Households' perceptions of earthquake risks and protective measure adoption intentions

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Abstract

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Preparedness levels vary among individuals who face common threats of natural hazards in the region in which they live. The studies in this dissertation explore the factors that may explain such differences, examining the relationships between key predictors of protective action decisions and protective behavior intentions in the context of Western Washington. Specifically, this dissertation aims to answer the following research question: How do Western Washington residents understand earthquake risks and form intentions to adopt protective measures? Chapter 2 investigates the effect of perceived efficacy of seismic reinforcement on people's intentions to pay for such protective measures using the Meta-Cognitive Model (MCM) approach. Using original data collected in King County, WA, the study examines the association between perceived efficacy and intended payments for seismic retrofits jointly with one's metacognitive

confidence in their assessment of efficacy using interaction effects. The hypothesized moderating effect of metacognitive confidence is not confirmed, but perceived efficacy is found to be an important determinant of intentions to pay for retrofits. Chapter 3 provides an international comparison of perceptions of earthquake risk, efficacy of earthquake early warning (EEW), and willingness to pay (WTP) for EEW between the city of Sendai, Japan and Seattle, WA that have similarities and differences in terms of earthquake hazards and availability of EEW. Risk perceptions and perceived effectiveness of EEW in personal protection are found to be significant determinants of WTP for EEW in both cities, while the association of fear with earthquakes is a significant predictor of WTP only in Seattle. In addition, this study uses a double hurdle model to examine if people's WTP is a two-stage decision that involves (a) an assessment of the determinants of the decision to pay nothing versus anything at all, and (b) among those who decide to pay something, an assessment of the factors that are associated with how much one is willing to pay. The study finds that the set of variables predicting whether one decides to pay or not does not predict the amount of payment. This suggests that indeed, two sets of decisions may be involved. Finally, Chapter 4 uses a choice experiment to investigate (a) how the key predictors of protective action affect the probability of one choosing to adopt a resource-intensive protection measure over taking no action, and (b) whether residents of Western Washington are willing to pay for resource-intensive measures. Perceived efficacy of each protective measure is found to be positively associated with the probability of one choosing the respective measure over taking no protective action. However, residents of King County are generally not willing to pay for resource-intensive measures, suggesting a need for policy to increase uptake of protective action in the region.

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Chapter 1. INTRODUCTION

Natural hazards pose a threat to human settlements. The consequences of natural hazards that affect human settlements are often made worse by man-made factors in the built environment, which can be mitigated through precautionary and protective actions. However, preparedness against disasters among jurisdictions and individuals varies. Some residents in high-risk areas are more prepared and/or more supportive of related regulations and infrastructure than others. The disaster preparedness literature points to several specific factors that influence an individual's intended or actual adoption of preparedness measures, including disaster experience, risk perceptions, and perceptions of how effective protective measures are. Who decides to prepare against natural hazards, and to what extent they prepare are questions that can be informed by assessing these factors (Eiser et al., 2012). This dissertation addresses the overarching question of how these factors are related in the decision-making for protective action intentions in the context of earthquake risks.

In the context of natural hazards, the recency, frequency, and intensity of one's experience of a hazard, in addition to the consequences and outcomes of the experience can play a direct or indirect role in shaping one's perceptions of risk and of the efficacy of protection measures (Reser and Bradley, 2020; Demuth, 2018; Ge et al., 2011; Lindell and Hwang, 2008). Risk perception is commonly viewed in the disaster risk literature in terms of a range of subjective criteria such as one's appraisal of (a) the severity of the risk, (b) their vulnerability to the risk, and (c) the affective associations they make with the risk object (Keller et al., 2012; Prentice-Dunn et al., 2009). These perceptions are thought to affect the probability of one's response to the risk in terms of protective or avoidance actions (Norman et al., 2015; Floyd et al., 2000). Furthermore, perceived efficacy of a protective action for personal and property protection is another important determinant thought to be associated with behavioral intentions and actual behavior (Botzen et al., 2013; Terpstra and Lindell, 2013). This dissertation is informed by the empirical findings on the relationships between these key predictors—namely experience, risk perception, and perceived efficacy (Scovell et al., 2021; Demuth et al, 2016).

This dissertation advances our understanding of three aspects of hazard preparedness. The first study (Chapter 2) investigates how metacognitive confidence might moderate the influence of one's perceived efficacy of seismic protection measures on adoption intentions, which is a topic that remains little explored to date. Metacognition, especially metacognitive confidence on one's judgments, affects behavioral decisions (Dunning, 2012). While metacognition has been studied for several decades in the judgment and decision-making literature in psychology (Schraw, 2001), there is currently only a small, but growing body of literature that does so in the context of protective behavior decisions pertaining to natural hazards. Using original survey data from King County, WA, I test the relationship between (a) one's perception of how effective structural retrofits are for providing protection in an earthquake of structural retrofits, and (b) one's intended payment for retrofits, using (c) their metacognitive confidence in their perception of efficacy as the moderating variable.

The second study (Chapter 3) contributes to the comparative disaster research, with a study of the determinants of earthquake preparedness intentions in Seattle, WA and Sendai, Japan. The study provides insights into the explanatory power of these determinants and their generalizability in the novel context of earthquake early warning. Although Seattle and Sendai face similar risks of high-magnitude (M9) earthquakes, compared to Seattle, Sendai has seen more and much stronger earthquakes in recent years, including the 2011 Great East Japan

Earthquake. At the time of our survey, the ShakeAlert system that now serves the West Coast states in the U.S. was still under development and not available to the public, while Japan had a running EEW system since 2007. This study surveys respondents in the two cities for a direct comparison, analyzing their responses using linear single-stage and two-stage models. In particular, I raise the question of whether or not the decision to pay anything at all is the same as how much to pay when respondents are faced with assessing their willingness to pay. In an appendix, I present the results from a two-stage model using data from Seattle to test whether the same set of predictors apply to the two decisions as previous studies have found (Roder et al., 2019; Wang et al., 2012).

The third study (Chapter 4) estimates the willingness to pay (WTP) for earthquake protection measures using a choice experiment. Measures of intentions for adopting or performing protective actions are commonly elicited using stated preference methods. One way is to directly ask respondents how much they would be willing to pay for a measure in an open-ended format (e.g., Dunn et al., 2016). Another way that is more common in the literature is to elicit the public's willingness to pay for improvements in existing protective measures (e.g., Nguyen and Robinson, 2015; Lazo and Waldman, 2011), or for novel hazard warnings (Wehde et al., 2021; Asgary et al., 2007) using contingent valuation or choice experiments. This chapter estimates the WTP for EEW relative to structural retrofits using original data from a choice experiment survey conducted in King County, WA.

The chapters herein highlight the potential value of research on the role of metacognition in preparedness decisions, and examine valuations of earthquake early warning across social and cultural contexts, and the possibility of a two-stage decision in determining people's intended payment amounts for protective measures. They also provide insights that can inform public outreach and communication efforts to promote and encourage higher levels of hazard preparedness.

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Chapter 2. THE ROLE OF PERCEIVED EFFICACY AND METACOGNITIVE CONFIDENCE IN DETERMINING INTENTIONS TO ADOPT SEISMIC REINFORCEMENT IN WASHINGTON STATE

Abstract
The state of Washington faces the risk of megathrust earthquakes that can cause severe harm to its residents and infrastructure. Despite this shared risk, residents of the state display varied levels of risk perception and attitudes towards protective measures such as structural hazard mitigation. A small but increasing number of studies have examined perceptions and behaviors (or intentions) regarding disasters from a Meta-Cognitive Model (MCM) perspective. Taking an MCM-informed approach, this study used survey data to examine the ways in which risk perception and perceived efficacy of seismic reinforcement affect intentions to pay for such protective measures. Specifically, the association between perceived efficacy and intended payments for retrofits was examined jointly with one's metacognitive confidence in their assessment of efficacy using interaction effects. A direct effect of earthquake risk perception and perceived efficacy of seismic reinforcement on intended payment amounts was also tested for a comparison. Perceived efficacy for property protection was found to have a direct positive effect on intended payment amounts, consistent with findings in the literature. Metacognitive confidence in efficacy for personal protection did not appear to moderate the effects of perceived efficacy on intended payment amounts in this study. This study sheds light on the potential importance of metacognition, a known determinant of behavioral changes, in shaping people's perceptions and attitudes toward disaster risk and preparedness.

1. Introduction

Western Washington lies within the Cascadia Subduction Zone, where the subduction of the Juan de Fuca plate beneath the North America Plate can generate rare but high-magnitude "megathrust" earthquakes. The strain caused by this subduction can and has also produced deep intraplate earthquakes, including the 2001 Nisqually Earthquake. The risk of crustal earthquakes from the North America Plate also adds to the threat in the region (PNSN, n.d.). Earthquakes strike with little to no warning and the impact of a high-magnitude earthquake can be devastating to infrastructure, businesses, and residents in the region. Preparedness at the individual, organizational, and public levels is therefore crucial to mitigate damages to infrastructure, reduce human injuries, and improve disaster resilience of affected communities.

The disaster preparedness literature points to a variety of factors that can influence an individual's intended or actual adoption of a specific type of protective actions or composites of preparedness measures. These factors include, among other things, one's risk perception, perception of how effective protective measures are, and disaster experience. When considering who decides to prepare against natural hazards, as well as how and to what extent they prepare, it is important to assess how these factors are related in the decision-making process (Eiser et al., 2012).

Moreover, strong and damaging earthquakes are rare in Western Washington, although the threat is ever-present due to the geophysical characteristics of its location. The region has seen only five earthquake events at or exceeding magnitude 5 since 1965, with the magnitude-6.8 Nisqually Earthquake of 2001 being the most recent (PNSN, n.d.). For this reason, questions about one's perceptions of how effective a hazard mitigation measure is for protection may be of a hypothetical nature for many, if not most, residents. When asked such questions in a survey, residents of the region therefore are likely to answer with varying degrees of confidence.
Indeed, the Meta-Cognitive Model (MCM) (Petty et al., 2007), developed and applied previously in the social psychology context to explain people's attitudes toward objects, suggests that people's initial assessments of the effectiveness of protective actions may be accompanied by metacognitive confidence in such assessments.

Research adopting the Meta-Cognitive Model (MCM) framework has shown that the effect people's initial assessment of an attitude object has on behavior can be moderated by a secondary thought. This secondary thought is on the validity of the initial assessment, such as one's confidence in it when forming an overall attitude about the object (Huang and Yang, 2020; Glasman and Albarracín, 2006). For example, Huang and Yang (2020) found that metacognitive uncertainty about respondents' self-assessed susceptibility to COVID-19 moderated the effect of this self-assessment on positive emotional associations with the disease. This may also apply to people's disaster preparedness decisions. For example, people's initial assessments of how effective structural retrofits are for personal and property protection, and consequently their influence on disaster preparedness decisions, may be moderated by their confidence in such assessments.

In terms of protection measures against natural hazards, low-cost protection measures are more likely to be adopted than others, such as stocking basic emergency supplies, likely due to ease and accessibility (Onuma, 2017; Terpstra & Lindell, 2013; Lindell et al., 2009; Basolo et al., 2009; Lindell & Prater, 2002; Lindell & Whitney, 2000; Mileti & Darlington, 1997). For seismic risks, earthquake early warning (EEW) alerts that are delivered to smartphones as Wireless Emergency Alert (WEA) messages or via smartphone apps are relatively low cost (often free and requiring minimal if any effort to install). Likely owing to such reasons, mobile phones have been found in surveys in Japan and New Zealand to be the preferred channel for EEW alerts (Becker et al., 2020; Nakayachi et al., 2019). In a previous survey study, Washington state residents were also generally supportive of the state's adoption of an earthquake early warning system (EEWS), as measured by their willingness to pay per month for an alert app on the smartphone (Dunn et al., 2016). Earthquake risk perception measured as the likelihood of being harmed by an earthquake in the future, as well as previous earthquake experience and perceptions of how effective EEW is for personal protection, were all found to predict one's willingness to pay for an EEW app (ibid).

In contrast, the adoption of more resource-intensive structural hazard mitigation measures (e.g., seismic retrofits) tends to be slow among homeowners (see Miranda et al., 2021) and commercial property owners (Egbelakin and Wilkinson, 2010) alike, with decision makers' perceptions of risks, costs and benefits impeding their adoption. Mandatory seismic retrofitting of all high-risk buildings including homes has been introduced only in a few earthquake-prone regions or countries (e.g., Los Angeles, New Zealand). In many high-risk places, including jurisdictions within Western Washington, seismic retrofitting still remains a recommendation instead of a requirement for practical and political reasons (Murphy, 2020; Segal et al., 2017; Egbelakin et al., 2011). In the absence of a mandate for structural reinforcement, some risks of building collapse and damages in the event of a strong earthquake remain a threat to the public. The public's strong support of such a mandate is crucial for policymakers to prioritize and make progress on such initiatives (Prater and Lindell, 2000). Understanding the public's attitudes toward seismic hazards and protection measures is therefore crucial in initiating and advancing related policies.

The goal of this study is to address this need for a better understanding of the public's attitudes toward seismic retrofits. The aim of this study is to answer the following research questions:

(1) Do the determinants of the adoption of low-cost protective actions also apply to the adoption more resource-intensive measures like seismic retrofits?

(2) Does metacognitive confidence in one's assessment of the effectiveness of retrofits play a role in determining adoption intentions?

This study reports results from a survey conducted in the King County-Seattle area of Washington state on people's attitudes and perceptions regarding earthquake risks and structural hazard mitigation. We investigated both the direct effects of risk perception and perceived efficacy on how much people intend to pay for seismic retrofits, and the moderating effect of confidence on the relationship between these variables and intended payment.

2. Determinants of protective action

Protective actions taken against natural hazards include both hazard mitigation and emergency preparedness. Hazard mitigation refers to precautionary measures taken ex ante to provide protection by reducing damage or casualties in the event of a natural hazard, such as building codes and land-use regulations (Tierney et al., 2001, p. 5; Lindell and Perry, 2000). Emergency preparedness measures help agents respond in the aftermath of a disaster, and include devising emergency plans, identifying safe zones, and stocking emergency supplies (ibid).

The term preparedness is used synonymously with readiness by some authors (Kirschenbaum et al., 2017; Kirschenbaum, 2002; Becker et al., 2017; Becker et al., 2012) as an all-encompassing term for the measures households take against a disaster risk, such as installing structural retrofits and stocking emergency supplies. We use the term preparedness in this paper in this general sense, and the terms hazard mitigation and emergency preparedness to refer to specific preparations where applicable.

2.1 Theoretical frameworks for protective action decisions

Decisions to prepare for a hazard are complex processes undertaken by individuals who have varying reference points or initial intentions (Eiser et al., 2012). Diverse theories and theoretical frameworks on behavioral decisions, social institutions and cultural world views have been employed by researchers to explain the variations among individuals in the decision-making process for protective actions. Appraisal theory focuses on the role of cognitive and/or affective risk appraisals in triggering differentiated emotions that consequently may affect behavioral decisions (Moors et al., 2013; Keller et al., 2012). The theory of reasoned action (TRA), protection motivation theory (PMT), and the protective action decision model (PADM) are adaptations and extensions of expectancy theory, which assumes that people's behaviors reflect conscious choices among alternatives based on their assessed value of the rewards of an expected outcome, also called *valences* (Vroom, 1964).

Cognitive theories of mental models and behavioral decision-making commonly identify a pre-decisional stage whereby external inputs induce appraisals of risks and the formation of behavioral intentions (Keller et al., 2012; Morgan et al., 2002, pp. 10-12; Norman, 1983). Such sequential mental processes resulting in behavioral decisions begin with environmental and social inputs in addition to prior attitudes, beliefs and personal experience.

Appraisal theories emphasize the association of affective processes and risk appraisal. This approach assumes that one's subjective appraisal of an object elicits specific corresponding emotions in response (Moors et al., 2013). While the appraisal is assumed to involve both cognitive and affective appraisals, appraisal theories posit that decisions on behaviors or action tendencies are largely influenced by the different emotions that arise from such appraisals (Scherer, 1999; Keller et al., 2012).

The theory of reasoned action (TRA) employs the idea that expected outcomes explain behavior. The TRA contends that people's attitudes about an action are driven by their beliefs about the particular action (Fishbein & Ajzen, 1975). Specifically, a stronger belief that a given behavior will lead to positive outcomes or prevent negative outcomes is thought to be linked to a more favorable attitude toward performing the behavior (Fishbein, 2008). Attitudes, in turn, play an important role in shaping behavioral intentions that are likely to lead to actual behavior (ibid.). An essential part of the theory is that the strongest predictor of volitional behavior is one's intentions to behave in such a manner, and such intentions are influenced by both attitudes toward the action and subjective norms regarding the behavior (ibid). It follows from the TRA, then, that perceptions of adopting protection measures would likely predict intentions and actual behaviors.

Protection motivation theory (PMT) is another theory frequently adopted in risk research. It suggests two key antecedents in the decision to take a certain action, i.e., protection motivation: threat appraisal and coping appraisal. When appraising a threat, individuals factor in both the perceived severity of, and their vulnerability to the threat. In the context of natural hazards, one's subjective judgments, or perceptions, of the consequences (severity) and one's vulnerability to them are a key element in the threat appraisal stage (Grothmann and Reusswig, 2006). The assessments affect the probability of one's response to the threat in terms of protective or avoidance actions (Norman et al., 2015). Coping appraisal addresses the perceived attributes of an action, namely *self-* and *response efficacy*, and the perceived resource requirements for protective behavior (Rogers, 1975; Kellens et al., 2013). Self-efficacy is an individual's belief in their own ability to successfully carry out a task. Response efficacy refers to an individual's beliefs about the effectiveness of an action in preventing or reducing a risk. If a perceived threat is assessed as being high, an individual engages in an appraisal of both self- and response efficacy to determine a strategy to cope with the risk (Rogers, 1975; 1983).

The protective action decision model (PADM) shares some components with the TRA and PMT for explaining the adoption of protective actions by individuals, especially with regard to how perceived efficacy of a protective action shapes expected outcomes and influence behavioral decisions (Lindell and Perry, 2012). According to the PADM, the decision-making process for protective action involves a series of decision stages consisting of risk assessment, protective action assessment and protective action implementation. The PADM highlights a pre-decisional stage that precedes risk assessment, in which individuals process information gathered from environmental and social cues, and from socially transmitted warnings. This processing of information shapes core perceptions of the threat (risk) and protective actions (ibid.). Perceptions of protective actions, such as adopting seismic reinforcement measures, are thought to better predict behavior than attitudes about the object itself, such as earthquakes (ibid.). Specifically, when protective actions are available and recognized by individuals, the implementation of such actions will depend not only on the perceived risk level, but also perceptions of hazard-related attributes (e.g., efficacy in protecting persons and property, usefulness for other purposes) and resource-related attributes (e.g., time, knowledge, cost and effort requirements) that shape expectations of outcomes.

The theoretical frameworks above suggest a decision-making process consisting of (a) a pre-decision stage that is informed by external cues, individual characteristics such as sociodemographic factors, knowledge and experience, and attention/information that influences (b) an appraisal stage where perceptions of risk and protective actions are formed, that results in (c) a decision, first as action intentions and then as actual behavior (e.g., the adoption of protective actions). The next sections examine in detail the factors identified by these approaches as being important determinants of behavior, with evidence from studies pertaining to natural hazard preparedness.

