Nat Hazards (2016) 80:1243–1256
DOI 10.1007/s11069-015-2021-2

ORIGINAL PAPER

Perceived ambiguity about earthquake and house destruction risks

Toshio Fujimi[1] · **Masahide Watanabe**[2] · **Ryuji Kakimoto**[1] · **Hirokazu Tatano**[3]

Received: 8 April 2014 / Accepted: 10 October 2015 / Published online: 22 October 2015

Abstract To create effective risk mitigation policies and improve risk communications, it is important to understand how individuals perceive ambiguity about certain risks. A significant number of studies have demonstrated that an individual's behavior is sensitive to ambiguity. Therefore, this study explores how Japanese homeowners perceive ambiguity about earthquake and house destruction risks by focusing on two research questions: (1) To what degree do people perceive ambiguity? and (2) What are the factors that affect the degree of perceived ambiguity? We administered a survey to 1200 homeowners in Japan. Respondents were asked to state their subjective probabilities and ambiguities about earthquake and house destruction risks. Next, we examined the socioeconomic characteristics affecting their perceived ambiguities by applying a sample selection model. The findings reveal four aspects related to ambiguity. First, some homeowners perceived considerable ambiguity, while the majority observed small degrees of it. Second, on average, homeowners perceived less ambiguity about house destruction risk compared to earthquake risk. Third, socioeconomic characteristics and house attributes had an effect on the perception of ambiguity. Finally, from the perspective of creating policies that mitigate house destruction risks due to earthquakes, seismic diagnoses can help correct subjective risks and reduce the perceived ambiguity regarding them.

Keywords Ambiguity · Risk · Earthquake · House destruction · Perception

✉ Toshio Fujimi
fujimi@kumamoto-u.ac.jp

1 Graduate School of Science and Technology, Kumamoto University, 2-39-1, Kurokami, Kumamoto 860-8555, Japan

2 Department of Economics, Osaka University of Economics, 2-2-8, Osumi, Higashiyodogawa-ku, Osaka 533-8533, Japan

3 Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

1 Introduction

When considering catastrophic natural disasters, people frequently face uncertainties when assessing risks and such vagueness is known as "ambiguity." Camerer and Weber (1992) described ambiguity as "uncertainty about probability, created by missing information that is relevant." Etner et al. (2012) defined it as "situations in which the decision maker is not given probabilistic information about the external events that might affect the outcome of a decision." To create effective risk mitigation policies and improve risk communications, it is important to understand how individuals perceive ambiguity since a considerable number of previous studies have demonstrated that an individual's behavior is sensitive to ambiguity. Although most of these studies utilized experimental settings such as lotteries, some studies examined ambiguity regarding disaster risks (Hogarth and Kunreuther 1985, 1989; Kunreuther et al. 1993, 1995) and health risks (Ritov and Baron 1990; Viscusi et al. 1991, 1999; Viscusi and Chesson 1999; Kivi and Shogren 2010). In these empirical studies, ambiguity about the relevant risk was exogenously given to the subjects. For example, they were asked to imagine a hypothetical situation in which the ambiguous risk was typically described as the range between *a%* and *b%* or based on disagreements among expert predictions. However, the subjects endogenously perceived ambiguity in a real-world setting.

This raises the following question: How do people perceive ambiguity about a relevant risk? Surprisingly, limited studies have addressed this question while extensive literatures have only investigated how and why people behave under a given ambiguity. This paper aims to fill this gap by exploring how homeowners perceive ambiguity about earthquake and house destruction risks as well as focuses on two research questions: (1) To what degree do people perceive ambiguity? and (2) What are the factors affecting the degree of perceived ambiguity? We administered a survey to 1200 homeowners in Japan. Respondents were asked to state their subjective probabilities and ambiguities regarding earthquake and house destruction risks. Next, we examined the socioeconomic characteristics affecting their perceived risks and ambiguities by applying a sample selection model.

There is a significant literature regarding the factors affecting perceived risk about health and environmental issues (Slovic 2000). As for natural disasters, risk perception is influenced by the socioeconomic characteristics of individuals and hazardous attributes. Kellens et al. (2013) reviewed extensive literature on the determinants of perceived flood risks and found that older women with less education, lower incomes, and limited disaster experience generally perceive higher flood risk compared to other respondents. Regarding earthquake risks, similar results obtained in previous studies showed that older women with more disaster experience perceived greater earthquake risks (Armas 2006, 2008; Tekeli-Yesil et al. 2011; Zhu et al. 2011; Kung and Chen 2012).

