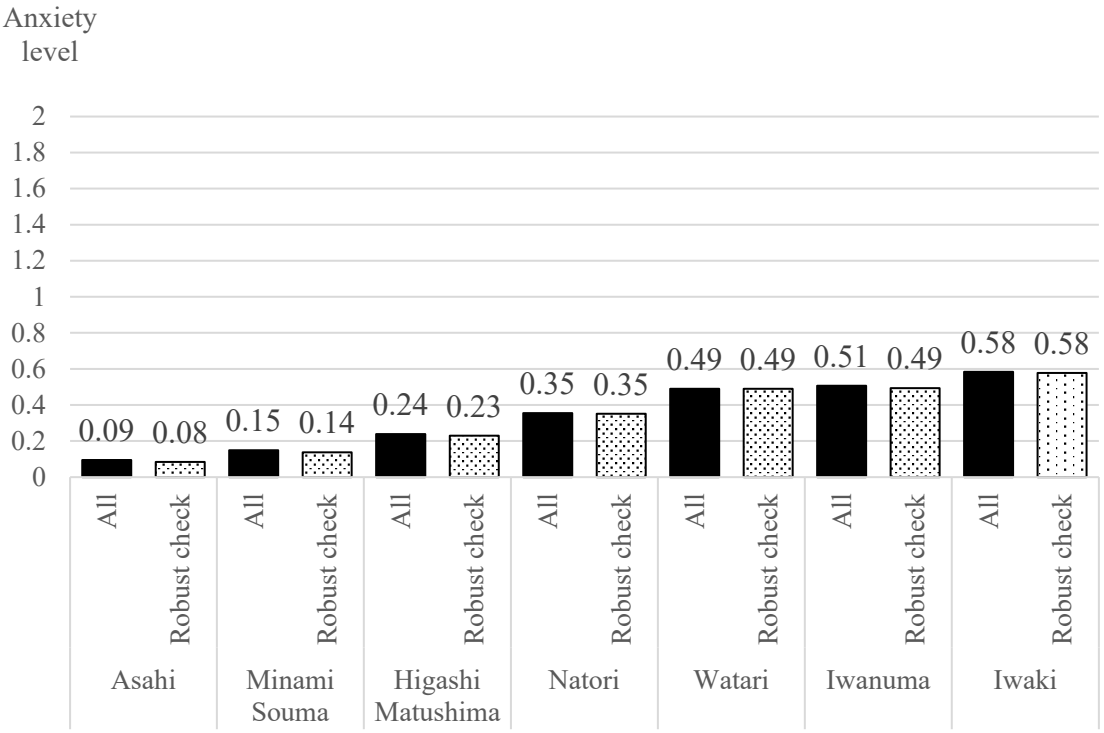

Figure 8-1 Comparison of average anxiety level (part 1)

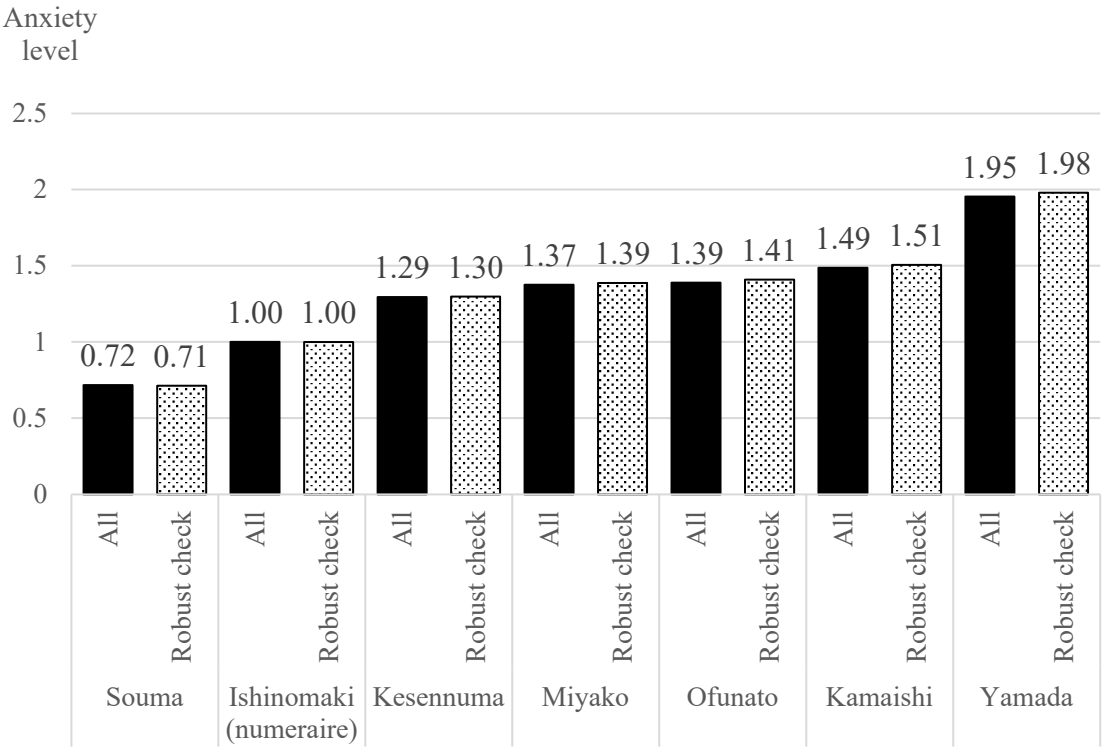

Figure 8-2 Comparison of average anxiety level (part 2)

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