2.2 Earthquake experience

Experience serves as a source of information. In the context of natural hazards, prior experience of a disaster event can provide one with knowledge, emotions, and assessments that are used in deciding the course of protective actions to take (Reser and Bradley, 2020; Demuth, 2018). The recency, number of earthquakes experienced, and intensity of one's experience, in addition to the consequences and outcomes of the experience may play a direct or indirect role in shaping one's perceptions of risk and of the efficacy of protection measures (Demuth, 2018; Ge et al., 2011; Lindell and Hwang, 2008).

Information from one's experience can be used as mental shortcuts, called heuristics, when people assess the risks of a hazard (Norris et al., 1999). Cognitive heuristics—for example, the availability of similar examples or representativeness of the appraisal object—expedite appraisals of risk. The affect heuristic in effect substitutes one's feelings towards an object of appraisal—which often draw from experience or familiarity with the object—for a deliberative appraisal of the object (Pacher et al., 2012; Finucane et al., 2000). Studies of the role of affect in risk perceptions and decisions examine both the affective responses prompted by hazards as well as the specific emotions that people associate with particular types of natural hazard, such as the worry or dread when thinking about, for example, hurricanes (Demuth et al., 2016; Smith & Leiserowitz, 2014).

In particular, appraisal theories incorporate decision-making mechanisms that are similar to cognitive and affect heuristics into their models of appraisal (Keller et al., 2012). Under this approach, the arousal of specific emotions such as fear and anger upon the appraisal of a risk is thought to enable a quick and associative response in determining action tendencies, similar to affect heuristics. Evidence suggests that there exists a feedback loop between affect and risk perceptions, and that experience feeds into this loop as a source of information (Van der Linden, 2014).

Empirical findings on the associations between experience and disaster preparedness decisions are mixed. Some studies find strong and positive associations between experience and preparedness (Catañeda et al., 2020; Onuma et al., 2017; Lindell and Hwang, 2008). Some findings indicate a partial effect, such as experience being associated with preparedness intentions but not necessarily with implementation (Miranda et al., 2021), or experience predicting post-disaster preparedness activities but not pre-disaster preparedness (Nguyen et al., 2006). Some studies also find that the effect of experience on preparedness is either moderated or partially or completely mediated by factors such as risk perception and hazard intrusiveness (Lindell and Prater, 2000), or that such a relationship is different by disaster type (Mishra and Suar, 2007) or religion (Kirschenbaum et al., 2017).

On the other hand, some studies report weak or non-significant effects of experience (Weber et al, 2018; Dunn et al., 2016; Martin et al., 2009) However, these studies by no means take such findings as evidence of an insignificant role of experience in preparedness decisions. Instead, they suggest that, consistent with theory, experience affects behavioral decisions through other variables, such as perceived risk and efficacy, that may not have been present in their models or may not have been modeled to manifest such mediating effects (ibid).

One commonly identified reason underlying these mixed findings is the difference in how experience is measured (Becker et al., 2017). Direct experience of an event and/or the number of events experienced are adopted in some studies as the experience variable that predicts preparedness (Castañeda, 2020; Kirschenbaum et al., 2017; Grothmann and Reusswig, 2006; Russell et al., 1995). Indirect experience such as observation of affected friends and/or family or via media are used in some studies (Miranda et al., 2021). The experience of having dealt with the consequences of an event, such as damage or evacuation, is also commonly adopted (Onuma et al., 2017; Martin et al., 2009; Nguyen et al., 2006). In some studies, the strength or intensity of the event is used the capture experience, such as the level of shaking experienced in an earthquake (Miranda et al., 2021; Nguyen et al., 2006). Many of these studies use a combination of these variables to account for the multifaceted nature of hazard experience (e.g., Miranda et al., 2021; Martin et al., 2009).

In addition, for rare natural hazards like earthquakes, the cues that individuals take away from one or just a few events that they have experienced may affect their perceptions (Dillon et al., 2014). When one experiences a "near-miss" of a hazard such as a hurricane, or experiences a natural hazard like an earthquake but with very little damage, people's decisions on preparedness depends on how they interpret the experience: if they see it as a major disaster that was avoided, they tend to underestimate the danger (normalization bias), whereas if they see it as a major disaster that could have happened, preparedness actions tend to increase (Dillon et al., 2014; Nguyen et al., 2006; Johnston et al., 1999). Therefore, whether or not experience leads to preparedness may depend on the nature and subjective interpretation of the experience (Becker et al., 2017).

Motivated by theory and to account for the multidimensionality of experience, this study hypothesized that one's earthquake experience in terms of the number of one's personal experience and the intensity of those experiences will be positively associated with one's intentions to pay for structural reinforcement.

Hypothesis 1: Earthquake experience has a direct positive effect on the intended payment amount for the adoption of seismic reinforcement measures.

2.3 Risk perception

Appraisal theory highlights the role of emotional responses associated with risk appraisal, suggesting that emotions play an important role in the relationship between risk perceptions (or appraisals) and behavior (Keller et al., 2012). More specifically, under appraisal theory's structural approach, objects are appraised on one or more of the following five dimensions: outcome desirability, agency, fairness, certainty, and coping potential. The resulting appraisal on these dimensions is theorized to elicit certain emotions. For example, an event that an individual evaluates as being undesirable for their goals or values (outcome desirability) may elicit anger, fear or guilt (Keller et al., 2012). Depending on whether the individual blames others or themselves (agency), the dominant emotion could be anger or guilt, respectively. If the undesirable event is associated with uncertainty, they might feel fear (Keller et al., 2012; Lerner and Keltner, 2001).

Moreover, object appraisal and ensuing emotions can influence attitudes toward risk and the associated action tendencies or action readiness. Anger, for example, has been found to lead to more optimistic risk assessment and risk-seeking behavior, while fear was more associated with pessimistic risk assessment and risk-averse behavior (Frijda, 2009; Lerner and Keltner, 2001). Consistent with this idea, fear felt during or in association with past disaster experiences has been found to predict protective behavior (Scovell et al., 2021; Bronfman et al., 2020; Weinstein et al., 2000).

Research on affective heuristics and other theories including PMT has also highlighted the role of emotions and affect: people assess risks faster based on how they feel about a hazard (see Siegrist and Árvai, 2020; Greenberg et al., 2012; Keller et al., 2012; Västfjäll et al., 2008). Emotions, therefore, are widely treated as a component of risk perception from the perspective that the appraisal of risk is a product of both cognitive and affective processing (Finucane and Holup, 2006).

Under PMT, risk perception is a component of threat appraisal, which is, in essence, how threatened an individual feels by a certain risk (Bubeck et al., 2012). PMT posits that this appraisal of risk, which includes perceived threat severity and one's vulnerability, is influenced by a wide array of cognitive inputs, such as information from previous experience and public sources (Prentice-Dunn et al., 2009). This appraisal is thought to partially affect the probability of one's response to the threat in terms of protective or avoidance actions (Norman et al., 2015; Floyd et al., 2000). Empirical findings suggest that this effect of threat appraisal on protective action need not necessarily be positive. An earlier meta-analysis found heightened perceptions of threat severity and vulnerability to increase adaptive intentions or behaviors (Floyd et al., 2000). However, later studies found threat appraisal to be more associated with non-protective responses such as denial and fatalism which causes the association between risk perception and protective action to appear weak in some studies (Babcicky and Seebauer, 2018; Bubeck et al., 2012).

Common measures of risk perception in the literature include, but are not limited to, the subjective probability of hazard occurrence, perceived consequences (phrased using words such as "chances", "likelihood" or "probability"), and the emotions associated with the hazard, especially of "concern" or "worry" (Wilson et al., 2019; Demuth et al., 2016; Terpstra and

Lindell, 2013; Miceli et al., 2008). Combined variables based on separately measured probability, consequence, and affect items have also been used to account for the high correlations between various measures of risk perception, which have also been shown to better fit risk perception responses (ibid). Other measures commonly seen in empirical studies include the psychometric model of risk perception that rate hazards on a set of risk attributes (Fischhoff et al., 1978; Slovic, 1987; Keller et al., 2012), in contrast to an also commonly used measure based on a unidimensional risk question such as "how risky/dangerous is …?" (Prati and Zani, 2012) and "how much will … negatively impact …?" (Saleh Safi et al., 2012).

Appendix 2.1 provides an illustrative list of studies that identify determinants of protective behavior against natural hazards. These studies were selected based on (a) the use of behavioral intentions or actual behaviors regarding protective actions as the dependent variable; and (b) the inclusion of appraisal stage variables as independent variables. Many of these studies find that risk perception is positively associated with the adoption of protective actions, while some find mixed, non-significant effects (for example, Terpstra, 2011; Miceli et al., 2008; see Wachinger et al., 2013 for review). Possible explanations offered in the literature for these mixed results include, for example, methodological errors or various ways of assessing the constructs of risk perception (Brewer et al., 2007), or as previously explained in the context of PMT, that a fatalistic attitude prevents some people from taking action for a risk perceived as high (Baytiyet and Naja, 2016; Lindell, 2012).

A number of studies included in Appendix 2.1 adopt risk perception measures that include both probability assessments and consequence assessments and find significantly positive associations with behavioral intention or actual behavior (Demuth et al., 2016; Terpstra and Lindell, 2013; Miceli et al., 2008). Following from these findings, we hypothesize that risk perceptions measured as probabilities of earthquake occurrence and of harm from earthquakes, as well as the association of fear with earthquakes have a direct effect on intentions to adopt protective measures.

Hypothesis 2: Appraisal of risk, as the perceived probability and consequence of earthquakes and affective responses, has a direct positive effect on the intended payment amount for the adoption of seismic reinforcement measures.

2.4 Perceived efficacy

Perceived efficacy of a protection action is one of the central components of the appraisal stage in PADM. The model predicts that hazard-related attributes increase behavioral intentions and actual behavior while resource-related attributes decrease them (Terpstra and Lindell, 2013). It should be noted that while both PMT and the PADM distinguish the concept of self- and response efficacy, one difference lies in how they incorporate these concepts.

Response efficacy as adopted by PMT is a component of PADM's *hazards-related attributes*, a term that encompasses the perceived efficacy of a protective action for personal and property protection, as well as utility for other purposes (Lindell and Perry, 2012). On the other hand, the concept of self-efficacy which is an integral part of PMT is replaced in the PADM with *resource-related attributes* which are treated as characteristics of protective actions rather than of one's ability as seen with the concept of self-efficacy (ibid). Both PMT and the PADM focus on decision-making at the individual level, and limited attention is given to perceived efficacy at other levels, such as collective- and proxy-efficacy that were also discussed in Social Cognitive Theory (Bandura, 2001; 1986).

For protective action perceptions, empirical evidence suggests that hazard-related attributes such as perceived response efficacy are positive predictors of protective action (Botzen et al., 2013; Lindell, 2012; also see Peers et al., 2021; Wang et al., 2016; Bubeck et al., 2013; Terpstra and Lindell, 2013; McFarlane et al., 2012 in Appendix 2.1). On the other hand, resource-related attributes have had weak or nonsignificant associations with protective actions (Demuth et al., 2016; Terpstra & Lindell, 2013).

Hypothesis 3: Perceived efficacy of structural reinforcement measures has a direct positive effect on the intended payment amount for their adoption.

2.5 Metacognitive confidence

PMT, TRA and PADM explain the cognitive processes that take place given a source of risk, such as a natural hazard or a health hazard, and lead up to decisions and behavioral responses. Appraisal of the risk and protective actions, being key components of PMT and PADM, are essential and widely studied predictors of decisions and behavior in disaster research. Most of the PMT- or PADM-based studies on perceptions of risk, efficacy and preparedness use measures of threat and coping appraisals obtained from singular items in a survey or additive composite indicators built from multiple survey items.

There is increasing research testing and employing a multi-dimensional approach to these appraisal variables. Secondary Risk Theory is one such approach, emphasizing a need to consider both the initial perceived risk and perceived secondary risks—i.e., "What happens when the cure [for a risk] itself may be perceived of as a risk?" (Cummings et al., 2021, p. 205)—as determinants of decisional outcomes. The Meta-Cognitive Model (MCM) is another approach that is only beginning to be included in disaster research. The MCM posits that people's evaluations of an attitude object (structural reinforcements in the current study) can be held with varying degrees of confidence (Petty et al., 2007). According to this perspective, an initial reaction or thought about an object is paired with secondary, or metacognitive, assessments in terms of, for example, confidence/doubt or true/false of varying strength to determine one's overall attitude towards an object.

Metacognition is a frequently used concept in the fields of education and learning, referring in that context to the awareness of one's own learning process, which is thought to influence learning outcomes (Frank & Kuhlmann, 2016; Chekwa et al., 2015). This concept has yet to be applied broadly to disaster preparedness research. Only a handful of studies have examined knowledge and preparedness for natural hazards at the individual or community level using the concept of metacognition in the appraisal of natural hazard risk. For example, iterative participatory modeling of tsunami hazards in Hawaii involving feedback-induced metacognition has been found to improve and facilitate social learning (Henly-Shepard et al., 2015). A significant association is found between one's ability to comprehend hazard maps and metacognition in a study that examined whether one's map comprehension skills are associated with their metacognition of such ability (MacPherson-Krutsky et al., 2020). These studies suggest that higher metacognition may be able to affect the appraisal of hazard risks and information, but further research is needed to evaluate the relationship between metacognition of one's knowledge on natural hazard protective behavior.

The MCM approach adds a dimension to models that operationalize concepts that are subjectively assessed by individuals. This approach can be informative when the objects being assessed (e.g., hazard mitigation measures) involve substantial uncertainties, such as those that are hypothetical or technically complex for the general public to fully comprehend. Asking one to assess the efficacy of an EEW system that was not available to the public in Washington state at the time of the survey, for example, or of structural retrofits that many do not have installed at home, can undoubtedly be a complex task. Individuals who respond to such questions are likely to do so with varying degrees of confidence. Dominant views in the psychology literature on when this confidence judgment is made are that it takes place during the decision process, or after making a decision, with evidence suggesting that retrospective judgments are more likely to be accurate and that post-decisional processing influences future decisions and confidence judgments (Petrusic & Baranski, 2003; Yeung & Summerfield, 2012; Nelson & Narens, 1994). Furthermore, high confidence in one's knowledge may be associated with a higher likelihood of the individual accepting new and conflicting information to correct misconceptions (Cordova et al., 2014). Following this view and applying it to disaster research, perceptions of how effective structural reinforcements are can be assessed by two components: (a) one's response to survey questions on how effective reinforcement measures are, and (b) one's confidence in their assessment of the efficacy of reinforcement measures.

One study assessed metacognitive confidence in past hurricane evacuation and found higher confidence to be associated with greater future intentions to evacuate again (Goldberg et al., 2020). The concept of metacognition used in Goldberg et al. (2020) was that of one's behavior, i.e., how confident one is that their decision to evacuate was right. The metacognitive confidence judgment employed in the study was one that arrived relatively long after a decision was made (post-decisional), possibly influenced by additional information and feedback, although this is not explicitly noted or examined in the study. The study found high confidence in past behavior to be reinforcing of the particular behavior. Evidence of the effects of metacognition regarding one's knowledge about natural hazards (e.g., one's confidence in their assessment of disaster risk or efficacy of protective actions) on behavioral intentions or actual behaviors is sparse in the literature. The current study aims to fill this gap by looking at the metacognitive confidence in one's assessment of the perceived efficacy of seismic reinforcement and how that metacognitive confidence is related to intentions to pay for protective measures.

It is therefore hypothesized that the effect of perceived efficacy of protection measures on the amount an individual is willing to pay for such measures is moderated by their confidence in their assessment. Specifically, it is hypothesized that the positive relationship between perceived efficacy and intended payment amounts as seen in Hypothesis 3 will be steeper for those with greater confidence in their perceived efficacy.

> Hypothesis 4: The effect of perceived efficacy on one's intended payment amount for seismic reinforcement is moderated by the respondents' metacognitive confidence in their perceptions, showing an interaction effect.

3. Methods

3.1 Survey implementation

The online survey was administered to a randomly drawn King County, WA sample (N=399 for complete responses, N=429 including partial responses) from May to June 2018. Following a Dillman approach (Dillman et al., 2014), multiple mailings were sent in order to increase response rates. Initial invitation letters that were mailed out to 2,443 randomly selected addresses explained the purpose of the survey and provided the survey URL and a unique access code for each household. Also enclosed in each letter was a one-dollar bill as an incentive to boost response rates. This was followed by three reminder postcards, each of which was sent approximately one week apart to all recipients, regardless of whether or not they had already completed the survey (see e.g., Mercer et al., 2015; Singer and Ye, 2013 for discussion of the effects of monetary incentives and follow-up mailings on response rates). The response rate including partial submissions was 17.6%[1]. The size of the subsample used for the analysis of this study was 242.

3.2 Dependent variable

The dependent variable in the analyses was the amount respondents were willing to pay for partial or full seismic retrofits. In the preceding survey items, respondents were asked if they had seismic retrofits or shake-resistant features in their homes or earthquake insurance. Based on their answers to these questions, participants were given an option they did not currently have, in order to preserve the hypothetical nature of stated preferences. Those who had both seismic retrofits and insurance were not shown these choices. A subsample consisting of those who were shown the seismic retrofit options (n=242) was used for this study. Of this subsample, observations that contained missing data for the independent variables were excluded from the analysis.

As shown in Figure 2.1, each respondent saw two choice sets under a given earthquake hazard description, consisting of an earthquake probability and the associated magnitude, with

[1] We report the response rate including partial completions (RR2) according to the American Association for Public Opinion Research (AAPOR, 2016) guidelines as the following:

$$RR2 = \frac{(\text{Complete surveys} + \text{Partial surveys})}{(\text{Complete}+\text{Partial})+(\text{Refusal}+\text{No contact}+\text{Other})+(\text{Unknown if household or occupied}+\text{Other unknown})}$$

where the denominator is essentially the total number of survey invitations sent out (AAPOR, 2016). We received a total of 429 survey submissions out of the 2,443 invitations sent out. Of these, 399 were complete submissions, among whom 238 reported not having any retrofit measures installed at home.

different prices, and then were presented with another two choice sets framed with a different presentation of earthquake hazards. The purpose of presenting these earthquake probabilities associated with varying magnitudes was to represent the way seismic risks in Western Washington are estimated and presented (Frankel et al., 2015).

The first choice set asked respondents to choose between Option A, which offered an EEW-activated gas shutoff but no seismic retrofit, and Option B, which did not include an EEW-activated gas shutoff but did include a *partial* seismic retrofit. The second set of choices consisted of Option C, which was identical to Option A, and Option D, which offered a *full* seismic retrofit but no EEW-activated gas shutoff. For both choice sets, the respondents also had the option of declining both options, a choice that would incur no monthly cost.

The price of each option that respondents saw was scaled by the monthly rent (for renters) or home value (for owners) as reported by the respondent. For example, respondents reporting paying less than $1,500 in monthly rent were assigned a cost of $15 for Option A, $20 for Option B, $15 for Option C and $30 for Option D. These amounts were higher for those reporting to pay a higher monthly rent (e.g., for those paying $2,500 or more, Option A/C cost $30, B cost $45, and D cost $60). The minimum amount was $0, and the maximum amount that respondents could choose within the setup of the survey was $150. Possible response amounts within this range were: $0, $20, $30, $40, $60, $75, $90, $100, $125, and $150. Below is an example of a choice card that was presented to the respondent.