Conversely, limited empirical studies have investigated how people perceived ambiguity. Riddel and Shaw (2006) estimated residents' subjective probability and ambiguity regarding nuclear-waste transport risks, and Riddel (2009, 2011) presented a model based on an induced distribution approach to estimate an individual's subjective probability and ambiguity about such risks. The results show that number of sources of information that the subjects had been exposed to increased the degree of perceived ambiguity, which suggests that ambiguity was increased with conflicting information, especially in topics of a controversial nature. Other variables, such as gender, distance from the transport route, health status, and education, did not have an influence on perceived ambiguity. Nguyen et al. (2010) examined individuals' subjective probability and ambiguity associated with arsenic contamination of drinking water by applying a similar method to the one used by Riddel (2009). They found that subjects living in areas where arsenic contamination received significant attention in local media perceived less ambiguity of subjective probability than those in other areas. They also found that the interaction between health status and any history of smoking had a positive and significant effect on ambiguity size.

This paper focuses on ambiguity under the framework of second-order probability in which subjective probability of an event, such as an earthquake or house destruction, includes a probability distribution known as "second-order probability distribution." Riddel and Shaw (2006), Riddel (2009, 2011), and Nguyen et al. (2010) formulated ambiguity through this framework and defined the variance of second-order probability distribution as the measure of ambiguity size. This paper defines "ambiguity size" as the 95 % confidence interval of subjective probability regarding the relevant risk in second-order probability distribution.[1] Furthermore, we focus on "relative ambiguity," which is the ratio of ambiguity size divided by the subjective probability of the relevant risk. This is because we are more interested in the relative size of ambiguity to subjective probability rather than the absolute size of ambiguity. In other words, this paper examines the extent to which subjective probability is amplified under ambiguous situations and the factors influencing such development.

A unique feature of this study is the investigation of perceived ambiguities regarding two different types of risks: earthquake risk and house destruction risk. In this paper, earthquake risk is defined as the probability of earthquake occurrence, while house destruction risk is described as the probability of house destruction due to an earthquake. For homeowners, earthquake risk is impossible to mitigate except for moving to safer areas. On the other hand, house destruction risk can be alleviated through seismic retrofitting, which enables the homeowners to feel relatively safe during earthquakes since their houses have been sufficiently strengthened. That is, earthquake risk is uncontrollable, whereas house destruction risk is controllable. Slovic (1987) showed that subjects tend to underestimate controllable risk. Klein and Kunda (1994) argued that this tendency is partly due to subjects believing that they have the ability to avoid certain risks better than others. Such differences might also influence the various ways in which they perceive ambiguities.

This paper is organized as follows. Section 2 describes earthquake and house destruction risks in Japan. Section 3 presents the data used in this study. Section 4 explains the model and estimation results. Section 5 discusses the results. Section 6 concludes.

2 Earthquake and house destruction risks in Japan

Japan faces a significant earthquake risk compared with other countries. Cabinet Office (2010) reports that approximately 20 % of the earthquakes in the world, with a magnitude (*M*) of 6.0 or greater, occurs in Japan. House destruction due to earthquakes is one of the most serious risks for homeowners. For instance, the 1995 Kobe earthquake completely destroyed 104,906 houses, which caused approximately 5000 deaths and 80 % of the total death (Cabinet Office 2010). According to the Ministry of Land, Infrastructure, and Transport of Japan (MLIT 2005), around 10.5 million (21 %) houses did not satisfy the current code of earthquake resistance in Japan.

[1] Cameron (2005) elicited the subjective distribution of future mean global temperatures in which the 95 % confidence interval was used for the dispersion measure. A similar measure was utilized in this paper by extending it to second-order distribution.

A considerable number of homeowners are concerned with earthquakes and house destruction risks, especially after recent reports by mass media regarding large earthquakes and their resulting house collapses. In addition, Japanese scientists continuously warn the public that based on historical patterns of earthquake occurrences, catastrophic earthquakes may occur in Japan in the near future. According to a 2010 survey by the Headquarters of Earthquake Research Promotion (2010), 70 % of the 2000 respondents were worried about a massive earthquake in their area and 56 % of them predicted that their houses would be damaged by such a catastrophe.

Some homeowners have been obtaining seismic diagnoses of their houses to determine their seismic capacity. During a seismic diagnosis, an architect examines portions of a structure to determine the house strength to earthquake. According to the Seismic Index of Structure (IS), 0–0.7, 0.7–1.0, 1.0–1.5, and more than 1.5 are judged as "No possibility of collapse," "Little possibility of collapse," "Moderate possibility of collapse," and "High possibility of collapse," respectively. The Japan Association for Seismic Retrofit Contractors (2012) performed such diagnoses on a total of 13,674 houses throughout Japan from April 2006 to November 2011. The results show that 70.8, 19.5, 8.2, and 1.5 % of the houses received IS scores of 0–0.7, 0.7–1.0, 1.0–1.5, and more than 1.5, respectively.