Choice 1

The probability of a **magnitude 9 (M9) earthquake** affecting Washington state **in the next 50 years is estimated to be 14%** (that is, a one-in-seven chance).

To prepare for earthquakes at your residence, suppose you could adopt one of the options below:

Description:	**Option A:** *Includes an early warning system with automatic gas shutoffs. Does not include seismic retrofits at home.*	**Option B:** *Includes partial seismic retrofits at home. Does not include an early warning system with automatic gas shutoffs.*
Features include:		
· Early warning system with automatic gas shut off	Yes	No
· Seismic retrofits at home	None	Partial
Monthly cost to household	${**15/20/30/45/50/55/60**}	${**20/30/45/60/75/90/105**}

Which option do you prefer?
1 Option A
2 Option B

Taking into account your choice above, which of the following would you prefer?
1 The option I chose above (at the indicated price).
2 Neither option for earthquake preparedness (no monthly cost to my household).

Choice 2

The probability of a **magnitude 6.5 or larger quake or megaquake** affecting Washington state **in the next 50 years is estimated to be 26%** (that is, more than a one-in-four chance).

To prepare for earthquakes at your residence, suppose you could adopt one of the options below:

Description:	**Option C:** *Includes an early warning system with automatic gas shutoffs. Does not include seismic retrofits at home.*	**Option D:** *Includes full seismic retrofits at home. Does not include an early warning system with automatic gas shutoffs.*
Features include:		
· Early warning system with automatic gas shut off	Yes	No
· Seismic retrofits at home	None	Full
Monthly cost to household	${**15/20/30/45/50/55/60**}	${**30/40/60/75/100/125/150**}

Which option do you prefer?
1 Option C
2 Option D

Taking into account your choice above, which of the following would you prefer?
1 The option I chose above (at the indicated price).
2 Neither option for earthquake preparedness (no monthly cost to my household).

Figure 2.1 Sample choices
(For each option, only one "monthly cost to household" was shown to each participant.)

The dependent variable was constructed from these choices using the price attached to the final choice each respondent made. For each choice made under a given earthquake hazard description, the respondent chose whether they would pay for EEW with gas shut-off, partial retrofits, full retrofits, or not to adopt any measures (no cost). The price tag attached to the respondent's final choice was used as the value for the dependent variable. Since each respondent reported two prices based on their choices for two earthquake characterizations, data were converted into a long format with each respondent getting two rows. The analysis used fixed effects (clustering by respondent ID) to account for this panel data-like format. Table 2.1 shows how the dependent variable was constructed to represent the amount each respondent was willing to pay for adopting seismic retrofits.

While the dependent variable is constructed using amounts elicited through a choice experiment setup, it is not estimated in this study using standard techniques for a *willingness-to-pay* (WTP) estimation. WTP estimation using methods like contingent valuation or choice modeling allow us to assess the value of an increased level of some attributes associated with a non-market good. While covariates other than the attributes of interest can be included in such models, the resulting coefficients indicate probability changes for the respondent choosing a particular alternative. The WTP derived from the results is a simple point estimate that is the ratio of the attribute coefficient and the price coefficient. Because we are interested in the effects of a set of independent variables on WTP in this study rather than their effects on the probability of choosing one protective action over another, a point estimate of WTP is not suitable. Instead, the amounts that respondents have chosen to pay for the installation of partial or full retrofits are treated as the dependent variable. For this reason, and to avoid any confusion arising from the terminology, we hereafter refer to our dependent variable as the *intended payment amount* for seismic retrofits.

Table 2.1 Configuration of the dependent variable for each earthquake hazard condition

Response 1 (EEW vs. partial retrofits)	Response 2 (EEW vs. full retrofits)	Choice	Dependent variable
EEW	EEW	EEW	0
EEW	No action	$0*	0
EEW	Full retrofits	Full retrofits	Price of full retrofits
No action	EEW	EEW *	0
No action	No action	$0	0
No action	Full retrofits	Full retrofits	Price of full retrofits
Partial retrofits	EEW	Partial retrofits	Price of partial retrofits
Partial retrofits	No action	Partial retrofits	Price of partial retrofits
Partial retrofits	Full retrofits	Full retrofits	Price of full retrofits

The final choices marked with an asterisk (*) in Table 2.1 indicate inconsistent responses. Five participants chose EEW-activated gas shutoff over partial retrofits but no action over the choice between EEW and full retrofits, although the cost of choosing EEW again was the same as the previous set; this cannot be explained other than by inattention or miscomprehension. Although this only pertains to five observations, for the purpose of our analysis, this is treated as a choice of no action. Similarly, 13 participants chose no action, between EEW and partial retrofits for the first choice, and chose EEW over full retrofits for the subsequent choice when the cost of EEW was the same between the two sets, which is inconsistent. This is treated as a choice of EEW, which was the second choice.

3.3 Independent variables

3.3.1 Earthquake experience

All participants were asked, “How many earthquakes have you experienced?” (None; One; A few (2 to 5); Several (6 to 10); More than 10) at the beginning of the survey.

Additionally, respondents were also asked, “How strong was the earthquake that you felt?”, referring to their “most memorable” earthquake experience if they reported more than one. The response scale was as below, based on the Modified Mercalli Intensity (MMI) scale:

1. Not felt
2. Weak shaking (felt noticeably but not recognized as an earthquake by many)
3. Mild shaking (dishes, windows, doors, and walls disturbed)
4. Moderate shaking (some dishes, windows broken, and unstable objects overturned)
5. Strong shaking (heavy furniture moved, negligible damage in well constructed buildings, some chimneys broken)
6. Violent shaking (great damage with partial collapse, buildings shifted off foundations)

For those who did not have any prior earthquake experience, their response to this item was coded as “0.”

Previous findings suggest that survey responses on the various aspects of hazard experience are strongly correlated (Demuth, 2018). A common way to address the fact that such variables are closely related is to combine the several indicators of the same construct into a single indicator (Schroeder et al., 1990). Studies often combine the measures of different experiential aspects into a single variable by summing or averaging them, both of which assume that indicators hold equal weights (e.g., Johnson and Nakayachi, 2017; Trumbo et al., 2011; Lindell et al., 2009). For this reason, an experience variable that is the combination of the number of earthquakes experienced and the intensity of one’s most memorable experience was adopted by taking the mean of the responses of both.

3.3.2 Risk perceptions

Measures for assessing the perceived probability and consequence, and affective associations as risk perception variables were the following:

(a) The perceived likelihood of an earthquake occurrence (scale from “Extremely unlikely (less than 0.1% chance)” to “Extremely likely (more than 99% chance)”;
(b) The perceived likelihood of harm from an earthquake (same scale as previous item); and
(c) Emotional reactions to earthquakes (scale: “No reaction”, “Very little reaction,” “Excitement,” “Somewhat frightened,” “Extremely frightened”).

The time frame for the items was bounded to “in the next five years.”

The emotional reaction item was presented as a follow up to the earthquake experience question. The survey item asked, “How did you react to this earthquake?”, with revised wording to ask about “your most memorable earthquake experience” for the respondents who reported having been in one or more earthquakes in the past (response categories: No reaction; Very little reaction; Excitement; Somewhat frightened; Extremely frightened). If the respondent said they did not have prior experience of an earthquake, their hypothetical reaction was asked (“When you think about being in an earthquake, how do you react?") using the same scale. The scale used in these items was adopted from Dengler & Dewey (1998) as an indicator for one’s reaction to an earthquake, specifically designed to assess fright felt during an earthquake.

Theories on risk appraisal highlight the multifaceted considerations involved in one’s perception of a risk, supported by empirical findings using different measures of risk perception as examined in the Section 2.3. The hypothesized relationships (Hypothesis 2) were modeled using the above three measures of risk perception separately to account for the various ways that risk perception can be captured.

However, given that the three risk perception variables were assumed in this study to measure the same underlying construct (i.e., risk perception), high correlations among these variables were likely, as observed in other studies previously mentioned. While collinearity may not pose a statistical problem[2], it would be difficult to draw conclusions about the effect of risk perception in this study if collinearity results in large uncertainties about the individual coefficients. Given that the three risk perception variables were designed to represent a single underlying construct and therefore collinearity is expected, further exploratory analyses such as a principal component analysis may be warranted. This method would enable a weighted risk perception index that can be used in lieu of the three separate variables.

3.3.3 Perceived efficacy

There are two appraisal stage-related independent variables of interest: perceived efficacy of retrofits on *personal* protection, and on *property* protection. In order to assess perceptions of efficacy and participants' confidence in their responses, respondents were asked the following questions.

- (Property protection) In an earthquake, a house can be damaged in several ways, including sliding off its foundation, leaning, or partial to full collapse.

  If all of the following earthquake resistant features were in place at your house, how effective do you think these features would be at *protecting your house against full collapse*?

[2] Concerns for collinearity arise when one independent variable of interest is highly correlated with another. In such a case, the unique variance of any given variable is small and therefore the independent effect of that variable will be estimated with large standard errors. That is, the effects of highly correlated variables will be hard to disentangle as each correlated variable can stand in for the other in predicting the outcome variable (Vanhove, 2021; York, 2012). Arguments have been made that collinearity should not be a statistical concern in multiple regressions because the coefficients from a multiple regression are unbiased estimates that factor in the other correlated variables, i.e., they are the isolated effects of a variable, holding the other variables constant (see, for example, Vanhove, 2021; Morrissey and Ruxton, 2018). According to these arguments, this is not a serious problem because the uncertainty underlying these estimates that arise from collinearity will be reflected in the standard errors (i.e., large standard errors).

- (Personal protection) If all of the following earthquake resistant features listed below were in place at your house, how effective do you think these features would be at *protecting you and your family members from life-threatening injuries or death*?

  - Roof-to-wall connections (* For URM: Wood floors to masonry walls tied)
  - Wall retrofits such as shear walls, wall sheathing or wall bracing (* For URM: Parapet reinforcement)
  - Frame bolted to the foundation (* For URM: Wall reinforcement (tie-backs))

  Response scale: *(1) Not at all effective; (2) Slightly effective; (3) Somewhat effective; (4) Very effective; (5) Completely effective*

  * Note that, for those reporting living in unreinforced masonry (URM) buildings, URM retrofits were provided.

- You indicated in the previous question that the following features *together* would be "{response to previous question}" in *protecting your house against full collapse*:

  - Roof-to-wall connections/Wood floors to masonry walls tied
  - Wall retrofits such as shear walls, wall sheathing or wall bracing/Parapet reinforcement
  - Frame bolted to the foundation/Wall reinforcement (tie-backs)

  a) Please indicate how confident you feel that these features *together* would be {response to previous question} *in protecting your house against full collapse.*

  b) Please indicate how confident you feel that these features *together* would be {response to previous question} *in protecting you and your family member from life-threatening injuries or death*.

  Use the slider to indicate your answer to this question. 50% means it is a toss-up (i.e., you are guessing); 100% means completely confident.

  I am ______% confident: _____ (Range: 50-100)

  (A slider scale ranging from 50% to 100% was provided. Respondents could choose a percentage in increments of 1. When respondents moved the slider, the corresponding percentage was shown in the blank above automatically.)

Similar to the risk perception variables, the perceived efficacy variables were highly and significantly correlated (r = 0.54) as expected. Given that there were only two efficacy variables to consider, separate regression models were run with each model containing one perceived efficacy variable (personal protection or property protection). For a comparison of results, models including both variables were also run.

3.3.4 Metacognitive confidence

A common way to measure metacognitive confidence judgments is to use a continuous scale (e.g., 0 – 100) from no confidence to complete confidence (Schraw, 2009; Nietfeld et al., 2005). Some studies have adopted ordinal (Likert-scale type) scales instead for simplicity (Butterfield & Metcalfe, 2001). An advantage of a continuous confidence scale is that it allows for more variation in confidence ratings (Nietfeld et al., 2005). A hybrid of the two scales has also been used; Petrusic & Baranski (2009) used a six-category confidence scale consisting of percentages from "50%" to "100%", where 50% confidence in a response was considered a "guess" and 100% confidence indicated "absolute certainty" in their choice.

The survey for this study bounded confidence responses between 50% and 100% and used a continuous scale within this range. The response one gave to the question on the efficacy of retrofits was assumed to reflect at least 50% confidence—if below 50%, they would have chosen another response. While this format resembled the half-range format used in assessing confidence (see Olsson, 2014, p. 1767), it did not ask the respondents to assess the probability that their choice is "correct." Instead, it more closely followed the full-range format where respondents were asked to assess the probability that a statement is true: for the survey in this study, that was "These features together would be {response to perceived efficacy question} in protecting you and your family member from life-threatening injuries or death." The full-range confidence assessment format presents a scale from 0% (certainly false) to 100% (certainly true), assuming that ratings over 50% reflect the respondents thinking that the statement is true (Olsson, 2014, p. 1767). This assumption was introduced to avoid inconsistent responses that report some chosen level of perceived efficacy with very low confidence in the response.

3.3.5 Demographics

Demographic characteristics of respondents have shown mixed effects on preparedness decisions, as suggested by a review of the literature on natural hazard preparedness (Lindell, 2013; Lindell and Perry, 2000). Some studies have found that age, education and/or income are significant determinants of emergency preparedness across studies (Kohn et al., 2012; note that the possibility of selection bias should be considered for findings from non-systematic reviews). Other factors such as occupation and residential district have also been shown to predict preparedness by some (Najafi et al., 2015). At the same time, some studies show weak or inconsistent associations between demographics and protective action intentions (Dunn et al., 2016; Lindell et al., 2009). We included the following set of demographic variables: age, income, gender (being female), and education. In addition, we included a binary indicator variable for residence in Seattle for two reasons. First, the city being the population hub of King County, much of the media coverage of the damages from the 2011 Nisqually Earthquake showed scenes from Seattle, such as building damage and fallen bricks from unreinforced masonry buildings in Pioneer Square. Second, Seattle also had an ongoing earthquake home retrofit permit program at the time of the survey that was designed to help homeowners initiate retrofits, and active community-based efforts to promote installing retrofits, such as the programs of Phinney Neighborhood Association. These factors together may have influenced Seattle residents' perceptions of risk and efficacy of retrofits.

3.4 Models

Table 2.2 shows the variables included in the regression models for this analysis.

Table 2.2 List of variables in regressions models for direct effect and interaction effects

Dependent variable: Intended payment amount	Models (1)	(2)	(3)	(4)	(5)	(6)
Direct effect models						
Perceived efficacy	Personal protection	Property protection	• Personal protection • Property protection	Personal protection	Property protection	• Personal protection • Property protection
Earthquake experience	Mean of number of earthquakes experienced, intensity of most memorable earthquake					
Risk perception	• Earthquake is likely • Harm from earthquake is likely • Emotional reaction to earthquake			Risk perception principal component		
Demographics	Age, income, female, education, Seattle resident					
Interaction models (In addition to variables in the direct effect models)						
Confidence in perceived efficacy	Personal protection	Property protection	• Personal protection • Property protection	Personal protection	Property protection	• Personal protection • Property protection
Interaction terms	(Perceived efficacy × confidence) for personal protection	(Perceived efficacy × confidence) for property protection	(Perceived efficacy × confidence) for both personal and property protection	(Perceived efficacy × confidence) for personal protection	(Perceived efficacy × confidence) for property protection	(Perceived efficacy × confidence) for both personal and property protection

To test Hypothesis 4 (metacognitive confidence moderates the effect of perceived efficacy on intentions to pay) the interaction terms between the two variables (perceived efficacy, confidence) for both property and personal protection were tested. The interactions were between the perceived efficacy variables (personal and property protection) and the level of confidence each respondent reported for their responses to the perceived efficacy questions. The perceived efficacy variables (personal and property protection) with ordinal response scales were treated as continuous for three reasons[3]. An interaction between each category of the perceived efficacy responses and confidence (a) uses up degrees of freedom; (b) complicates the interpretation of the interaction terms; (c) and perhaps most importantly, is unlikely to substantially improve model fit. Using each response category as a binary variable would have resulted in fewer observations for each and affected the power of estimation. This was an especially important consideration given the limited sample size for this study. In addition, a model with interaction terms for each response category of the perceived efficacy items would have yielded a coefficient for each response category as well as a coefficient for each interaction term. If some pairwise categories for the interaction were to have signs and significance that are different from other pairwise categories, the only reasonable conclusion would have been that the interaction is not significant. Treating the variables as continuous was also likely to produce the same conclusion with less complexity in interpretation and, if model fit was not substantially reduced by doing so, could be justified.

Therefore, our perceived efficacy variables treated as continuous are interacted with confidence, also continuous. Interaction terms for both perceived efficacy variables and their respective confidence variables, along with our set of covariates were included in the regression models below to test Hypothesis 4.

[3] Using ordinal variables as continuous offers parsimony, and as long as postestimation tests indicate that model fit is not considerably weakened, such treatment as a continuous variable may be justified (Williams, 2021; Pasta, 2009). One of the most frequently mentioned concern for including it in a linear model is the assumption that the categories are equidistant when they are not (Long and Freese, 2006; Winship and Mare, 1984). This is a bigger concern when the categories are inherently unequally distanced, such as with scales like "1-One day", "2-One week", "3-One month", and so on. The concern applies to Likert-type scales but it remains common practice to treat them as continuous. Advanced methods have also been suggested for modeling ordinal variables (Helwig, 2017).

4. RESULTS

4.1 Descriptive statistics

4.1.1 Demographics

The median age of our sample was 49. The median category for income was "$50,000 to $99,000." Female respondents made up 44.6% of the sample. The majority of respondents (74.4%) reported having a bachelor's degree or higher. Almost 43% of the respondents reported living in Seattle at the time of the survey. Table 2.3 shows the comparison of the demographics of our sample to that of King County, WA. While the invitations to our survey were sent out to randomly selected addresses in King County, various factors influencing one's decision to take and complete the online survey, such as one's availability and familiarity with the topic, could not be ruled out as influences on the differences we observed between our sample and the actual county demographics.

Table 2.3 Comparison of demographics between survey sample and King County, WA

	Sample	King County (Census Bureau, 2019)
Median age	49	37[1)]
Median household income	"$50,000 to $99,000"	$94,974
% Female	44.6%	49.7%
Bachelor's degree or higher	74.4%	52.5%

1) The median age for King County includes all ages, while the sample of this study was limited to 18+. The median age category for the 18+ residents of King County was 40-44 years.

Age was significantly correlated with a number of variables including the risk perception component (positive), metacognitive confidence for perceived efficacy in property protection (negative), and earthquake experience (positive) (see Appendix 2.2 for correlation matrix).

Female gender was significantly correlated with both the risk perception component (positive) and efficacy for personal protection (negative).

4.1.2 Intended payment amount

The median and modal response for the dependent variable, intended payment amount, was $0. About 78% of the respondents chose to pay $0 for retrofits, while there were also small spikes at $40, $100 and $125. Figure 2.2 show the fraction of responses observed for the intended payment amount variable.