3 Data

This paper utilizes data from a web-based survey conducted in late March 2009, which was originally designed to investigate homeowners' preferences regarding seismic retrofitting by Fujimi and Tatano (2013). Although the detailed explanation of the survey is presented by Fujimi and Tatano (2013), we have briefly sketched an outline of the survey. The respondents of our survey were 1200 homeowners in Japan who had never implemented seismic retrofitting. After displaying a national seismic hazard map provided by HERP (2005), we elicited respondents' subjective probabilities about earthquakes with the Japanese seismic intensities of 6 Lower, 6 Upper, and 7 within 30 years. In addition, they were asked to state their upper and lower guesses so that the subjective probability between them included a 95 % probability. Then, the respondents were asked for the subjective probability and their upper and lower guesses of complete house destruction contingent upon an earthquake at each seismic intensity level.[2] The respondents used an interactive web tool to facilitate stating their subjective probabilities and upper and lower guesses. In addition, this survey included questions regarding socioeconomic characteristics and house attributes.

4 Methods

This section explains the applied econometric model to examine the determinants of relative ambiguity of earthquake and house destruction risks.

[2] In the survey, we established three classifications of house damage: partial destruction, half destruction, and complete destruction. However, this paper focused on complete destruction in order to obtain more reliable results since it was easier for the respondents to imagine complete destruction. The classifications of partial and half destruction can be unclear for the respondents, which might create additional ambiguity in them.

4.1 Model

This paper focuses on relative ambiguity, which is defined as the ratio of ambiguity size to subjective probability of the relevant risk. In this case, subjective probability of the relevant risk is shown as the "best guess" and the ambiguity size is given as the range between its upper and lower guesses. To examine the determinants of relative ambiguity for earthquake and house destruction risks, the logarithm of relative ambiguity is regressed on the socioeconomic and house attribute variables. The logarithmic transformation of relative ambiguity is implemented because it makes the regression model better fitted to data than the original values. However, logarithmic transformation requires special attention regarding their zero values since the logarithm of zero is negative infinity.

To deal with this problem, we applied a sample selection model that consists of a probit part determining whether or not to perceive ambiguity and regression part in which logarithms of relative ambiguity were regressed on the explanatory variables. This model requires specific distribution assumption of error terms, and if the assumption is incorrect, then the estimation result can be biased. For comparison, an ordinary least squares (OLS) method with heteroskedasticity-robust errors was also applied to samples where responses of zero for relative ambiguities are eliminated. The latter model does not require distribution assumption of error terms but includes the possibility that the omission of zero relative ambiguity samples might result in sample selection bias. Both methods include pro and cons but if we can obtain common results in both models, then these results can be considered as robust and reliable.

Sample selection model consists of a probit part determining whether or not to perceive ambiguity and a regression part where relative ambiguity is regressed on explanatory variables. The probit part is written as follows:

$$y_1 = \begin{cases} 1 & \text{if } y_1^* > 0 \\ 0 & \text{if } y_1^* \leq 0 \end{cases}$$

$$y_1^* = x_1'\beta_1 + \varepsilon_1$$

where y_1 is a dummy variable that takes the value of 1 if the relative ambiguity is positive and 0 otherwise. x_1 is the independent variables vector, β_1 is the parameter vector, and ε_1 is the error term. In the regression part, the relative ambiguity y_2 is determined by the latent variable y_2^*. We assume that y_2^* follows a log-normal distribution:

$$y_2 = \begin{cases} y_2^* & \text{if } y_1^* > 0 \\ - & \text{if } y_1^* \leq 0 \end{cases}$$

$$\ln(y_2^*) = x_2'\beta_2 + \varepsilon_2$$

where x_2 is the independent variables vector, β_2 is the parameter vector, and ε_2 error term. The error terms ε_1 and ε_2 are assumed to be joint normally distributed.

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{pmatrix}\right]$$

where σ^2 is the variance of ε_2 and ρ is the correlation coefficient between ε_1 and ε_2. This model includes the following likelihood function:

$$L = \prod_{i=1}^{n} \left\{ \Pr\left[y_{i1}^{*} \le 0\right] \right\}^{1-y_{i1}} \left\{ f\left[\ln(y_{i2}) | y_{i1}^{*} > 0\right] \times \Pr\left[y_{i1}^{*} > 0\right] \right\}^{y_{i1}},$$

where f is the density function of normal distribution and subscript i represents individual response.

4.2 Explanatory variables in the models

Unlike subjective probability, much less is known regarding what factors influence perceived ambiguity. It is natural to suppose that factors affecting perceived risk may also influence their perceptions of relative ambiguity. Our model includes respondent's age, gender, child, education, income, and disaster experience since previous research has showed that perceived risk can be influenced by these variables. Furthermore, we added a dummy variable to represent whether or not a respondent is self-employed. Self-employed people are known to be more tolerant of risk and uncertainty compared to other types of employees (Barsky et al. 1997; Cramer et al. 2002; Hartog et al. 2002). For perceived ambiguity of house destruction risk, the model also includes house age, house structure (wood or concrete, etc.), and experience of having seismic diagnoses performed on their houses. In addition, we control the effect of seismic intensity that respondents were asked to suppose by including dummy variables of seismic intensity of 6 Upper and 7. The definitions of these variables are listed in Table 1.