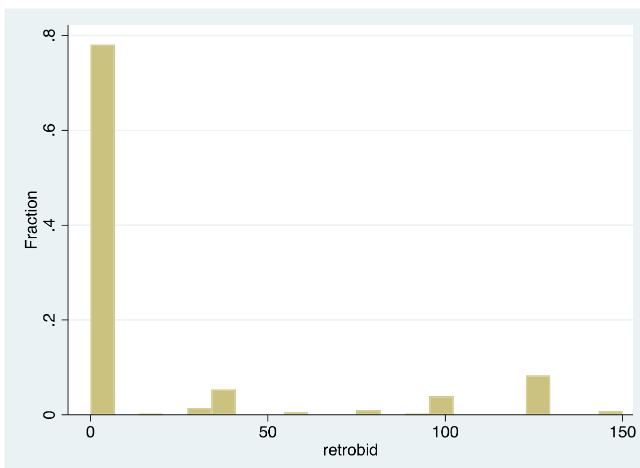


Figure 2.2 Fraction of responses for intended payment amount

4.1.3 Earthquake experience

Experience was measured in terms of the number of earthquakes experienced and intensity. Most of the respondents in our sample reported having prior earthquake experience (84.7%).

Table 2.4 Mean and modal reported shaking intensity of most memorable earthquake, by number of earthquakes experienced

Earthquakes Experienced	Mean intensity	Mode (freq.)
None	0	0 (74)
One	3.1	3 (40)
A few (2-5)	3.6	3 (112)
Several (6-10)	3.9	5 (18)
More than 10	4.4	3, 5 (10)

Categories for earthquake experience intensity
0: No shaking (no experience)
1: Not felt
2: Weak shaking
3: Mild shaking
4: Moderate shaking
5: Strong shaking
6: Violent shaking

Table 2.4 shows the mean reported shaking intensity by the number of earthquakes experienced. There was a visible increasing pattern in the mean responses for shaking intensity as the number of earthquakes experienced increased.

Experience was also positively correlated with risk perceptions. The number of earthquakes experienced was correlated with perceived likelihood of earthquake occurrence (r=0.26; see Appendix 2.2). It was also positively and significantly correlated with the risk perception principal component (r=0.15). The earthquake experience intensity variable was significantly and positively correlated with all risk perception variables, namely probability of occurrence (r=0.36), probability of harm (r=0.18), emotional reaction (r=0.16) and the principal component (r=0.33).

Table 2.5 Mean and modal reactions to most memorable earthquakes, by number of earthquakes experienced

Earthquake Experience	Mean	Mode (freq.)
No	3.8	4 (33)
One	3.1	4 (36)
A few (2-5)	3.5	4 (111)
Several (6-10)	3.4	4 (25)
More than 10	3.6	4 (15)

Categories for reaction to earthquake
1: No reaction
2: Very little reaction
3: Excitement
4: Somewhat frightened
5: Extremely frightened

Of all respondents, with and without earthquake experience, 55% associated earthquakes with fright. Table 2.5 shows the mean and modal responses to earthquakes by earthquake experience: the modal emotional reaction when experiencing an earthquake was “4-somewhat frightened.” The mean responses were between 3 (excitement) and 4 (somewhat frightened), with the mean for those with no earthquake experience being slightly higher than those with experience.

4.1.4 Risk perceptions

About 47% of our respondents assessed the likelihood of experiencing an earthquake in Washington state to be likely, very likely, or extremely likely, as shown in Table 2.6. On the other hand, only 11% said they are likely, very likely, or extremely likely to be harmed by an earthquake.

Table 2.6 Tabulation of risk perception and perceived efficacy responses

Variables and responses	Frequency (Percentage)	
a. Risk perception	Likelihood of earthquakes	Likelihood of harm from earthquakes
Extremely unlikely (less than 0.1% chance)	6 (2.5)	29 (12.0)
Very unlikely (less than 10% chance)	20 (8.3)	55 (22.7)
Unlikely (less than 33% chance)	30 (12.4)	66 (27.3)
About as likely as not (33% to 66% chance)	73 (30.2)	66 (27.3)
Likely (more than 66% chance)	64 (26.5)	15 (6.2)
Very likely (more than 90% chance)	33 (13.6)	8 (3.3)
Extremely likely (more than 99% chance)	16 (6.6)	6 (1.2)
Observations	242	242
b. Perceived efficacy	Personal protection	Property protection
Not at all effective	1 (0.4)	2 (0.8)
Slightly effective	8 (3.3)	8 (3.3)
Somewhat effective	101 (42.1)	101 (41.9)
Very effective	127 (52.9)	120 (49.8)
Completely effective	3 (1.3)	10 (4.2)
Observations	240	241

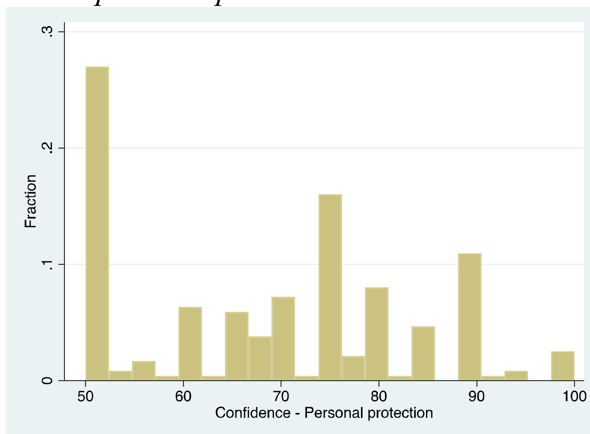
4.1.5 Perceived efficacy and metacognitive confidence

The modal response to the efficacy questions was "very effective" for both personal and property protection, and those who chose this category or "somewhat effective" together account for more than 90% of total responses, as seen in Table 2.6.

A high proportion of those choosing "very effective" (83% for personal protection, 63% for property protection) reported a confidence rating of 75% or higher. The correlations between perceived efficacy and confidence are also strongly positive ($r = 0.55$ for personal protection; $r = 0.35$ for property protection). Together, this can be seen as an indication that people in the Seattle area generally perceived retrofits to be effective, albeit with perhaps some uncertainty.

For the confidence assessment questions that followed, there were visible response peaks at 50%, and at 75% to a lesser extent (see Figure 2.3). The majority of respondents who selected 50% were those who selected "somewhat effective" for the perceived efficacy items.

a. For *personal protection*



b. For *property protection*

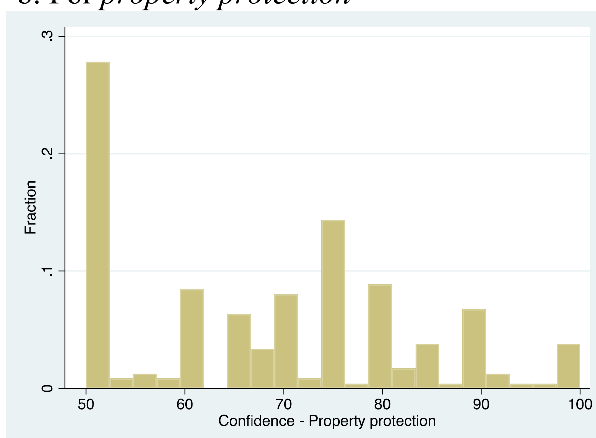


Figure 2.3 Level of confidence in one's own assessment of the effectiveness of retrofits

4.2 Regression results

4.2.1 Earthquake experience

The results indicated that earthquake experience was not significantly associated with intended payment amount. The direction of this association was also the opposite of what was hypothesized: for example, a one-unit increase in earthquake experience was associated with

$4.07 less in intended payment amount in the personal protection model (Table 2.7, Column 1). This negative but non-significant association is consistent across all direct models.

4.2.2 Risk perception

The initial results (Table 2.7, Columns 1, 2, 3) indicated that the three risk perception indicators, namely probability of occurrence, probability of harm (consequence), and emotional association were not predictive of intended payment amounts. The direction of the coefficients, however, indicated a positive association, i.e., higher risk perception is associated with higher intended payment amounts.

These findings were in contrast to Hypothesis 2 (appraisal of risk has a positive and direct effect on intended payment amount). As described in Section 4.1, high correlations between the risk perception variables were likely and signs of multicollinearity were present: standard errors of the consequence (probability of harm) and emotional reaction variables are large (Table 2.7, Columns 1, 2, 3), while the correlation coefficients between the two probability variables, and between emotional reaction and probability of harm were significant, with the correlation coefficient between perceived probability of earthquake occurrence and harm being 0.56 and that of reaction and probability of harm being 0.20, both of which are significant (Appendix 2.2). While these correlation coefficients were not so large that they were definite evidence of multicollinearity, the magnitude of the standard errors for the perceived probability of harm and emotional reaction variables indicated extraordinarily large variance.

In order to better assess the effect of risk perception in the absence of collinearity, a risk perception variable was created using principal component analysis (PCA), a technique of analyzing multivariate data that contain multiple variables measuring a single construct

(Bartholomew et al., 2008). The three risk perception variables were included in the PCA. Table 2.8 shows the eigenvalues of each component and proportion of variance explained. The eigenvalue of component 1 was over 1 and met the general rule of thumb in terms of the criteria for selecting components to retain (eigenvalue > 1).

Table 2.7 Effects of risk perception and perceived efficacy on intended payments for retrofits

The coefficients shown are estimates from OLS regressions and indicate changes in intended payment amounts (in dollars) with a one-unit increase in each variables, controlling for other variables. Models (1) to (3) included the three risk perception variables separately, while models (4) to (6) used the risk perception principal component. Large standard errors seen for the coefficients of the separate risk perception variables likely due to multicollinearity (the condition index, a collinearity diagnostic, for the three risk perception items is 11.7) are reduced in the models including the risk perception principal component.

Variables	(1) Personal protection	(2) Property protection	(3) Full model	(4) Personal protection (PCA)	(5) Property protection (PCA)	(6) Full model (PCA)
Efficacy for personal protection	15.34** (4.81)		9.51 (5.00)	15.44*** (4.39)		9.61 (5.48)
Efficacy for property protection		13.91** (4.74)	9.56* (4.66)		13.97** (4.27)	9.55 (4.93)
Earthquake experience	-4.07 (2.33)	-3.59 (2.41)	-3.83 (2.37)	-3.75 (2.37)	-3.23 (2.23)	-3.51 (2.55)
Earthquake is likely	3.49 (2.31)	3.74 (2.55)	3.61 (2.47)			
Harm from earthquake is likely	0.74 (2.86)	0.66 (2.76)	0.90 (2.85)			
Emotional reaction to earthquake	1.06 (2.87)	1.31 (2.63)	1.02 (2.93)			
Risk perception (Principal component)				4.06 (2.75)	4.30 (2.22)	4.31 (2.72)
Age	0.11 (0.19)	0.05 (0.21)	0.08 (0.21)	0.11 (0.20)	0.04 (0.22)	0.08 (0.23)
Income	5.45** (2.00)	5.89* (2.33)	6.01** (2.29)	5.67** (1.95)	6.11** (2.00)	6.24** (2.30)
Female	-3.94 (5.19)	-5.04 (5.63)	-3.47 (5.68)	-3.99 (5.11)	-5.20 (5.85)	-3.47 (5.20)
Education	2.62 (2.08)	2.17 (2.23)	2.19 (2.34)	2.48 (2.50)	2.01 (2.29)	2.06 (2.31)
Seattle	13.21* (6.62)	13.39* (6.46)	12.91 (6.97)	13.21* (5.96)	13.40* (6.29)	12.91* (6.03)
Constant	-89.23** (29.83)	-82.99** (28.10)	-102.38** (31.46)	-69.08** (24.97)	-60.76** (20.83)	-81.39** (27.95)
Observations	378	380	378	378	380	378
Wald chi^2	20.33	34.12	30.88	34.74	34.38	34.17
df	10	10	11	8	8	9
Prob > chi^2	0.03	0.00	0.00	0.00	0.00	0.00
Adjusted R-squared	0.12	0.12	0.13	0.12	0.12	0.13

Note
1) Bootstrapped standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)
2) Alternate rows shaded for enhanced visibility.

Table 2.8 Eigenvalues and proportion of variance explained by components

Component	Eigenvalue	Proportion	Cumulative
Comp1	1.62	0.54	0.54
Comp2	0.95	0.32	0.86
Comp3	0.43	0.14	1.00

Table 2.9 shows how each of the risk perception variables were related to the principal components. The loadings of perceived likelihood of earthquakes and perceived likelihood of harm from earthquakes on the first component were large, while reactions to earthquakes loaded on the first component moderately. The second component had high loadings for only the emotional reaction variable. Component 1 was retained as a risk perception variable in the models for this study based on a) an eigenvalue that is greater than 1, b) its ability to explain over 50% of the total variance of the three variables, and c) the moderate to strong correlations with the three variables.

Table 2.9 Loadings of risk perception variables on principal components

Variables	Components		
	1	2	3
Earthquake likely	**0.66**	-0.33	0.68
Harm from earthquake likely	**0.69**	-0.11	-0.72
Reaction to earthquake	**0.31**	0.94	0.16

The estimates of the regression models that contained this principal component for perceived risk are shown in Table 2.7, Columns 4, 5 and 6. The findings were highly similar to those of the models employing separate measures of risk perception: the risk perception principal component had positive effects on intended payment amount. The estimated coefficients were non-significant, but standard errors were much smaller than the models with separate risk perception indicators.

4.2.3 Perceived efficacy

The perceived efficacy variables had significant estimates in the hypothesized direction in the models containing the two efficacy variables separately (Hypothesis 3: Perceived efficacy has a direct and positive effect on intended payment amount). A one-category increase in perceived efficacy of retrofits for personal protection was associated with a $15.34 increase in intended payment amount in the model using separate risk perception indicators (Table 2.7, Column 1). In the model with the risk perception principal component, the coefficient was $15.44, holding all other variables constant (Column 4).

Perceived efficacy for property protection also had significant and positive estimates in the separate models: a one-category increase was associated with an intended payment amount that is higher by $13.91, all else equal (Table 2.7, Column 2). The coefficient estimate was $13.97 in the risk perception principal component model (Column 5).

However, in the full models containing both efficacy variables, only perceived efficacy for property protection was significantly positive (Table 2.7, Column 3). Perceived efficacy for personal protection, while positive, was not significant. In the model containing both efficacy variables and the separate risk perception variables, a one-category increase in perceived efficacy for property protection was associated with a $9.56 increase in intended payment amount. In the model containing the risk perception principal component, a one-category increase in property protection efficacy was associated with a $9.55 increase in intended payment amount, but this effect size was non-significant, indicating an effect indistinguishable from zero. (Table 2.7, Column 6).

4.2.4 Demographics

Demographic factors showing significant associations with intended payment amount were income and residence in Seattle. The intended payment amount of Seattle residents approximately $13 across the four models shown in Table 2.10. A one-category increase in income was associated with an intended payment higher by $5.45 in the model with perceived efficacy for personal protection (Table 2.7, Column 1), by $5.89 in the property protection model (Column 2), and by $6.01 in the full efficacy model (Column 3). The income coefficients for the personal, property protection and full models using the risk perception principal component were $5.67, $6.11, and $6.24, respectively (Columns 4, 5, 6).

4.2.5 Metacognitive confidence

The models with interaction terms between perceived efficacy and metacognitive confidence in the perceived efficacy items displayed two noticeable patterns (see Table 2.10). First, none of the perceived efficacy or metacognitive confidence variables were significant. Second, the effect sizes of both metacognitive confidence and the interaction terms were very small, while the standard errors were quite large for the perceived efficacy variables, metacognitive confidence, and the interaction terms.

Although our interaction terms were not significant, when combined with the perceived efficacy coefficients that are also positive, they indicated a positive slope for the effect of efficacy on payment intentions. For example, in the model that includes perceived efficacy for personal protection, the effect of a one-unit increase in perceived efficacy could be computed as follows, holding all other variables constant: $15.75 + 0.04 \times (\text{Confidence})$. Given that the responses for metacognitive confidence ranged from 50% to 100%, this would translate to the effect of a one-category increase in perceived efficacy for personal protection ranging from $17.72 (when confidence is 50%) to $19.75 (when confidence is 100%). Appendix 2.3 graphically shows the interaction effects, using the predicted mean intended payment amount by each perceived efficacy category for models (1) to (6). Although slight differences in the slope of the linear relationship between perceived efficacy and intended payment amount were observed by metacognitive confidence levels ranging from 50 to 100, reversals of slopes that were indicative of interactions were not observed as the coefficient estimates suggest.

Table 2.10 Interaction of perceived efficacy and metacognitive confidence on intended payments for retrofits

The coefficients shown are estimates from OLS regressions and indicate changes in intended payment amounts (in dollars) with a one-unit increase in each variables, controlling for other variables. Models (1) to (3) included the three risk perception variables separately, while models (4) to (6) used the risk perception principal component. Large standard errors seen for the coefficients of the separate risk perception variables due to multicollinearity (the condition index, a collinearity diagnostic, for the three risk perception items is 11.7) are reduced in the models including the risk perception principal component. In addition, metacognitive confidence and interaction terms between perceived efficacy and metacognitive confidence are added in each model.

Variables	(1) Personal protection	(2) Property protection	(3) Full model	(4) Personal protection (PCA)	(5) Property protection (PCA)	(6) Full model (PCA)
Efficacy for personal protection	15.75		21.82	11.54		17.96
	(21.73)		(22.31)	(28.14)		(28.20)
Confidence in personal protection efficacy	-0.40		-0.28	-0.62		-0.50
	(1.10)		(1.21)	(1.34)		(1.48)
Interaction (pers. prot. efficacy × confidence)	0.04		-0.14	0.11		-0.07
	(0.32)		(0.34)	(0.40)		(0.43)
Efficacy for property protection		9.53	1.58		7.51	0.30
		(19.32)	(17.11)		(22.42)	(19.06)
Confidence in property protection efficacy		-0.00	0.21		-0.11	0.15
		(1.04)	(1.18)		(1.27)	(1.24)
Interaction (prop. prot. efficacy × confidence)		0.05	0.11		0.08	0.13
		(0.30)	(0.28)		(0.35)	(0.32)
Earthquake experience	-3.83	-3.58	-3.48	-3.52	-3.24	-3.16
	(2.45)	(2.44)	(2.57)	(2.50)	(2.51)	(2.76)
Earthquake likely	3.70	4.19	3.98			
	(2.61)	(2.47)	(2.70)			
Harm from earthquake is likely	0.30	0.87	0.46			
	(3.03)	(2.54)	(3.33)			
Emotional reaction to earthquake	1.25	0.97	1.16			
	(3.35)	(3.10)	(3.34)			
Age	0.10	0.04	0.08	0.10	0.04	0.08
	(0.21)	(0.20)	(0.20)	(0.19)	(0.21)	(0.22)
Income	5.56*	5.94*	5.66*	5.82**	6.23**	5.94**
	(2.43)	(2.81)	(2.46)	(2.17)	(2.09)	(2.17)
Female	-3.65	-6.23	-4.35	-3.79	-6.20	-4.41
	(5.77)	(5.07)	(5.88)	(5.75)	(6.16)	(6.15)
Education	2.54	2.23	1.90	2.41	2.06	1.75
	(2.57)	(2.15)	(2.43)	(2.11)	(2.11)	(2.38)
Seattle	14.09*	13.49*	12.23	14.16*	13.47*	12.32*
	(6.47)	(6.46)	(6.88)	(5.87)	(6.84)	(6.26)
Risk perception (Principal component)				3.97	4.80	4.34
				(2.99)	(3.19)	(2.65)
Constant	-74.51	-80.20	-104.12	-39.67	-50.07	-64.67
	(69.84)	(69.19)	(74.95)	(86.78)	(79.39)	(94.73)
Observations	374	374	372	374	374	372
Wald chi^2	29.69	27.84	32.84	26.64	38.35	44.53
Df	12	12	15	10	10	13
Prob > chi^2	0.00	0.01	0.01	0.00	0.00	0.00
R-squared	0.12	0.12	0.14	0.12	0.12	0.14

Note
1) Bootstrapped standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)
2) Perceived efficacy and confidence variables were uncentered and highly correlated with the interaction terms, resulting in high standard errors.
3) Alternate rows shaded for enhanced visibility

5. Discussion

This study hypothesized and tested two mechanisms by which appraisal stage variables affect intentions to adopt protective measures using survey responses about earthquakes in Washington state and seismic reinforcement.