5 Results and discussion

5.1 Perceived risks and ambiguities

The respondents' perception of subjective probabilities and ambiguities on earthquake and house destruction risks is reported in Fujimi and Tatano (2013), which indicates that "the

Table 1 Definitions of independent variables

Variable	Definition
AGE	Age of respondent (years)
FEMALE	Gender (1, female; 0, male)
EDUCATION	Did respondent graduate university? (1, yes; 0, no)
INCOME	Annual income (million yen)
CHILD	Does respondent have a child under 12 years old? (1, yes; 0, no)
SELF_EMPLOYED	Is respondent self-employed? (1, yes; 0, no)
DISASTER_EXP	Has respondent experienced loss from a disaster? (1, yes; 0, no)
WOOD	House material (1, wood; 0, otherwise)
HOUSE_AGE	Age of house (years)
DIAGNOSIS	Has respondent implemented seismic diagnosis to house? (1, yes; 0, no)
EQ6U	Dummy variable that takes 1 if response is for an earthquake with seismic intensity of 6 Upper, and 0 otherwise
EQ7	Dummy variable that takes 1 if response is for an earthquake with seismic intensity of 7, and 0 otherwise

The variables, except for DIAGNOSIS, EQ6U and EQ7, are also explained in Table I of Fujimi and Tatano (2013)

Table 2 Medians of subjective probabilities about house destruction risks with and without seismic diagnosis

Seismic intensity	Objective probability	Subjective probability		
		All samples ($N = 1200$)	With seismic diagnosis ($N = 38$)	Without seismic diagnosis ($N = 1162$)
6 Lower	0–0.05	0.01	0.03	0.01
6 Upper	0.05–0.25	0.02	0.10	0.02
7	0.25–0.55	0.10	0.20	0.10

The objective probabilities about house destruction risks are obtained from the report of Japan Meteorological Agency and Fire and Disaster Management Agency (2009)

majority of homeowners considerably underestimate the risk of house destruction," whereas "no evidence that subjective probabilities are overestimated or underestimated regarding objective probabilities" of the earthquake occurrence. In addition, a seismic diagnosis of house might improve homeowners' perceived risk of house destruction. Table 2 indicates that the medians of respondents' subjective probabilities of house destruction with and without seismic diagnosis. Those of the former are closer to the objective probabilities.

Figure 1 shows the relative frequencies of relative ambiguities for earthquake and house destruction risks. "No perception" means that respondents perceived no ambiguity in the sense that their stated probabilities for upper and lower guesses were equal. In general, the distribution shapes are similar for both earthquake and house destruction risks, and the distribution of relative ambiguities is skewed to the right. In most cases, relative ambiguities are less than or equal to 1. Only 15 and 8 % of the respondents perceived relative ambiguity to be equal to or greater than 2 for earthquake and house destruction risks, respectively.

On average, the relative ambiguity of house destruction risk was less than that of earthquake risk. The difference between these distributions was clear at 0–1 and greater than 6 for relative ambiguity. Compared to house destruction risk, fewer respondents stated

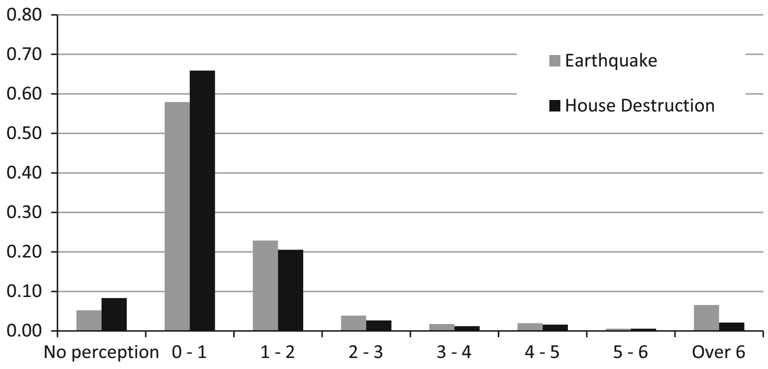

Fig. 1 Distributions of relative ambiguity for earthquake risk and house destruction risk: The *horizontal axis* shows the relative ambiguity where a label "$\alpha - \beta$" means "from equal to or more than α to less than β." The *vertical axis* shows the response ratios