5.1 Direct effects of experience, risk perception, and perceived efficacy

5.1.1 Earthquake experience

The estimates from the models for testing the direct effect of the key variables on intended payment indicated that earthquake experience was not a significant predictor of intended payment amount. This finding contradicted Hypothesis 1. The results also did not suggest a possibility of mediation by other variables such as risk perception, as suggested by some studies discussed in Section 2.2. As seen in Appendix 2.2, experience and risk perception were significantly correlated, but neither were significant predictors in the regression models. Normalization bias, as discussed previously in Section 2.2, might have been present if most respondents experienced mild to moderate earthquakes as seen in recent decades in Washington state, or even strong ones elsewhere but managed to avoid severe damage that one might have expected. The more times an individual has experienced such an outcome, the more likely it may be for normalization bias to occur.

5.1.2 Risk perception

The risk perception variables in the models showed a positive effect on intended payment amount as hypothesized (Hypothesis 2), but were non-significant. As discussed in Section 4.2, the separate risk perception variables for perceived probability of earthquake occurrence and harm, and emotional reactions were correlated and yielded large standard errors. Substituting them with a risk perception principal component resolved collinearity, and while the effects of this principal component variable were positive, they were not significant.

The effect of risk perception may have been moderated or mediated by another variable omitted from the models, which warrants further investigation. The current study asked respondents about their perceived *response* efficacy; that is, how effective they thought seismic retrofits would be for providing protection in an earthquake. The concept of self-efficacy was not included. However, seismic retrofits are protective measures that require knowledge, time and financial resources to implement. If a respondent with high perceived earthquake risk (either occurrence or harm) had a low sense of self-efficacy in implementing such resource-intensive measures, they may have reported a low intended payment amount. If a respondent had high perceived response efficacy and high self-efficacy, they may have been more likely to report a high intended payment amount.

In addition to the non-significance, two aspects of the risk perception variables stood out. First, the likelihood of harm from an earthquake, which was one of the risk perception indicators in the survey, was negatively and significantly correlated with the confidence ratings for perceived efficacy in both personal protection and property protection, although the correlations were weak (-0.14 and -0.16, respectively; see Appendix 2.2). The causal direction of this association was unclear. That is, the question remains whether higher perceived risk of harm from an earthquake leads to lower confidence in the assessed efficacy of retrofits, or whether low confidence in one's assessment of efficacy leads to a higher sense of risk of personal harm. Based on risk communication theories such as the Theory of Motivated Information-Management (Afifi and Weiner, 2004) and the Risk Information Seeking and Processing Model (Griffin et al., 1999) it is most likely to be an iterative feedback process that cannot be resolved in a cross-sectional survey. Under uncertainty about a threat, people may be motivated to seek more information or avoid information as a coping mechanism (for a summary, see Lindell, 2014). Individuals who perceive a potential threat but are uncertain about effective ways to avoid it have been found to seek information on the threat (Yang et al., 2014), which may influence their appraisal of risk and uncertainties about preventative measures. There is also evidence pointing in the opposite direction: when people perceive a threat but are uncertain about the efficacy of available protective measures, they have been found to resort to maladaptive measures like information avoidance (Goodall and Reed, 2013). The relationship between one's perceived risk of a natural hazard and their metacognitive confidence in protective action efficacy is an area for future research.

Second, the emotional reaction variable did not load as heavily on the risk perception principal component as the probability of earthquake occurrence and harm. Instead, the second principal component, which was excluded from the models, predominantly captured the emotional reaction variable (Table 2.9). Emotional reactions to an appraisal object, as examined in Sections 2.1 and 2.3, are mainly seen as risk perception variables by many theories and models. However, the emotions felt during a disaster experience may also characterize the experience itself, just as the intensity of an experience may define the experience. As discussed in Section 2.2, prior experience of a disaster event is a source of knowledge, emotions, and assessments that are used in deciding the course of protective actions to take (Reser and Bradley, 2020; Demuth, 2018). Further investigation into emotions as not only a risk perception variable but also as a potential mediator or moderator of the effect of experience could add clarity to the role it plays in determining protective behavior.

5.1.3 Perceived efficacy

The perceived efficacy variables were positive and significant in the direct effect models that included personal and property protection efficacy items separately. However, when the two efficacy items were present in the same model, only perceived efficacy for property protection was significantly positive. That is, those who perceived retrofits as being more effective for property protection were willing to pay more to have them installed. Given the moderately high correlation between the two perceived efficacy items, omitting one of them in the model is likely to have caused the efficacy variable included in the model to partially represent the effects of the omitted variable.

The significance of property protection efficacy but not personal protection efficacy may be an indication that people associate the effects of retrofits primarily with keeping property from being damaged in an earthquake, more so than with protecting people from injuries or even deaths. Because people tend to have a clear idea of the value of their property but not the value of personal protection, respondents may have found it easier or may have been more willing to report a concrete intended payment amount to protect their property than an amount for personal protection. An excerpt from a local news coverage of Seattle homeowners who have decided to pay to get their homes retrofitted perhaps best illustrates this point: “The wood frame is bolted inside and out to the cement foundation. It was a job that took a few weeks and cost [the interviewee] about $10,000. Things will likely still fall off walls, windows might break -- but [the interviewee's] house will likely be livable" (Joyce, 2017).

5.2 Moderating effect of metacognitive confidence

The metacognitive confidence models showed non-significant estimates for all perceived efficacy variables, confidence indicators and interaction terms between the two. It should be noted that, similar to what was observed among the three risk perception variables, standard errors of the coefficient estimates for these variables were quite large in all of the models. Appendix 2.2 also indicated high correlations between each perceived efficacy item and the corresponding metacognitive confidence item (r=0.55 for personal protection, r= 0.35 for property protection), as well as between the two metacognitive confidence items (r=0.84), all of which were significant.

These correlations between the uncentered main perceived efficacy variables and the interaction terms were expected given that the interaction terms are derived from the main effects. However, there did appear to be a correlation between perceived efficacy and confidence that needs further investigation. As mentioned in Section 4.1, the majority of respondents who selected 50% for the confidence rating were those who chose "somewhat effective" for the perceived efficacy items. The piles at 50% confidence in association with the midpoint choice of "somewhat effective" may have reflected respondents' uncertainty in how effective retrofits are. Whether the 50% on the confidence scale was seen by respondents as the lower endpoint (lowest possible choice) or as a midpoint of 0-100% is unclear from the data, but both are possible. The observed piles at 50% and 75% (75% is the middle of the 50 – 100 range), therefore, could be a manifestation of high uncertainty and/or a middle-option bias that respondents resorted to when faced with the complexity of the assessment and uncertainty. If the midpoint responses were "true" responses and happened to be highly correlated, it may not be a measurement error. However, if these were manifestations of a middle-option bias due to factors such as uncertainty or fatigue, future survey designs must account for this possibility. Follow-up questions may be helpful in distinguishing these types of responses.

Another methodological consideration for future research is in the survey items that are designed to assess people's metacognitive confidence. The object of confidence assessment that respondents are asked to consider may determine people's confidence ratings differently. Findings from a meta-analysis of 29 research reports have suggested that attitudes and actual behavior were more strongly correlated when one had (1) direct experience of an attitude object; and (2) higher confidence that they were correct in their attitude about an object (Glasman and Albarracín, 2006). The object of confidence assessment for our study was seismic retrofits, which the respondents in our sample reported not having at the time of the survey. This is in contrast with Goldberg et al. (2020), who assessed people's confidence in a past protective action they took (i.e., hurricane evacuation), and found that metacognitive confidence was associated with higher future protective action intentions. Difference in findings might arise from the difference between asking respondents to assess their confidence in an object to which they have not yet committed (i.e., seismic retrofits), in contrast to their confidence in an action they took in the past and have since received feedback on it.

Another factor associated with reported confidence ratings is the possibility of over- or under-confidence in one's assessment. Psychological studies have found overconfidence in survey responses to be a phenomenon in both the social context and lab experiments.

Explanations on why overconfidence is abundantly observed include the Dunning-Kruger effect[4] (Dunning, 2011; Kruger and Dunning,1999), and issues with the survey such as item sampling, task format, and regression of responses to the mean (Olsson, 2014). Of relevance to the survey used for this study may be over- and under-confidence arising from the format of the confidence questions. There is evidence that the half-range format for confidence assessment is associated with under-confidence, while near-zero or moderate overconfidence is often found with the full-range format (for this study, see Juslin et al., 1997; for discussion, also see Olsson, 2014).

While our results did not confirm that one's meta-cognition has a moderating effect on perceptions on efficacy as a predictor for behavioral intentions, further investigation of metacognition and disaster preparedness is warranted as higher metacognition is a known determinant of improved learning and behavioral changes. Improving the public's access to accurate and reliable information about seismic hazard mitigation measures may boost people's confidence in their assessment of how effective such measures would be in the event of a large earthquake. Information from trusted sources disseminated using various media outlets may be useful in reaching a wide audience. In sequential decision-making theoretical frameworks such as the PADM, information enters the decision-making process as both an external input and as a behavioral response of information-seeking (Lindell and Perry, 2012). Access to information and trust in the sources may influence one's appraisals and decisions leading up to a behavioral response such as information seeking and adoption of protective actions. The availability, accessibility, and trust of information sources are generally pre-decisional variables that may also affect metacognitive confidence, which should be tested in future studies. At the same time,

[4] The Dunning-Kruger effect describes the tendency of those who perform poorly on tasks ("incompetent") to have low metacognitive knowledge of their incompetence (Dunning, 2011, p. 260). Due to this "metaignorance," the Dunning-Kruger effect posits that even when these individuals make a series of errors, they tend to think that they are performing the tasks well (ibid).

the effect of metacognitive confidence on eliciting information seeking behavior is also an important aspect, especially with a focus on what kind of information is sought and from where, as those may have policy implications for how to best disseminate relevant information.

5.3 Demographic variables

The demographics variables that were significant predictors of intended payment across all models were income and residence in Seattle. The significance and positive direction of the effect of income does not come as a surprise because the options for intended payment amount that were available to respondents depended on their monthly rent or home value, which are presumed to be correlated with income. Given that residence in Seattle is not highly correlated other variables included in this study including risk perception, its significant and positive effect on intended payment amount may be attributed, with much speculation that needs validation through further research, to higher awareness of retrofits through city programs as mentioned in Section 3.3.

5.4 Caveats and limitations

It should be noted that there is wide consensus on the need for more earthquake preparedness measures in Washington state, and that public demand and support for structural reinforcement is likely higher than the intended payment amounts we used in our study. This study presented payment options based on one's housing prices to those who did not have structural retrofits for their homes at the time of the survey. While such decisions to do without retrofits may have been affected by various socioeconomic factors or personal values, this subset of our sample is not representative of the state's population.

A few limitations of this study must be noted. First is the limited number of observations resulting from a modest sample size, further reduced by including in the sample only those without retrofits to maintain hypotheticality of responses (61% of all respondents). The regression models have been bootstrapped and Tables 2.7 and 2.10 report bootstrapped standard errors to address limitations of smaller sample sizes, in particular the assumption of normally distributed data. Second, the possibility of respondent fatigue affecting data quality, especially for the confidence items and intended payment amount items cannot be ruled out. Both the confidence items and intended payment amount items were information-heavy and involved multiple tasks that required comparisons and assessments of the information provided. Given that the majority of our respondents took longer than 10 minutes to complete the survey (28 minutes maximum), the possibility of fatigue and satisficing on the responses cannot be ruled out.

6. Conclusion

We examined the role of appraisal stage variables, namely risk perception and perceived efficacy, in determining intended payment amounts for seismic reinforcement. We found that perceived efficacy matters, but further investigation is needed to determine the reason that our risk perception variables did not prove significant. Metacognition of efficacy perceptions was not found to be a determinant of intended payment for retrofits. As risk perceptions are also subjective assessments like perceived efficacy, future research should look into whether metacognition for risk perception has similar effects on behavioral intentions and actual behaviors.

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OF PREVIOUS STUDIES ON THE EFFECTS OF RISK PERCEPTION AND PERCEIVED EFFICACY ON PROTECTIVE ORDER BY NEWEST PUBLICATION YEAR)

isal stage	Protective action DV	Hazard type	Key findings
nal and tion se equences	Preparedness index for each hazard (emergency preparedness and hazard mitigation items)	- Volcanic eruption - Wildfire - Earthquake	- Perceived efficacy is significant and positive for all three hazard types. - Risk perception is only a significant positive predictor for volcanos.
n: cognitive ccurrence/ ive event) of self and cy (personal ums of	Hurricane evacuation intention scale	Hurricane	Six experience dimensions were the focus of this study. - All appraisal stage variables were strongly associated with evacuation intentions. - Effect of evacuation experience was mediated by appraisal variables.
aged rating tive actions utility for n: Averaged ood of ough s	Behavioral expectations of protective action adoption	Influenza pandemic	- Hazard attributes completely mediate the effect of age on adoption expectations. - Risk perception was also a significant predictor of behavior but not a mediator of age.
l attributes kit; mergency nents with andbags; on of flood	Adoption intention of hazard adjustments	Flood	- Significant and positive effect of perceived efficacy on adoption intention (except for sandbags). - Risk perception was also significant and positive but explained less than perceived efficacy.

Citation	IV for appraisal stage	Protective action DV	Hazard type	Key findings
Bubeck et al. (2013)	- Perceived efficacy of flood mitigation measures - Risk perception as perceived probability and consequence	Implementation of: - Structural building measures - Adapted building use - Flood barriers - Purchase of flood insurance	Flood	- Significant and positive (except for structural building measures). - No significant relation between risk perceptions and mitigation behavior was found.
McFarlane et al. (2012)	Property protection efficacy response	Wildfire hazard potential (Completion, intention to complete within 1 year/5 years/5+ years/no intention)	Wildfire	Significant and positive* (*Negative sign in actual results because DV was coded in reverse, i.e., 0 for completion, 30 for no intention)
Egbelakin et al. (2011)	Belief in seismic retrofit techniques	Seismic retrofit implementation	Earthquake	Case studies reveal that damage to new buildings with high seismic strength affect people's perception of efficacy of structural solutions. Uncertainties in the efficacy of mitigation techniques deter adoption. Uncertainties about earthquake occurrence are also found to deter action.
Miceli et al. (2008)	- Risk perception: Probability of possible consequences of event, worry about the same set of outcomes	- Set of emergency preparedness behaviors	Flood	- Significant and positive
Lindell & Hwang (2008)	Risk perception for property damage, personal injury, health problems	Flood mitigation scale for HVAC, raised electrical system above flood level; raised house above flood level; waterproof exterior	Flood Hurricane Chemical release	Risk perception mediates the effect of experience on protective action adoption.

Citation	IV for appraisal stage	Protective action DV	Hazard type	Key findings
Lindell & Prater (2002)	- Efficacy in protecting person, property, and use for other purposes - Risk perception of likelihood of damage from earthquake	Adoption intentions Actual adjustments	Earthquake	- Significant and positive for efficacy. - Risk perception did not predict adoption intention.
Lindell & Whitney (2000)	- Hazard adjustment attributes (efficacy) - Risk perception of likelihood of damaging earthquake, and likelihood of actual damage	- Adoption of each of 12-item on Earthquake Preparedness scale - Adoption intention	Earthquake	- Perceived efficacy of hazard adjustments strongly predicts adoption and intention. - Perceived risk did not predict adoption intentions or adoption.
Winter & Fried (2000)	Perception of fire management strategies	Adoption of "fireproofing" safeguards for homes and properties	Wildfire	Focus group results indicate that perceptions of fire management strategies were biased from a few selective cases from the past: random destruction of fire-proofed homes in the 1990 fire, while vulnerable homes survived led many to believe fireproofing efforts were futile.
Norris et al. (1999)	Perceived control (usefulness of measure)	Hazard preparedness: - Advance planning - Basic supplies - Alertness	Hurricane	Perceived control mediated the effects of the severity of previous hurricane exposure.

APPENDIX 2.2 MEANS (MS), STANDARD DEVIATIONS (SDS), MEDIANS (MDS), AND INTERCORRELATIONS OF VARIABLES

	Variable	M	SD	Md	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Payment	19.45	41.13	0	1.00																
2	Personal protection	3.51	0.61	4	.20*	1.00															
3	Property protection	3.53	0.67	4	.21*	.54*	1.00														
4	Confidence in perceived personal protection	68.95	14.75	70	.06	.55*	.30*	1.00													
5	Confidence in perceived property protection	68.30	14.85	70	.16*	.46*	.35*	.84*	1.00												
6	Number of earthquakes experienced	1.78	1.06	2	-.07	-.07	-.06	-.00	-.02	1.00											
7	Intensity of memorable earthquake	3.05	1.64	3	-.03	-.02	-.07	.08	.05	.69*	1.00										
8	Earthquake experience	2.41	1.25	2.5	-.05	-.04	-.07	.05	.02	.88*	.95*	1.00									
9	Earthquake likely	4.37	1.40	4	.08	-.03	-.10	-.02	-.05	.26*	.36*	.35*	1.00								
10	Harm likely	3.08	1.31	3	.03	-.09	-.10	-.14*	-.16*	.07	.18*	.15*	.56*	1.00							
11	Reaction	3.44	0.96	4	.01	.01	.01	.04	.02	-.03	.16*	.09	.09	.20*	1.00						
12	Risk perception PC	0.00	1.27	0.04	.05	-.08	-.10	-.11	-.14*	.15*	.33*	.28*	.83*	.87*	.40*	1.00					
13	Age	49.59	15.37	49	-.10	-.11	.03	-.11	-.16*	.17*	.28*	.26*	.12*	.15*	.03	.15*	1.00				
14	Income	3.83	1.36	4	.20*	-.05	-.10	-.07	-.01	.07	.02	.04	-.04	-.16*	-.13	-.11	-.15*	1.00			
15	Female (=1; 0 if male)	0.45	0.50	0	-.07	-.21*	-.12	-.05	-.02	.06	.08	.08	.21*	.29*	.00	.25*	.06	-.19*	1.00		
16	Education	4.97	1.31	5	.14*	.05	.05	.01	.05	-.04	-.13*	-.10	-.16*	-.10	-.05	-.12	-.04	-.13*	-.05	1.00	
17	Location: Seattle	0.43	0.50	0	.13*	.07	.07	.07	.16*	-.06	-.12	-.10	-.07	-.06	-.04	-.11	-.20*	-.02	-.05	.12*	1.00

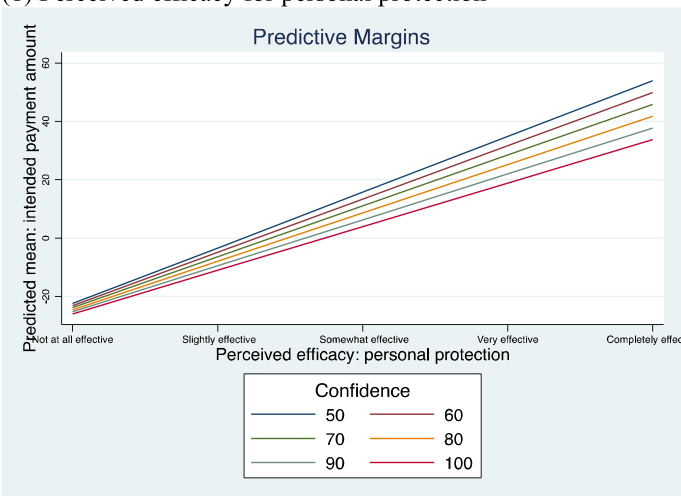
Note

1) Asterisks (*) indicate correlation coefficients that are significant at the 0.01 level.
2) Recommendations in the literature for significance-level adjustments for lowering the probability of falsely rejecting true null hypotheses have been considered (Glickman et al., 2014) and the significance level at 0.01 which allows 1.2 false positives in the 120 pairwise correlation tests above have been chosen.

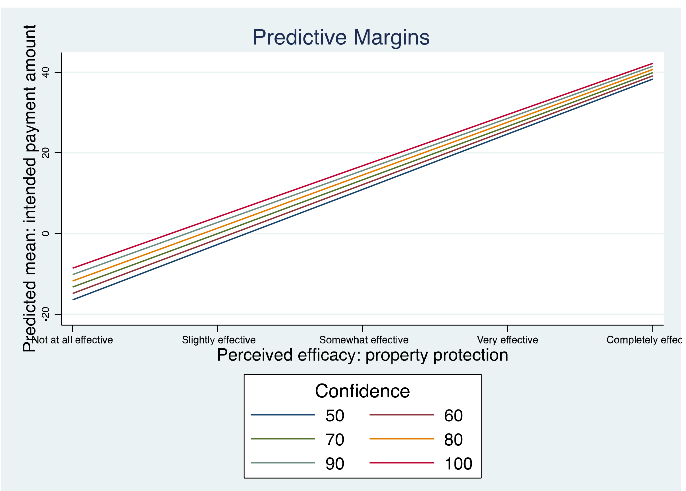
APPENDIX 2.3 PREDICTED MEAN OF INTENDED PAYMENT AMOUNT BY PERCEIVED EFFICACY CATEGORY

Separate risk perception variables

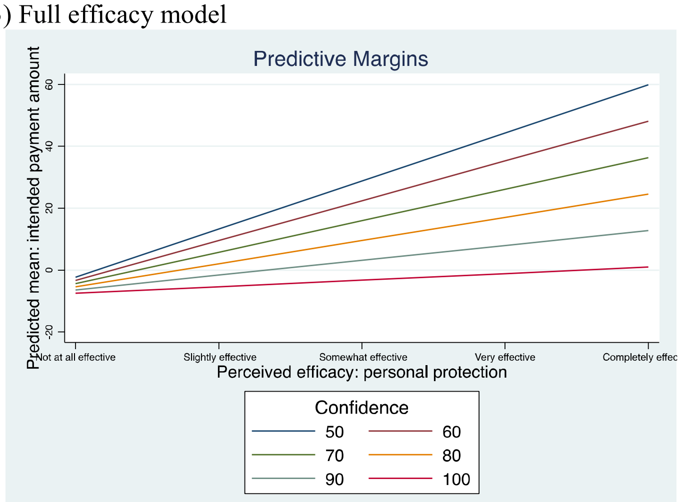
(1) Perceived efficacy for personal protection



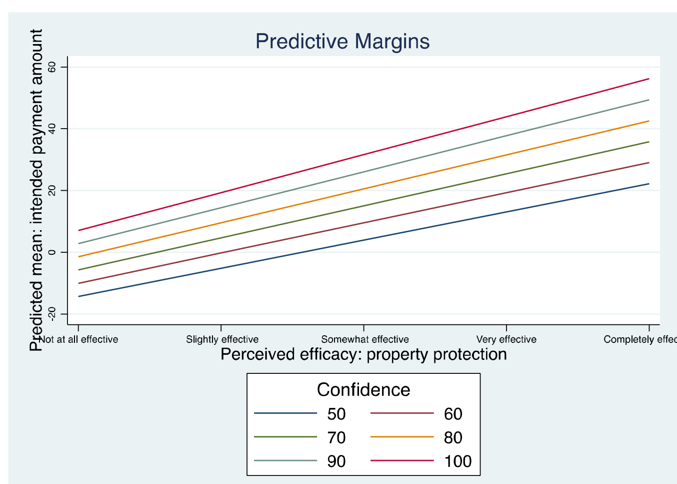
(2) Perceived efficacy for property protection



(3) Full efficacy model



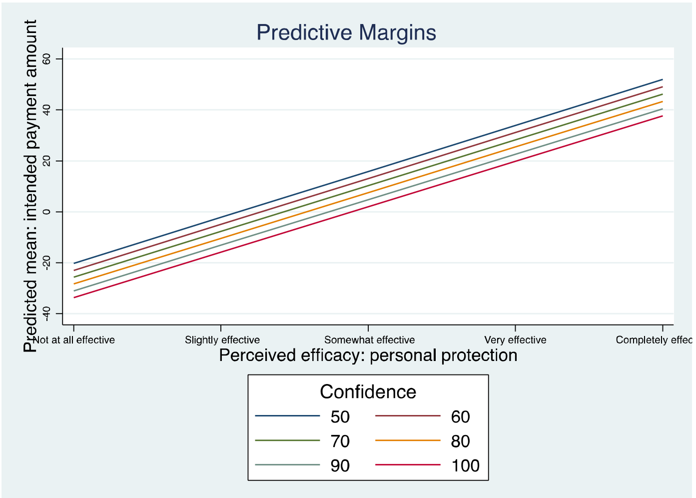
Predictive margins for personal protection



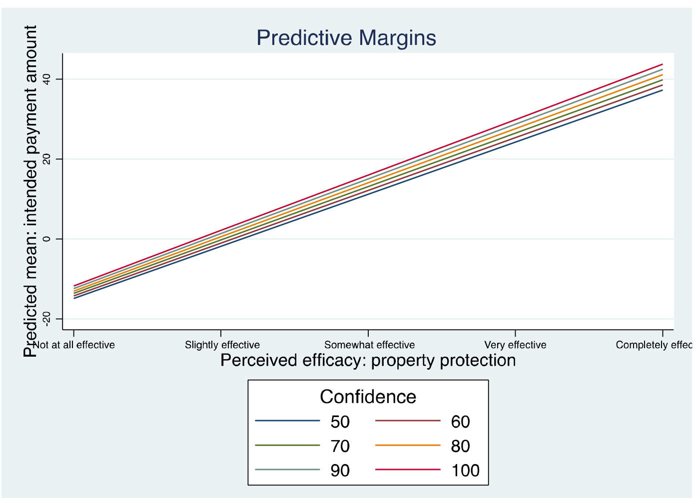
Predictive margins for property protection

Risk perception principal component variables

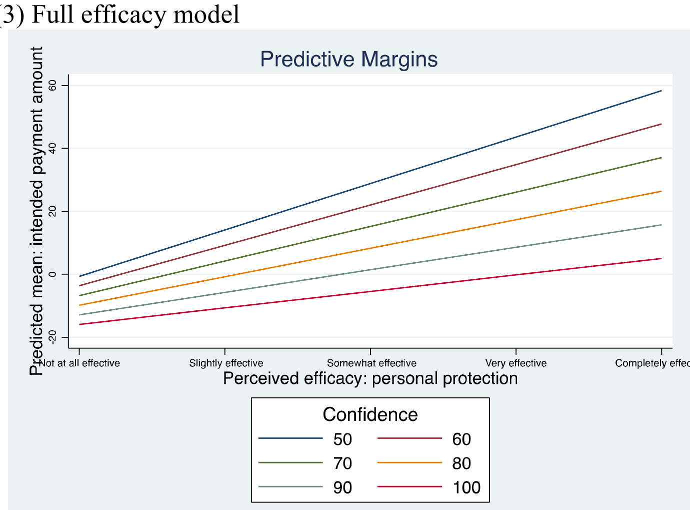
(1) Perceived efficacy for personal protection



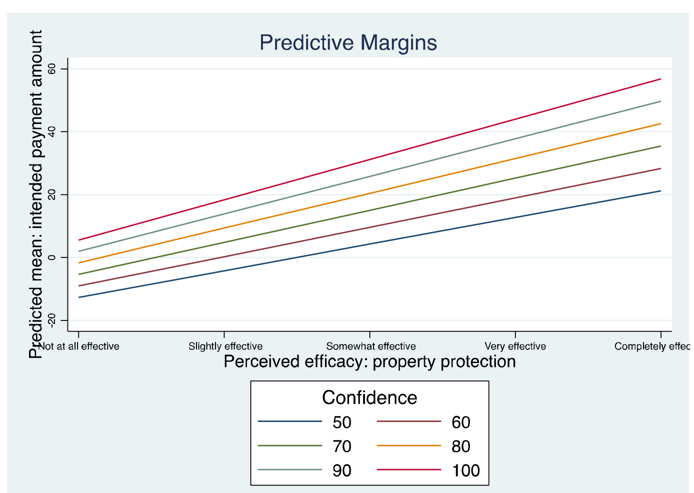
(2) Perceived efficacy for property protection



(3) Full efficacy model



Predictive margins for personal protection



Predictive margins for property protection

Chapter 3. PERCEPTION OF EARTHQUAKE RISKS AND DISASTER PREVENTION AWARENESS: A COMPARISON OF RESIDENT SURVEYS IN SENDAI, JAPAN AND SEATTLE, WA, USA

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Abstract

Both Sendai City in Japan and Seattle-King County (hereafter referred to as “Seattle”) in Washington State in the United States are in seismically active areas with high earthquake risks. An Earthquake Early Warning (EEW) system has been publicly available in Japan since 2007. The

ShakeAlert system on the U.S. West Coast is still being developed and was at the time of this study being rolled out to provide earthquake early warning to institutional and public users. Given the high costs, concomitant need for public funding, and protective behavior aims of EEW systems, a better understanding of how society and individuals perceive the system and how they react to alerts is crucial to maximize the benefits of EEW. In this study, we compared how Sendai and Seattle residents perceived earthquake risk and EEW effectiveness, as well as their willingness to pay (WTP) for an improved (Sendai) or newly adopted (Seattle) EEW system. Similarities in the risks of megaquakes and the differences in recent events and earthquake early warning implementation enabled us to test the extent to which associations between earthquake risk perceptions, risk preparedness, and support for government policies to reduce earthquake risks can be generalized across these contrasting conditions. We found that risk perceptions and perceived effectiveness of EEW in personal protection were significant determinants of WTP for an (improved) EEW system in both regions. However, the association of "fear" with earthquakes was a significant predictor of WTP only in the Seattle survey. One possible explanation for this is that emotional reactions to earthquakes were more varied in the Seattle sample than Sendai, likely due to the much milder earthquakes that have occurred in the Pacific Northwest of the US in recent decades than in Japan. In contrast, most Sendai respondents reported that they felt danger and fear in their recent earthquake experiences.

Keywords

Earthquake Early Warning, Risk perception, Risk communication, Willingness to pay

1. Introduction

Sendai City is located on the Pacific coast of the Tohoku region of Japan and has a history of repeated experience of earthquakes and tsunamis. There are active faults in and near Sendai, which has also experienced rare high-risk disasters, like the Great East Japan Earthquake of 2011. Meanwhile, King County of Washington State, which includes the metropolitan area of Seattle, is located on the active faults of the Cascadia Subduction Zone in the Pacific Northwest region of the United States (the Seattle-King County area is hereafter referred to as "Seattle")[1]. Both are major urban areas in close proximity to coasts and located in active earthquake zones, where residents are likely to have prior earthquake experience.

Although earthquake forecasting is not possible, an earthquake early warning (EEW) system can provide a warning that arrives a few seconds to a few minutes before strong shaking starts, which allows those receiving the warning to take protective action. EEW is publicly available in some countries that face high earthquake risks, such as Japan, Mexico, Romania, Italy and now on the U.S. West Coast [1,2,3]. The U.S. Geological Survey had as of May 2021 rolled out the ShakeAlert earthquake early warning system (EEWS) in all three U.S. West Coast states to provide alerts to institutional and public users (www.shakealert.org); rollout had not occurred in Washington state at the time of this study. ShakeAlert and other robust EEWS operate as a network of seismic monitoring and alerting systems; ShakeAlert relies on sensor data from the Advanced National Seismic System.

Geographically distributed ground motion sensors in the system detect primary waves (also known as *p waves*) from earthquakes and send the information to computer servers where the signals are processed and alerts sent out to alert delivery providers, who then convey the alerts to subscribers or activate automated response systems (e.g., slowing down trains). The secondary waves (*s waves*) caused by earthquakes are what cause potential damaging shaking; they travel slower than the *p* waves, thereby allowing EEW alerts sent at the speed of light to provide seconds to tens of seconds of warning. The farther away the epicenter of the earthquake is from a location, the longer the lead time between the alert and the arrival of potentially damaging shaking at that location.

In countries that have a running EEWS like Japan and Mexico, alerts are sent out as Wireless Emergency Alert (WEA) messages on radio, television, public sirens and now smartphones. Tens of seconds before the strong shakings of the 2011 Great East Japan Earthquake arrived in the Tohoku region, the Japanese Meteorological Agency issued EEW alerts to the public that were immediately disseminated via TV, radio, and mobile phones [4,5]. A survey study in Japan also found that about 80% of respondents who received EEW alerts prior to the 2011 earthquake were able to take protective action [6].

In U.S. West Coast states, the EEW alert system called ShakeAlert currently uses Wireless Emergency Alerts and smartphone apps such as MyShake and QuakeAlertUSA to deliver alerts to the public. Alerts are also utilized by many hospitals, transit systems and utilities to trigger automatic responses (e.g., slowing down trains) in the event of strong shaking [3].

One difference in circumstances between Sendai and Seattle at the time of our survey was that an EEWS had been publicly available since 2007 in Japan, while in Washington state, EEWS was under development and was not widely available. Successful development and operation of a robust EEWS like ShakeAlert requires large investments in technology and infrastructure. Covering such high costs requires public funding, at least partially if not entirely, for which reason public consensus and support are indispensable. At the same time, the goal of EEWS is to facilitate protective behavior and enable automated responses when strong shaking is expected. Therefore, a better understanding of how society and individuals perceive the system and how they react to alerts is crucial in order to maximize its benefits of earthquake hazard mitigation. Further, cross-national comparative disaster research has long been considered essential and a source of critical insight, given the increasing consequences of disasters globally [7]. The comparative research reported here addresses these needs.

1.1 Research aims and questions

To contribute to a better understanding of how society and individuals perceive the system and how they react to alerts we report survey research examining whether previous findings regarding perceptions of earthquake risks and EEW [8] hold in the two contrasting cases of Sendai and Seattle. Both Seattle and Sendai are near subduction zones, but differ with regard to recent earthquake activity and public availability of EEW.

Sendai has seen more frequent shakings in recent years, including the destructive magnitude-9 Great East Japan Earthquake and Tsunami of 2011 as well as the 1978 and 2005 Miyagi earthquakes of magnitude 7.4 and 7.2, respectively. Seattle, by contrast, has had fewer shakings in recent decades, with only five earthquake events at or exceeding magnitude 5 since 1965, and the magnitude-6.8 Nisqually Earthquake of 2001 being the most recent one [9]. The similarities in the risks of megaquakes and the differences in recent events and availability of EEW across Sendai and Seattle enable examination of the extent to which associations between earthquake risk perceptions, risk preparedness, and support for government policies to reduce earthquake risks can be generalized across these contrasting conditions. To this end, we conducted surveys in both Sendai and Seattle.

As noted above, our surveys investigated how residents of Sendai and Seattle perceived (1) earthquake risks and (2) EEW effectiveness, and (3) how willing they were to pay (WTP) for an EEW app for smartphones (Seattle) or an improved EEW app (Sendai). More specifically, we asked:

1) How do perceptions, past experiences and expectations about earthquakes compare between Sendai and Seattle residents? What is their level of disaster prevention awareness and what actions have they taken to prepare for earthquakes? How do intended and actual behaviors at the time of an earthquake and for emergency preparedness differ between residents of Sendai and Seattle?
2) Do people perceive earthquake early warning that might alert them a few seconds or a few minutes before shaking starts to be useful for personal protection in both regions? Do perceptions of EEW effectiveness as a method of mitigating earthquake risks vary in the two regions based on whether it is already available?
3) Are people willing to pay for EEW? Are the variables previously found to predict protective action intentions associated with willingness to pay for EEW in both cities?

2. Predictors of Risk Perception and Protective Action Intentions

Despite the risk of earthquakes that communities in regions like Sendai and Seattle share, residents often display varied levels of risk perception, perceptions of effectiveness regarding hazard mitigation measures, preparedness, and willingness to pay for protective measures. Some residents in high-risk areas are highly prepared while others are underprepared for earthquakes [8,10,11,12]. Similarly, some residents are willing to pay more for protective measures against hazards than others [8]. Individuals process and interpret the information associated with natural hazard risks and uncertainties in various ways, and also vary in their perceptions of risk and behavioral intentions and outcomes [13,14].

Prior research suggests that a complex web of variables explain risk perceptions and behavioral intentions and outcomes [15]. Experience of a natural hazard disaster, among other things, is shown to influence risk perceptions for that particular hazard [8,16,17,18]. Experience can serve as a source of heuristics to reduce uncertainties in one’s mind [19]. One such heuristic is the affect heuristic, when emotional responses substitute for cognitive risk assessment [20]. The emotions felt during an earthquake may later be used to assess the risk associated with earthquakes, with unfavorable emotions such as dread or fear tending to lead to high perceived risks [21,22]. Individuals could also use availability or anchoring heuristics, basing their assessments of risk on prior experiences [22], or an initially presented value [19]. It follows that the intensity and frequency of natural hazard experiences, such as earthquakes, and the emotions associated with such experiences are likely to affect people’s assessments of future risks.

Risk perception and experience are among the key predictors of preparedness [15,23,24,25,26]. In prior studies, predictors such as the attributes of the hazard itself and the resources required for preparing for it have often been highly correlated [25,27,28,29]. Furthermore, individuals’ perceptions of how effective a given hazard mitigation measure is in offering protection against a natural hazard vary, and tend to be associated with preparedness [25,27,29,30,31,32]. In addition to being associated with preparedness, perceptions of risk and of the effectiveness of risk mitigation measures such as earthquake early warning have been associated with willingness to pay for such measures [8,33].