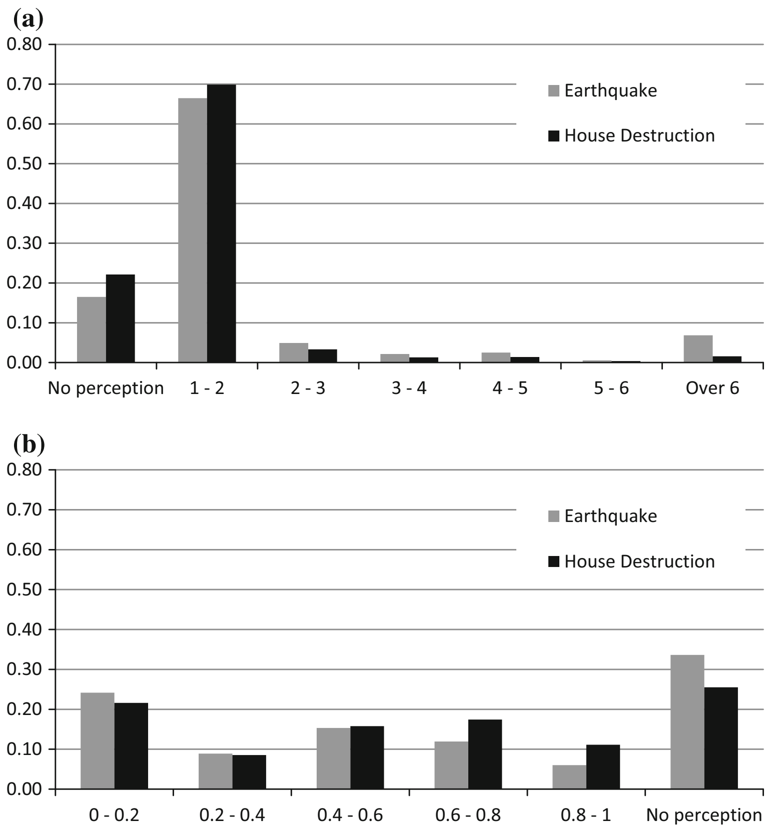

Fig. 2 Distributions of upper and lower guess divided by best guess for earthquake risk and house destruction risk: The *horizontal axis* shows the relative ambiguity where a label "$\alpha - \beta$" means "from equal to or more than α to less than β." The *vertical axis* shows the response ratios. **a** The distributions of upper guess divided by best guess. **b** The distributions of lower guess divided by best guess

that their relative ambiguity was 0–1 for earthquake risk, whereas more respondents stated that their relative ambiguity was greater than 6 for earthquake risk, which suggests that homeowners have more confidence on their subjective probability for house destruction risk compared to that for earthquake risk.

Figure 2a, b shows the ratio of upper and lower estimates divided by "best guess," respectively. The former describes the distribution of perceived ambiguity from a pessimistic perspective, while the latter describes that from an optimistic perspective. "No perception" means that the upper (or lower) guess is equal to the "best guesses" in the former (or latter) figure. In both figures, the distribution shapes are similar for both earthquake and house destruction risks as a whole. Figure 2a indicates that the majority of the respondents perceived the upper guess to be less than two times the "best guess," while Fig. 2b shows that the ratio of the lower guess divided by the "best guess" was roughly constant. These figures suggest that the majority of homeowners does not perceive so large ambiguity from a pessimistic perspective, whereas they perceived ambiguity variously from an optimistic perspective.

5.2 Estimation results and discussion for relative ambiguity

The estimation results for relative ambiguity are shown in Table 3. The second column presents the estimation results of the probit part for relative ambiguity of earthquake risk in the sample selection model. EQ7 in the probit part is negative and significant at the 5 % level, which indicates that respondents are less likely to perceive ambiguity of earthquake risk with a seismic intensity of 7 compared to 6 Lower and 6 Upper. This is probably because respondents can imagine earthquakes with higher seismic intensities more easily than smaller ones. The third column in Table 3 presents the estimation results of the regression part. EDUCATION is positive and significant at the 5 % level, which suggests that the respondents with higher education have a greater ability to recognize that their "best guess" of the probability of earthquakes could be wrong and, due to this uncertainty, they perceive greater ambiguity. SELF_EMPLOYED is negative and significant at the 1 % level, which shows that self-employed people are not only risk tolerant but also confident of their perceived risks. This is consistent with the assumption that such entrepreneurs are accustomed to facing uncertainties in their relative working environments.

The fifth and sixth columns in Table 3 present the estimation results of the probit and regression parts for relative ambiguity of house destruction risk in the sample selection model, respectively. EQ6U and EQ7 are negative and significant at the 1 % level in the regression part, in which the latter includes a larger absolute value of the coefficient than the former. This means that respondents perceive less relative ambiguity of house destruction risks regarding earthquakes with higher intensities, which are based on the idea that homeowners can more easily imagine their house being destroyed by such earthquakes. WOOD and HOUSE_AGE are significantly positive in the probit part, whereas HOUSE_AGE is significantly negative in the regression part. This finding shows that respondents living in fragile houses are more likely to perceive ambiguity of house destruction risk, even though they perceive smaller relative ambiguity. This is probably due to their easiness of imagining the destruction of their fragile house, which triggers the perception of ambiguity and reduces the relative ambiguity.