Previous survey-based studies have found that most people in Japan consider EEW to be helpful [6,34]. These studies emphasize the importance of pairing an EEW system with public education and training in order for the system to effectively enhance public safety in an earthquake situation. A survey-based study previously conducted in Washington state also found that most people perceived EEW likely to be helpful for personal protection in an earthquake [8]. In this study, respondents with previous earthquake experience also perceived a higher risk of being personally harmed by an earthquake than did those without earthquake experience.

Willingness to pay (WTP) estimation is a technique widely used to assess the value of a nonmarket good. For example, WTP has been used to assess the value of other hazard early warning services [35]. It is generally estimated using contingent valuation or choice experiments [36]. Given the known susceptibility of stated WTP responses to various framing effects (e.g., anchoring [37]) the responses to the question of WTP in this study were elicited as—and are interpreted as—a relative expression of interest and support in EEW, rather than as an accurate or reliable measure of how much someone might pay for EEW.

3. METHODS

We conducted the present study in accordance with the guidelines of the Declaration of Helsinki and all other applicable guidelines. The protocol for the survey of Sendai residents was reviewed and approved by the institutional review board of Tohoku University Graduate School of Medicine (IRB ID:2019-1-725) and Tohoku University International Research Institute of Disaster Science (IRIDeS). The procedures and contents of the study conducted in Seattle, Washington were reviewed and approved by the institutional review board of the University of Washington (IRB ID: STUDY00002942).

3.1 Measures and data analysis

Measures of risk perception, risk preparedness, and perceptions of hazard mitigation efficacy were derived from the studies described above, previous research on protection motivation theory and on fear appeals [38], efficacy [39], and mental models of hazardous processes [13,40].

As mentioned in the previous section, Dunn et al. [8] found the following determinants to be significant predictors of WTP: earthquake experience, prediction of harm caused by earthquakes, feeling of fear in association with earthquakes, perceived effectiveness of EEW, and income. All of these items were included in the Seattle survey.

In the Sendai survey, we adjusted some of the variables to better reflect the different circumstances. Instead of earthquake experience, which most people had in the Sendai area, we asked about previous experience of damage from earthquakes. Survey items measuring civic “trust” and “fairness” were also included in the Sendai survey. Social capital constructs such as civic trust (e.g., “Can you trust most other people?”) and fairness (e.g., “Would you try to take opportunities to do well or try to act fairly?”) have been associated with disaster preparedness and recovery in prior studies [41,42,43,44]. These variables were added to the survey as possible alternative explanations for willingness to pay for higher accuracy of the current EEW system in Sendai.

Our dependent variable, willingness to pay for EEW, was measured as the amount a respondent reported being willing to pay for an earthquake early warning app (Seattle), or the amount a respondent reported being willing to pay for an improved early warning app (Sendai) on a smartphone. Three different forms of this dependent variable were used in our models:

1. The raw WTP, excluding (i.e., trimming) the top 5% reported WTP values applied to the Sendai data but not the Seattle data; and
2. A binary WTP variable generated by splitting WTP at the median (0 if below median, 1 if equal to or greater than median)
3. A binary WTP variable generated by splitting WTP at zero (0 if reported WTP is zero, 1 if reported WTP is greater than 0)

All three approaches address the skewed distributions of the WTP responses as previously mentioned. In the first approach, eliminating the few very high outliers that are reasonably presumed to be protest responses helps lower the mean closer to the median. The second approach, using a binary WTP that splits WTP responses at the median, also resolves distributional concerns about a big difference between the mean and the median. The purpose of the third approach is similar to that of the median-split WTP approach and in a linear probability model, this approach allows us to interpret the coefficients as a change in the probability that an individual would be willing to pay anything at all, i.e., a non-zero amount.

Analysis of the Seattle data was conducted using STATA 16, and analysis of Sendai data used R version 3.6.2. To assess correlates of WTP, we conducted two analyses. First, we conducted mean difference analyses using two-sample t-tests where applicable, for example to examine differences in WTP between men and women, or between those who had previously experienced an earthquake and those who had not. For non-binary variables of interest, we examined their pairwise correlations with WTP. Second, we conducted linear regression analyses (generalized linear models) to examine the associations between the hypothesized variables and the three forms of the WTP variable.

The model specifications for Sendai and Seattle are provided in Appendix 3.1. All variables used in this study are described in detail in Table 3.2.

Our choice of generalized linear models was for ease of interpretation. However, we also included results from a logistic regression model to demonstrate that the results are highly similar. We also treated our ordinal independent variables as continuous in our models for the same reason[2].

3.2 Data collection

Data from Sendai City residents were obtained through an online mobile phone survey implemented by Docomo Insight Marketing Co., Ltd.; questionnaire requests were sent to users who had contracts with NTT DOCOMO, one of the major telecommunications companies in Japan. The sample was recruited on an opt-in basis that allowed us to secure a large sample size efficiently, i.e., at a low cost in a short period of time. The survey was distributed to 27,653 people that opted to take surveys on the platform, with valid responses from 3,040 people, for a response rate of 11%. A comparison of demographics between the sample and population is provided in Section 4 (Results) below. The survey period was between Sept. 20 – Sept. 22, 2018.

Data from Seattle were obtained through two waves of online surveys in 2018, of which the first wave ran from March 1 to April 11 and the second from May 22 to June 25. The target population consisted of individuals age 18 or older, residing in King County, WA. For each wave, we purchased a random sample of local mailing addresses from Survey Sampling International (SSI) that was drawn from a sampling frame of addresses covering over 95% of postal households. Each household address in the sample came with a name and demographic information. Invitations to participate in the survey were mailed in letter form to a sample of 5,000 randomly selected households in King County in the first wave. In the second wave, survey invitations were sent out to another 2,443 households of a separate random sample, and a one-dollar bill was enclosed in the invitation letters to incentivize response. Three follow-up postcards were mailed to encourage participation in each wave. Each mailing included an individualized URL for the named household member to participate in the survey online. A total of 407 surveys were completed submitted online for Wave 1 (8.1% response rate) and 429 for Wave 2 (17.6%). Data from the two waves were merged for this analysis. We report results from the full King County dataset here, and refer to the area as Seattle, with 41% of the sample having reported residing in Seattle.[3]

3.3 Data availability

All of the data used in the study are available upon request.

4. RESULTS

In this section, we present our descriptive statistics for the samples and variables of interest, and the results from our generalized linear models, guided by our research questions. The model outputs identify the factors that are associated with willingness to pay for EEW in the two cities. For each research question, results from Sendai and Seattle are presented first separately, then compared and discussed.

4.1 Sample demographics

Table 3.1 compares the demographics of our samples with the populations in the two regions. The median age group of our Sendai sample is 45-49 years, which is lower than that of the population of Sendai for ages 20 and older. The median age of our Seattle sample is higher (53 years) than the population, with the median age group for residents who are 20 years old and older is 40-44 years. The percentage of female respondents in Seattle is noticeably lower than that of the population, while the Sendai sample includes a slightly higher percentage of females than the general population of the region. The median annual household income level is higher in the sample than in the population for both regions.

4.2 Earthquake experience, risk perceptions and preparedness in Sendai and Seattle

4.2.1 Earthquake experience

The vast majority (90%) of Sendai respondents reported that they had personally experienced an earthquake in which they felt danger. Of those, 94% had experienced the Great East Japan Earthquake in March of 2011 (see Table 3.3a). A majority (62%) of all Sendai respondents had experienced an earthquake with strong shaking that had caused damage.

Similarly, the vast majority (88%) of Seattle respondents reported having previously experienced one or more earthquakes. However, in contrast to Sendai, only 26% of those who had experienced an earthquake reported that the shaking during their one or most memorable earthquake experience was strong (23%) or violent (3%). Of the 741 respondents who shared the year and city of their earthquake experience, 65% identified a city in western Washington state. About 14% of them mentioned “Nisqually”, a 6.8-magnitude earthquake of 200 that shook the Puget Sound area including Seattle and Olympia. A small number (less than 1%) of the respondents mentioned the Northridge or Loma Prieta quakes in California, which were similar to the Nisqually earthquake in magnitude. Consistent with such responses, 56% of the respondents said the earthquake they felt involved either mild or moderate shaking.

4.2.2 Actual versus hypothetical response to earthquake (behavioral and emotional)

When asked what action they would take if they experienced an earthquake indoors, 34% of Sendai respondents replied that they would “stop what they are doing and keep still,” followed by “drop cover and hold on” (21.8%), “turn off the gas or open a window (16.3%) and “try to protect people, pets, or property nearby" (16.1%). Those who said they would exit or get away from the building made up 9.4% of responses (Table 3.3b).

Of the Sendai respondents who had actually experienced an earthquake in which they felt danger, 42% reported that their response had been to "stop what I was doing and keep still," 18.6% reported their response as "drop, cover and hold on" (18.6%), 14.8% as "protect people, pets or property nearby", and 12% as "exit/get away from the building". Only 5.5% said their response had been to "turn off the gas or open a window."

When asked about how they felt when thinking about experiencing an earthquake, 29.8% of all Sendai respondents said extremely frightened, 34% said they felt very frightened, and 29.5% said somewhat frightened. However, of the respondents who had actually experienced an earthquake where they felt danger, 44.6% reported feeling extremely frightened, 36.8% were very frightened, and 14.6% were somewhat frightened.

In Seattle, nearly 55% of respondents who had no experience with earthquakes reported they would "drop, cover and hold on" if they were to experience an earthquake. Only 7% of the respondents with no earthquake experience reported that they would "stop what they were doing and stay put". However, similar to Sendai, the most common first response reported in response to actual shaking among those with earthquake experience in Seattle was to "stop what they were doing and stay put" (36%). This was followed by "drop, cover and hold on" (22%) and "immediately leave the building" (16.1%). In terms of emotions, 65% of those who had not experienced an earthquake reported that they felt somewhat (48%) or extremely (17%) frightened when they thought about being in an earthquake. However, only 46% of those who had experienced an earthquake reported that they had felt somewhat (39%) or extremely (7%)

frightened in the earthquake they actually experienced; 30.4% reported “Excitement” as their actual reaction to their earthquake experience.

In sum, the behavioral and emotional responses of those who had faced the reality of an actual earthquake differed from the subjectively predicted behaviors and emotions. Moreover, only about a fifth of respondents with earthquake experience had taken the recommended action--to drop, cover and hold on, across both Sendai and Seattle.

4.2.3 Risk perception: likelihood of earthquake in the region, personal harm from earthquake

Almost half (47.3%) of Sendai respondents felt that their chance of experiencing an earthquake in the next year was “about as likely as not (33% to 66% chance),” followed by 40.7% who thought it was “likely (more than 66% chance).” (Table 3.3c) When asked to estimate the likelihood that an earthquake would harm them in the next year 13.3% answered “likely (more than 66% chance),” whereas 59.5% answered “about as likely as not (33% to 66% chance),” followed by 16.7% who answered “unlikely (less than 33% chance).”

Results were similar in Seattle (see Table 3.3c), although the time frame provided for the hypothetical question was five years, as compared to a single year for the Sendai survey. When asked about how likely they were to experience an earthquake in Washington State in the next five years, approximately 44% of respondents chose “likely (more than 66% chance),” and 35% of respondents selected “about as likely as not (33% to 66% chance).” Only 9% of the respondents said that it was either “very unlikely (less than 10% chance) or “extremely unlikely (less than 0.1% chance).”

In contrast to Sendai and despite the five-fold longer time frame, only 7% of Seattle respondents replied that it was “likely (more than 66% chance)” that they would be harmed in an earthquake, while 28% judged this “about as likely as not (33% to 66% chance).” Slightly more than half of Seattle respondents said a Washington State earthquake was either “unlikely (less than 33% chance)” or “very unlikely (less than 10% chance)” to harm them in the next five years (30% and 27%, respectively).

4.2.4 Emergency preparedness

Of Sendai respondents, 68.2% prepared a supply of water and emergency food, 48.9% had prepared a first aid kit, and 60.3% had a battery-powered radio. 46% had earthquake insurance, 23% had identified a safe place, and 21.2% had made an emergency plan as a family or individual. 8.8% had not taken any emergency measures listed in the question (see Table 3.3d).

Of the Seattle respondents, 73% reported that they kept a stocked first aid kit. In addition, 68% reported having a supply of water and non-perishable food for an emergency, and of those more than 98% had a three-day supply or more (see Table 3.3d for percentage of respondents selecting other items). Eleven percent reported not having any emergency preparedness measures listed in the question, while only 4% said they had all six measures available at home. Having three out of the six items listed was the most common (23% of respondents), followed by two (20%) and four items (19%).

4.3 Effectiveness of EEW in personal protection

About 60% of Sendai respondents assessed EEW as effective personal protection against the risk of death (10% strongly agreed and 50% agreed with *Does Earthquake Early Warning* *provide good protection for yourself from earthquake risks, including death? (a few seconds from the warning)*). More than 90% of respondents in Sendai felt that seismic reinforcement was effective (strongly agreed or agreed with *Do you think that earthquake disaster prevention and mitigation efforts such as seismic reinforcement of buildings reduces the risk of death from an earthquake?*).

In Seattle, as compared to Sendai, a higher proportion of respondents—80%—agreed (52%) or strongly agreed (28%) that EEW would help protect them from earthquake risks including death. Similar to what was found in Sendai, however, a significantly higher proportion (96%) in Seattle agreed or strongly agreed that structural hazard mitigation reduces the risk of death from earthquakes.

4.4 Willingness to pay for EEW and its determinants

4.4.1 Willingness to pay for EEW

Respondents in Sendai and Seattle were asked directly how much they were willing to pay for EEW. However, given that Japan already had a publicly available early warning system while Seattle did not, the question was phrased differently in the two cities. For Sendai residents, we asked: *What is the most you would be willing to pay per month for a more accurate and detailed earthquake early warning system than the current one?* Seattle residents were asked: *What is the most you would be willing to pay per month for an earthquake early warning app on your smartphone or personal computer?* Accordingly, the amounts reported by Sendai respondents should be interpreted as being for improvements in the existing system while the amounts from the Seattle survey are for access to earthquake early warning. In Seattle, the survey item prompting one's willingness to pay per month for an EEW system asked for a dollar amount in the range of $0 to $10, while the amount was not capped in the Sendai survey.

As reported in Tables 3.4a and 3.4b, the majority in both cities supported (better) earthquake early warning, although fewer respondents in Sendai opted out of paying (23% selected a zero amount) as compared to in Seattle (33.8% selected zero). In both cities the distribution is highly skewed, with the median WTP amounting to less than half the value of the mean. In Sendai the median WTP was ¥300, or around $3 (Table 4a; about $2.70 using the average USD-JPY exchange rate for 2018), whereas the median WTP in Seattle was $1 (Table 3.4b).

4.4.2 Descriptive statistics by key determinants related to WTP

Before conducting our regression analysis, we evaluated the mean differences in WTP by major determinants. A visual examination of the Sendai data showed a U-shaped relationship between age and WTP. In other words, young (age group 20-39) and older people (age group 60 and over) had a higher willingness to pay than the middle-aged (age group 40-59) (Figure 3.1). However, two-sample t-tests conducted for the three age groups (20-39; 40-59; and 60 and over) showed significant differences in the mean WTP only between the groups 40-59 and 60 and over ($t(1993)=-4.771$, $p<0.001$). There was almost no difference by sex, and also very little difference by income (Figure 3.2b and 3.2c). There was also no difference based on whether respondents had experienced an earthquake or not. However, as noted above, most respondents in Sendai had not only experienced an earthquake, but the vast majority had experienced a severe and frightening earthquake, and therefore there was not very much variation in their experiences. With this small amount of variation, little association with other variables was detected. Based on these data alone, it may not be possible to evaluate the meaningfulness of experience in a practical sense.

The U-shaped trend in WTP by age seen in Sendai was not evident in the Seattle data. Respondents in their early 20s had a zero mean WTP while older respondents tended to report higher WTP values. The correlation between age and WTP was r=0.0812 (p=0.023). Female respondents reported a slightly higher mean WTP ($2.49) than males ($1.91). A t-test showed the mean WTP for females to be significantly higher than males by $0.58 ($t(787)=-2.72$, $p=0.007$). Figure 3.3 shows the mean WTP by age and sex.

The mean WTP of the highest income group ($2.56) was about a dollar higher than that of the lowest income group ($1.50). We observed only a slight difference in the mean WTP by earthquake experience in Seattle surveys (Figure 3.4). Those with experience reported a mean of $2.10 while those without reported a mean WTP of $1.92, although a t-test did not indicate a significant difference between the two groups (Figure 3.4).

There was, however, a clear increase in the mean WTP as perceived likelihood of being harmed by an earthquake increased in both Seattle and in Sendai. In Seattle, the mean WTP for those who said harm from an earthquake was "extremely unlikely" was $1.11 and it increased with each likelihood category to an average $2.76 WTP for the highest category ("likely"). The correlation between WTP and perceived likelihood of being harmed was 0.17 ($p<0.01$). In Sendai, those who reported the highest perceived likelihood of harm reported a mean WTP of 457 yen, while lower perceived likelihood of harm was associated with lower mean WTP (Figure 3.2a).

Furthermore, both Sendai and Seattle residents who perceived EEW to be more effective for personal protection showed a higher mean WTP. Those who "strongly agreed" that they would be better able to protect themselves from earthquake risks with EEW had a mean WTP of $2.88 compared to $1.74 for those that "strongly disagreed" in Seattle (see Figure 3.5 for mean WTP by perceived likelihood and perceived effectiveness). The correlation between these two variables was r=0.18 (p<0.001).

In Sendai, mean WTP was also higher for those who perceived EEW to be effective for personal protection (Figure 3.2c). Further, as civic trust increased, mean WTP also increased (Figure 3.2d).

4.4.3 Generalized linear models

In the Sendai model with the top 5% WTP values trimmed (see Table 3.5, Column (1)), "age", "prediction of harm caused by the earthquake of next year", "EEW effectiveness (in reducing mortality risk)", and "trust" significantly predicted WTP. With each year of age, WTP increased by about 2.7 yen. A one-point increase on the response scale for the perceived likelihood of harm caused by an earthquake in the next year was associated with an additional WTP of ¥51. With a one-point increase in perceived EEW effectiveness for reducing deaths, willingness to pay increased by about ¥35. A one-point increase in trust was associated with an increase in willingness to pay by about ¥24.

In the median division model, "sex", "age", "prediction of harm caused by the earthquake of next year", and "trust" were associated with willingness to pay, all else equal (Table 3.5, Column (2)). Each of these has a small positive coefficient. In both models, earthquake experience (earthquake danger experience in the Japanese survey) and experiencing fear were, unexpectedly, not associated with WTP, after controlling for the other variables. In both cases, it is possible that there was insufficient variation in these independent variables because in Sendai, over 80% of people reported having experienced fear.

To test the robustness of our models, we also tested a model with the dependent variable as a binary WTP variable split at zero (i.e., whether a respondent is willing to pay anything) instead of the median to further test for robustness (Table 3.5). Perceived effectiveness of EEW in protecting oneself and preventing injuries were both significant predictors for WTP split at zero for the Sendai data, while they were not significant in the median split WTP model. We also tested the binary (median-split and zero-split) WTP models using logistic regression to ensure that the linear probability modeling results were robust; the resulting signs of the coefficients and significance for each variable did not differ from the GLM model (Table 3.5, Columns (3) and (5)).