FEMALE in the probit part is positive and significant at the 1 % level, indicating that women respondents are more likely to perceive ambiguity. AGE is positive and significant at the 1 % level in the regression part, which shows that older respondents perceive greater relative ambiguity. EDUCATION is significantly positive in both the probit and regression parts, which implies that educated respondents are more likely to perceive greater relative ambiguity of house destruction risks, which is possibly due to the same reason for that of earthquake risk. INCOME is statistically significant and positive at the 1 % level in the regression part, thus showing that respondents who earn higher income perceive greater ambiguity. CHILD is positive and significant in the regression parts for both earthquake and house destruction risks, which indicates that respondents with children perceive greater relative ambiguity for both risks. DIAGNOSIS is negative and significant at the 1 % level, which means that seismic diagnoses by professionals can reduce the ambiguity of house destruction risk.

In general, the socioeconomic characteristics of homeowners have similar effects on the relative ambiguities of both earthquake and house destruction risks. There are no parameter estimates that have opposite sign with statistical significance between them. Finally, the estimates of ρ are 0.820 and 0.544 with statistical significance at the 5 % level in the

Table 3 Estimation results of the sample selection models and OLS method for relative ambiguities of earthquake and house destruction risks

	Relative ambiguity					
	Earthquake			House destruction		
	Sample selection		OLS	Sample selection		OLS
	Probit	Regression		Probit	Regression	
CONSTANT	1.819** (0.307)	−0.087 (0.120)	0.042 (0.113)	0.451 (0.304)	−0.272* (0.114)	−0.059 (0.099)
EQ6U	−0.100 (0.138)	0.044 (0.056)	0.046 (0.050)	0.135 (0.123)	−0.127** (0.042)	−0.144** (0.039)
EQ7	−0.260* (0.130)	0.110 (0.056)	0.145** (0.051)	0.237 (0.130)	−0.283** (0.043)	−0.311** (0.039)
AGE	−0.006 (0.004)	0.003 (0.002)	0.003 (0.002)	−0.001 (0.004)	0.004** (0.001)	0.004** (0.001)
FEMALE	0.190 (0.120)	0.057 (0.050)	0.007 (0.041)	0.318** (0.119)	0.061 (0.036)	0.019 (0.033)
EDUCATION	0.089 (0.120)	0.114* (0.051)	0.088* (0.042)	0.267* (0.113)	0.113** (0.038)	0.079* (0.032)
INCOME	0.004 (0.016)	−0.011 (0.007)	−0.012** (0.005)	−0.001 (0.012)	0.011** (0.004)	0.011* (0.005)
CHILD	0.168 (0.159)	0.264** (0.057)	0.247** (0.067)	0.039 (0.142)	0.095* (0.047)	0.094 (0.048)
SELF_EMPLOYED	0.126 (0.185)	−0.218** (0.078)	−0.253** (0.049)	0.055 (0.164)	−0.085 (0.052)	−0.094* (0.044)
DISASTER_EXP	−0.093 (0.147)	−0.021 (0.060)	0.008 (0.046)	0.014 (0.132)	0.028 (0.042)	0.028 (0.039)
WOOD				0.455** (0.120)	−0.040 (0.052)	−0.113* (0.052)
HOUSE_AGE				0.009* (0.004)	−0.004** (0.001)	−0.004** (0.001)
DIAGNOSIS				−0.281 (0.235)	−0.305** (0.101)	−0.253** (0.096)
SIGMA		1.255** (0.011)			0.945** (0.009)	
RHO		0.820** (0.030)			0.544** (0.074)	
Number of sample	3600		3413	3600		3309
R^2			0.017			0.039
Log likelihood	−6074			−5344		

**, * Significant at 1, 5 %

Standard errors are shown in parentheses

"Sample Selection" means sample selection model

"OLS" means ordinary least squares method with heteroskedasticity-robust errors

sample selection models of relative ambiguities for earthquake and house destruction risks, respectively. This indicates that the error ε_1 in the probit part is correlated with error ε_2 in the regression part.

5.3 Comparison of estimation results between the sample selection model and the OLS method

In this subsection, we compare the estimation results between the sample selection model and the OLS method with heteroskedasticity-robust errors. Table 3 shows that the results of both models are quite similar. More specifically, the statistically significant variables include the same signs in both models. This finding suggests that the assumption of error term distribution in the sample selection model may be appropriate and that the sample selection biases in the OLS method may be small. Several statistically significant variables in the OLS method are insignificant in the sample selection model. However, all of the statistically significant variables in the sample selection model are also significant in the OLS method. From now on, we discuss on the results of sample selection model for obtaining more robust implication.

5.4 Discussion on the research questions

Two research questions were raised in the introduction: (1) To what degree do people perceive ambiguity? and (2) What are the factors affecting the degree of perceived ambiguity? As for the first research question, the following two results were obtained. First, it was found that the distribution of relative ambiguity was skewed to the right. Roughly 10 % of the respondents stated that their relative ambiguities were more than 2 for both earthquake and house destruction risks, while roughly 60–70 % of the respondents stated that their relative ambiguity ranged between 0 and 1. This finding indicates that some homeowners perceive greater ambiguity that was more than two times the subjective probability, whereas the majority perceived smaller ambiguity that was less than the subjective probability. Second, on average, relative ambiguity of house destruction risk was less than that of earthquake risk, which suggests that homeowners tend to have more confidence regarding their subjective probability of house destruction risk than that of earthquake risk. By combining with the finding in Fujimi and Tatano (2013), "the majority of homeowners considerably underestimate the risk of house destruction," it suggests that homeowners underestimate their risks of house destruction with more confidence. This might be attributed to one characteristic of house destruction risk: controllable risk. The tendency in which subjects underestimate controllable risk is a well-known fact (Slovic 1987) and this is partly due to the subjects believing that they have the ability to avoid such risks better than others (Klein and Kunda 1994).

Their underestimation of house destruction risk with less ambiguity can be a troublesome phenomenon. If homeowners are ambiguous regarding house destruction risk, then ambiguity-averse homeowners should be willing to undergo diagnoses and seismic retrofittings to reduce their ambiguity. However, since homeowners feel confident about their subjective probability of house destruction risk, they are unwilling to perform such an important task. Such confidence might be one of the barriers to implementing seismic retrofitting.

As for the second research question, relative ambiguity can be reduced by the ease of imagining the situation in which a relevant risk occurs. For example, relative ambiguity is smaller for a fragile house during earthquakes with higher intensities. Conversely, homeowners who have higher education perceive greater relative ambiguity since they can more easily understand that they have uncertainties in earthquake and house destruction risks. Meanwhile, the self-employed perceive less ambiguity, which is consistent with the assumption that they have experience dealing with uncertainties. In general, the socioeconomic characteristics of homeowners include similar effects on relative ambiguities of both earthquake and house destruction risks.

Finally, we discuss the policy implication for mitigating house destruction risks due to earthquakes, which includes two possible approaches. The first approach is to educate or communicate with homeowners to modify their subjective probabilities of house destruction into objective ones and reduce their perceived ambiguity. The second is to amplify their perceived ambiguity of subjective earthquake and house destruction risks. Under the assumption that the majority of homeowners are ambiguity averse, this can inspire them to take appropriate mitigation actions. However, we believe that the latter approach should not be permitted since it would worsen homeowners' perceptions of risks. Hence, we focused on the first approach.

Our survey results show that seismic diagnosis can be effective for correcting homeowners' subjective risks of house destruction and reducing their perceived ambiguity. Seismic diagnosis is quite important for homeowners to make better informed decisions regarding the reduction in house destruction risk due to earthquakes. In Japan, 78.7 % of local governments provide financial support for homeowners to have seismic diagnoses performed on their properties. Homeowners who underestimate house destruction risk with confidence have less incentive to undergo such a procedure. To overcome this problem, it might be effective to make seismic diagnoses mandatory for both older and fragile houses.

Since some homeowners perceive more ambiguity than the majority, effective risk education and communication for reducing perceived ambiguities should be established. Based on our survey results for the determinants of relative ambiguity, certain individuals should be the subject of focus. For example, older females with higher education and higher income homeowners with children should be given more attention compared to their counterparts.

6 Conclusion

This study explored how Japanese homeowners perceived ambiguity about earthquake and house destruction risks and obtained the following results. First, some homeowners perceived considerable ambiguity, while the majority perceived less ambiguity. Second, on average, homeowners perceived less ambiguity of house destruction risk compared to those of earthquake risk. Third, homeowners perceived less ambiguity if they could easily imagine a situation in which an earthquake or house destruction occurred. Fourth, those who were more educated and more concerned with health and safety perceived greater ambiguity than their counterparts. Fifth, the self-employed perceived less ambiguity compared to other types of employees. Finally, based on the perspective of creating policies that mitigate house destruction risks due to earthquakes, seismic diagnosis is important since it can correct subjective risks of house destruction and reduce ambiguity regarding such risks.

This study focused on the effects of homeowners' socioeconomic characteristics and house attributes on their perceived ambiguity. However, the findings might have been influenced by various psychological factors. For example, the respondents might have perceived greater ambiguity when they felt more ignorant or uninformed than others, when their choices were observed by others, or when they feared manipulation. In this regard, an examination of psychological factors should be addressed in future research.

References

Armas I (2006) Earthquake risk perception in Bucharest, Romania. Risk Anal 26(5):1223–1234

Armas I (2008) Social vulnerability and seismic risk perception. Case study: the historic center of the Bucharest Municipality/Romania. Nat Hazards 47:397–410

Barsky RB, Juster FT, Kimball MS, Shapiro MD (1997) Preference parameters and behavioral heterogeneity: an experimental approach in the health and retirement study. Q J Econ 112(2):537–579

Cabinet Office, Government of Japan (2010) White paper on disaster management, 2010. http://www.bousai.go.jp/kaigirep/hakusho/h22/index.htm. Accessed 5 Jan 2013 **(in Japanese)**

Camerer C, Weber M (1992) Recent developments in modeling preferences: uncertainty and ambiguity. J Risk Uncertain 5:325–370

Cameron TA (2005) Updating subjective risks in the presence of conflicting information: an application to climate change. J Risk Uncertain 30(1):63–97

Cramer JS, Hartog J, Jonker N, Van Praag CM (2002) Low risk aversion encourages the choice for entrepreneurship: an empirical test of a truism. J Econ Behav Organ 48:29–36

Etner J, Jeleva M, Tallon JM (2012) Decision theory under ambiguity. J Econ Surv 26(2):234–270

Fujimi T, Tatano H (2013) Promoting seismic retrofit implementation through "nudge": using warranty as a driver. Risk Anal 33(10):1858–1883

Hartog J, Ferrer-i-Carbonell A, Jonker N (2002) Linking measured risk aversion to individual characteristics. KYKLOS 55:3–26

Headquarters for Earthquake Research Promotion (2005) National Seismic Hazard Maps for Japan, 2005. http://www.jishin.go.jp/main/index-e.html. Accessed 17 Apr 2013 **(in Japanese)**

Headquarters for Earthquake Research Promotion (2010) Outline of survey on earthquake. http://sparc1038.jishin.go.jp/main/seisaku/hokoku11a/sg16-4-2.pdf. Accessed 5 Jan 2013 **(in Japanese)**

Hogarth R, Kunreuther H (1985) Ambiguity and insurance decisions. Am Econ Rev 75:386–390

Hogarth R, Kunreuther H (1989) Risk, ambiguity, and insurance. J Risk Uncertain 2:5–35

Japan Association for Seismic Retrofit Contractors (2012) Results of seismic diagnosis. http://www.mokutaikyo.com/data/20120420.pdf. Accessed 5 Jan 2013 **(in Japanese)**

Japan Meteorological Agency, Fire and Disaster Management Agency (2009) Report of the investigative commission on the Japanese seismic intensity scale, 2009. http://www.seisvol.kishou.go.jp/eq/shindo_kentokai/kentokai_houkoku/report.pdf. Accessed 5 Jan 2013 **(in Japanese)**

Kellens W, Terpstra T, Maeyer PD (2013) Perception and communication of flood risks: a systematic review of empirical research. Risk Anal 33(1):24–49

Kivi PA, Shogren JF (2010) Second-order ambiguity in very low probability risks: food safety valuation. J Agric Resour Econ 35(3):443–456

Klein WM, Kunda Z (1994) Exaggerated self-assessments and preference for controllable risks. Organ Behav Hum Decis Process 59:410–427

Kung YW, Chen SH (2012) Perception of earthquake risk in Taiwan: effects of gender and past earthquake experience. Risk Anal 32(9):1535–1546

Kunreuther H, Hogarth R, Meszaros J (1993) Insurer ambiguity and market failure. J Risk Uncertain 7:71–87

Kunreuther H, Meszaros J, Hogarth R, Spranca M (1995) Ambiguity and underwriter decision processes. J Econ Behav Organ 26:337–352

Ministry of Land, Infrastructure, Transport and Tourism (2005) White paper, 2005. http://www.mlit.go.jp/hakusyo/mlit/h17/index.html. Accessed 5 Jan 2013 **(in Japanese)**

Nguyen TN, Jakus PM, Riddel M, Shaw WD (2010) An empirical model of perceived mortality risks for selected U.S. arsenic hot spots. Risk Anal 30(10):1550–1562

Riddel M (2009) Risk perception, ambiguity, and nuclear-waste transport. South Econ J 75(3):781–797

Riddel M (2011) Uncertainty and measurement error in welfare models for risk changes. J Environ Econ Manage 61:341–354

Riddel M, Shaw WD (2006) A theoretically-consistent empirical model of nonexpected utility: an application to nuclear-waste transport. J Risk Uncertain 32:131–150

Ritov I, Baron J (1990) Reluctance to vaccinate: omission bias and ambiguity. J Behav Decis Making 3:263–277

Slovic P (1987) Perception of risk. Science 236:280–285

Slovic P (2000) Perception of risk. Earthscan, London

Tekeli-Yesil S, Dedeoglu N, Braun-Fahrlaender C, Tanner M (2011) Earthquake awareness and perception of risk among the residents of Istanbul. Nat Hazards 59(1):427–446

Viscusi W, Chesson H (1999) Hopes and fears: the conflicting effects of risk ambiguity. Theor Decis 47:153–178

Viscusi W, Magat W, Hubert H (1991) Communication of ambiguous risk information. Theor Decis 31:159–173

Viscusi W, Magat W, Hubert H (1999) Smoking status and public responses to ambiguous scientific risk evidence. South Econ J 66(2):250–270

Zhu D, Xie X, Gan Y (2011) Information source and valence: how information credibility influences earthquake risk perception. J Environ Psychol 31:129–136