In the Seattle survey, respondents were asked to report an amount they were willing to pay for EEW in the range of $0 to $10. This bounding eliminated any potential need to trim the WTP responses. As with the Sendai models, we ran models using as dependent variables both the complete WTP data (Table 3.6, Column (1)) and WTP binary categories that split responses at the median and at zero (Table 3.6, Columns (2) and (4)). Our generalized linear models did not include weights or imputed data. The results of our model with the WTP split at zero were consistent with the results from the median-split model (Table 3.6, Column (5)). In addition, we tested the binary WTP models of Seattle using logistic regression; the resulting signs of the coefficients and significance for each variable did not differ from the GLM model (Table 3.6, Columns (3) and (5)).

Consistent with the results from Sendai, “likelihood of harm from earthquake” and “age” were significant. A one-year increase in age was associated with a 2-cent increase in WTP on average, controlling for all other variables. The effect size of perceived likelihood of harm was greater, with an estimated 23-cent increase with each ascending category from “extremely unlikely” to “likely.” Similar to the Sendai results, sex, earthquake experience, and location (residence in or outside Seattle) had little to no association with WTP after controlling for other factors.

In contrast to Sendai, in Seattle-King County data a reported emotional response of “fear” while experiencing or anticipating an earthquake was associated with a higher willingness to pay in both models. The emotional response of “somewhat frightened” or “extremely frightened” to earthquakes was associated with an estimated 61-cent higher WTP than non-fear emotions, all else equal. Also, the extent to which one agreed that EEW could provide personal protection from earthquake risks (including from death) was positively associated with WTP. With a one-category increase on a four-point Likert scale ranging from “strongly disagree” to “strongly agree”, WTP increased by 53 cents. In other words, WTP was considerably higher among those who agreed that EEW would protect them effectively.

In the model with the binary WTP as the dependent variable (Table 3.6, Column (2)), the significant predictors of WTP were similar. Age was significant, although the effect size was small (0.003). Fear-based emotional response to earthquakes had a higher WTP by 13 cents than non-fear responses. Each ascending category of perceived likelihood of harm from earthquakes was associated with a 4.5-cent increase in WTP. Each descending response category for agreement that EEW would provide personal protection in an earthquake decreased WTP by 11 cents. In addition, the binary WTP model also showed that those who expected EEW to be effective in preventing personal injuries in an earthquake were willing to pay 15 cents more on average than those that did not. Perceived effectiveness of EEW in preventing deaths was not a significant predictor in this model, however. Results of the logistic regression (Table 3.6, Column (3)) were consistent with those from the linear regression.

5. Discussion

Sendai and Seattle share a common risk of experiencing subduction zone megaquakes. However, many Sendai residents experienced the magnitude 9.0 Great East Japan Earthquake and Tsunami in 2011, which caused devastation not only within areas of Sendai City, but along the entire coastline of the Tohoku region of Northeast Japan. In this respect, therefore, residents of Sendai generally have a different level of direct experience with a massive and damaging earthquake than do residents of Seattle. In addition, as previously mentioned, Japan currently has a running EEW system that has been issuing advance earthquake early warnings to the public since 2007.

Such varying circumstances between the two regions must be accounted for in understanding our results. As has been noted in recent studies examining the role of experience in risk [18] and hazard [17] research, all too often experience has been undertheorized and reported in conflicting and incomplete ways. In this study we asked survey participants if they had personally experienced an earthquake, but also asked about their emotional response to that experience. We find that the emotion of "fear" in reaction to an earthquake experience is a significant predictor of WTP for an early warning system in Seattle, but not in Sendai. One caveat to bear in mind in interpreting these results is that this question in the Sendai survey was specifically phrased to ask about "an earthquake in which you felt danger" which may have prompted respondents and made them more likely to report a fear response than had they been asked simply about “an earthquake”.

There are at least two compelling explanations for this difference. The first is that the modal earthquake experience in Seattle was a moderate earthquake [8], in contrast to the violent shaking experienced by most in Sendai. A corollary to this is that having experienced stronger earthquakes that induced fear was more commonly reported in Sendai than in Seattle. Little variation was observed among Sendai residents surveyed regarding fear felt during an earthquake, with over 80% saying that they felt fear. By contrast, responses from Seattle were more varied: 40% of Seattle respondents reported feeling somewhat or extremely frightened during their earthquake experience, while 27% said they felt “excitement.”

Similarly, the perceived effectiveness of up to ten seconds of early warning in preventing injuries was a significant predictor of WTP only in Seattle and not in Sendai, where many respondents would have experienced earthquake early warnings. However, in the model with a binary WTP split at zero as the dependent variable, effectiveness of EEW in personal protection and prevention of injuries both had significant, positive associations with WTP, controlling for other factors (note that the response scale of the effectiveness for personal protection variable is from “Strongly agree” to “Strongly disagree” and therefore a negative coefficient indicates a positive relationship). This result could be reflective of the fact that those in Sendai had experienced the effectiveness of EEW, or that the U.S. West Coast did not yet have an EEW for the general public. Seattle responses were most likely based on expectations rather than experiences, while Sendai respondents would have based their responses on their and their friends’ and families’ experiences with early warning in earthquakes. As pointed out previously, 80% of Seattle respondents assessed EEW as being effective in reducing the risk of death, while only 60% of those in Sendai did so. The difference in the regression results of the two regions may suggest that the relationship between efficacy and WTP depends on experience, and that is likely related to the availability of and experience with an EEW system. In addition, much of the human loss due to the 2011 Great East Japan Earthquake was caused by tsunamis rather than the shakings of the earthquake and aftershocks. It is possible that the respondents' perceived effectiveness of EEW was affected by the losses reported from both the earthquake and the tsunami. Further research is needed to validate this point. Future studies concerning perceptions of EEW in this region should also examine people's perceptions of tsunami warnings.

A second possible explanation for differences between Sendai and Seattle with regard to the associations of emotions and effectiveness perceptions with WTP could be sampling. Whereas the Sendai survey was sent to opt-in panelists, the Seattle survey was of a self-selected sample from a random sample of households, albeit with relatively low response rates and possible self-selection bias. This may have resulted in an underrepresentation of some kinds of variability in the Sendai response, although we deem this unlikely. It should be noted, however, that the possible response biases mean that our results may not generalize beyond our sample.

Regarding preparedness, whereas respondents in both cities had made some preparations, our findings demonstrate considerable room for improvement in both cities. This was also the case for the immediate actions of people who had experienced earthquakes in both cities. The gap between predicted and experienced responses to earthquakes revealed a significant opportunity to improve the protective action awareness and practices of both Sendai and Seattle residents to increase the likelihood that they will "drop, cover and hold on" in an earthquake. Similar discrepancies between anticipated and actual responses to earthquakes have been found in other recent studies as well [34,45]. These results suggest that even for people who understand the risk and possibility of experiencing an earthquake, more training may be useful to reinforce the message of "drop, and hold on" as the immediate response.

At the time of this study the Japanese government had already provided standard EEW information to all residents at no direct cost to them. In Japan, people receive alert messages on their cell phones, and the general public is familiar with the EEW system. Therefore, in Japan, our survey questions about the benefits, appropriate provision, and cost of EEW to end users may not have been as salient or meaningful to survey participants (given that the costs were presumably relatively invisible to individual warning recipients), in contrast to the more obvious relevance of the survey questions to the evolving situation on the U.S. West Coast. However, the percentage of Sendai respondents who reported a zero WTP amount for an improved EEW app (23%) was lower than the percentage of respondents not willing to pay anything for an EEW app in Seattle (33.8%).

It is possible that a zero amount reported by Sendai residents indicated satisfaction with the current alerts, and the majority of residents wanted an improved EEW app. In Seattle, a zero amount in reported WTP was likely a "protest response," indicating one's preference against the adoption of an EEW system or one's preference for some other entity to pay for it. A lack of prior experience with EEW alerts at the time of the survey may have affected such protest responses among Seattle respondents.

Given that Japan already had an EEW in place at the time of the survey, the results from Sendai are potentially informative for Seattle regarding the implementation of EEW. However, further research is needed to explain the effect of the availability of EEW on reported WTP. The difference in utility between not having EEW versus getting EEW (Seattle) may be higher than the difference in utility between having EEW versus having a better EEW (Sendai). Another possible effect, in the opposite direction, could be that previous experience with EEW alerts among Sendai residents makes the value of EEW more obvious, and leads survey participants to be more willing to pay for improvements.

The variable “Estimates of damage from next year’s earthquake” in the Sendai survey was a significant predictor of WTP, while the variable “Prediction of damage caused by earthquakes during your lifetime” was not significant. Consistent with Construal Level Theory (CLT) and the related notion of psychological distance, the proximity of “next year” may make it easier for respondents to think concretely about earthquake risks and more likely to consider paying for an improved EEW app, in contrast to the more abstract and distant hypothetical time scales of “within my lifetime” or even “within 5 years” [46]. For Seattle, this suggests that earthquake risk and EEW-related messages that are more concrete and temporally proximate may affect behavioral intentions and attitudes toward EEW differently than abstract and temporally distant messages. The relationship between psychological distance and earthquake preparedness-related behavioral intentions and/or outcomes is an area for future research that could provide useful information for policymakers and implementers in earthquake-prone areas.

In addition, these findings re-affirm that clear communication with diverse publics about the risks of earthquakes and the effectiveness of EEW may increase public support for EEW. As expected, Seattle residents who associated earthquakes with a higher likelihood of personal harm and perceived EEW as more effective tended to report a higher WTP for an EEW app. Public outreach and education about the ShakeAlert EEW system will be most effective when it contains clear and accurate communication about the potential damages from an earthquake in Seattle, including hazards from building structures, along with information about the recommended courses of action upon receiving the alerts, the efficacy of those actions, and the accuracy of EEW alerts [47]. The gap between predicted and experienced responses to earthquakes seen from our surveys shows that there is still significant opportunity to improve the protective action awareness of both Sendai and Seattle residents toward the desired response action of "drop, cover and hold on," as other recent studies have also highlighted [45].

6. Conclusion

Our surveys of Sendai and Seattle residents show that risk perception and perceived effectiveness of EEW for personal protection are significantly and positively associated with their willingness to pay for an (improved) EEW app in both regions. However, we found that having felt fear during previous experience of an earthquake significantly predicted WTP only in Seattle, and not in Sendai. Together, these findings suggest that public outreach and communication to inform the public about the risks and the effectiveness of EEW are likely to improve public support for maintaining and improving the EEW systems, although that support will in part be affected by the earthquakes that the residents of the two regions experience.

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8. Conflict of interest

The authors declare no conflict of interest.

Notes

1. For simplicity, we refer to the Seattle-King County area as "Seattle" hereafter, but it should be noted that our data analyses use data collected from King County, including Seattle.

2. Some of the categories used in our survey items are indeed arguably not equally spaced. However, a likelihood ratio test for models that treat them as continuous variables versus those that include them as categorical (i.e., include each category of the ordinal variables as a binary variable) suggests that the former is justified for parsimony (see Table 3.7).

3. The greater Seattle metropolitan area includes King County, as well as the Snohomish and Pierce counties. We also conducted the same analyses with the subset of only Seattle residents and found that the small differences between the two jurisdictions did not affect the overall conclusions.

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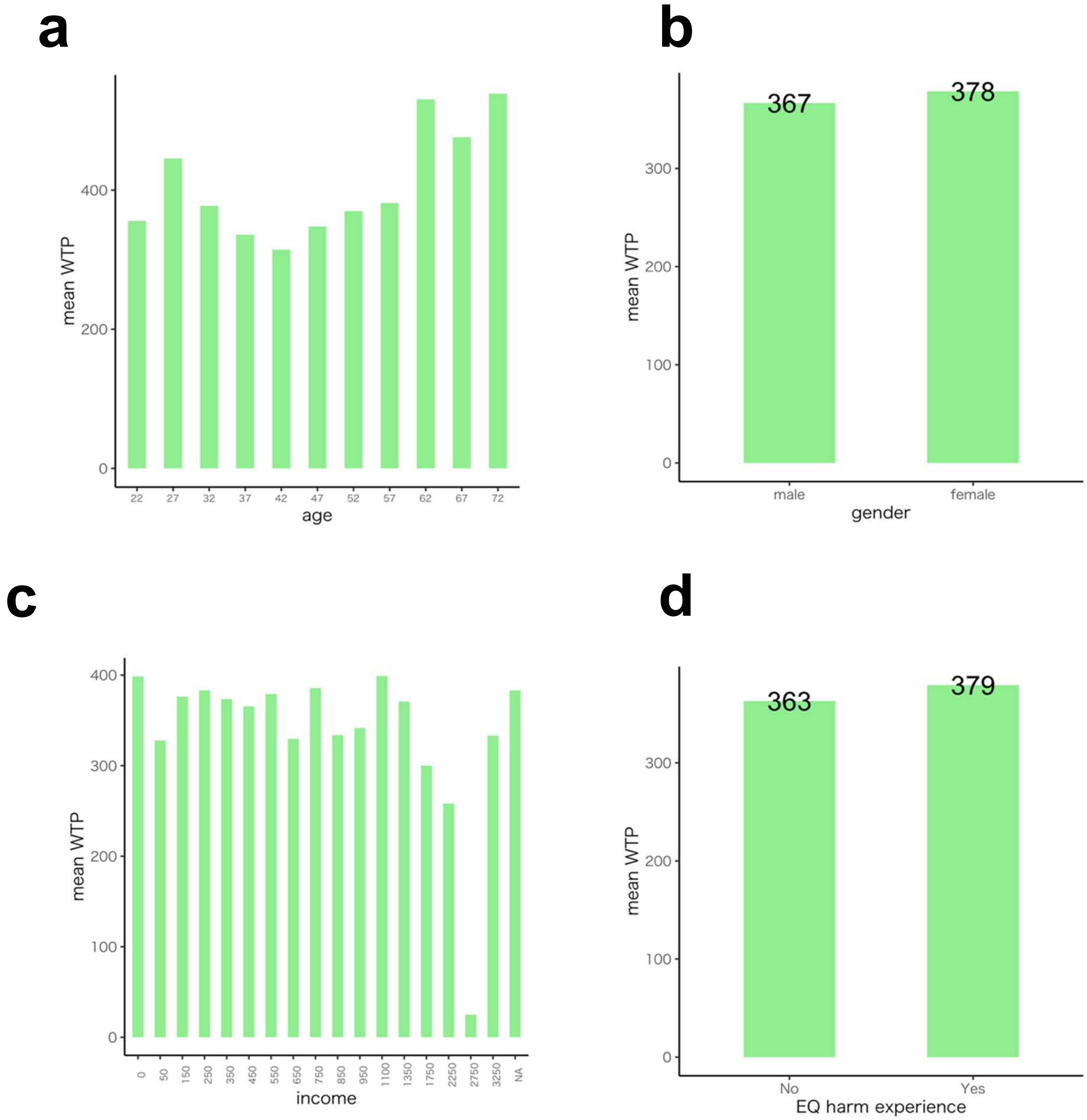

Figure 3.1 Sendai: WTP by age (a), sex (b), income (c) and earthquake harm experience (d)

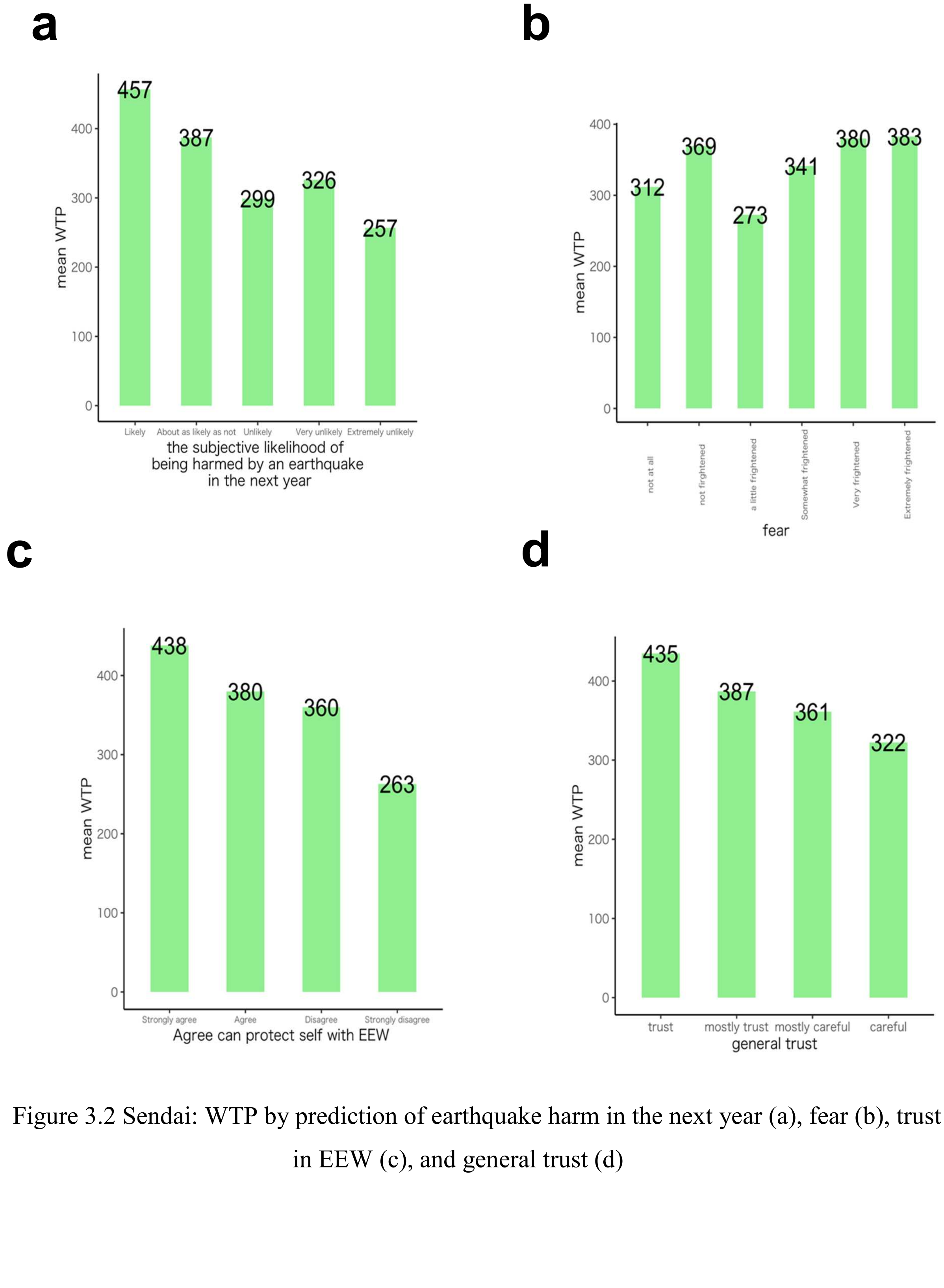

Figure 3.2 Sendai: WTP by prediction of earthquake harm in the next year (a), fear (b), trust in EEW (c), and general trust (d)

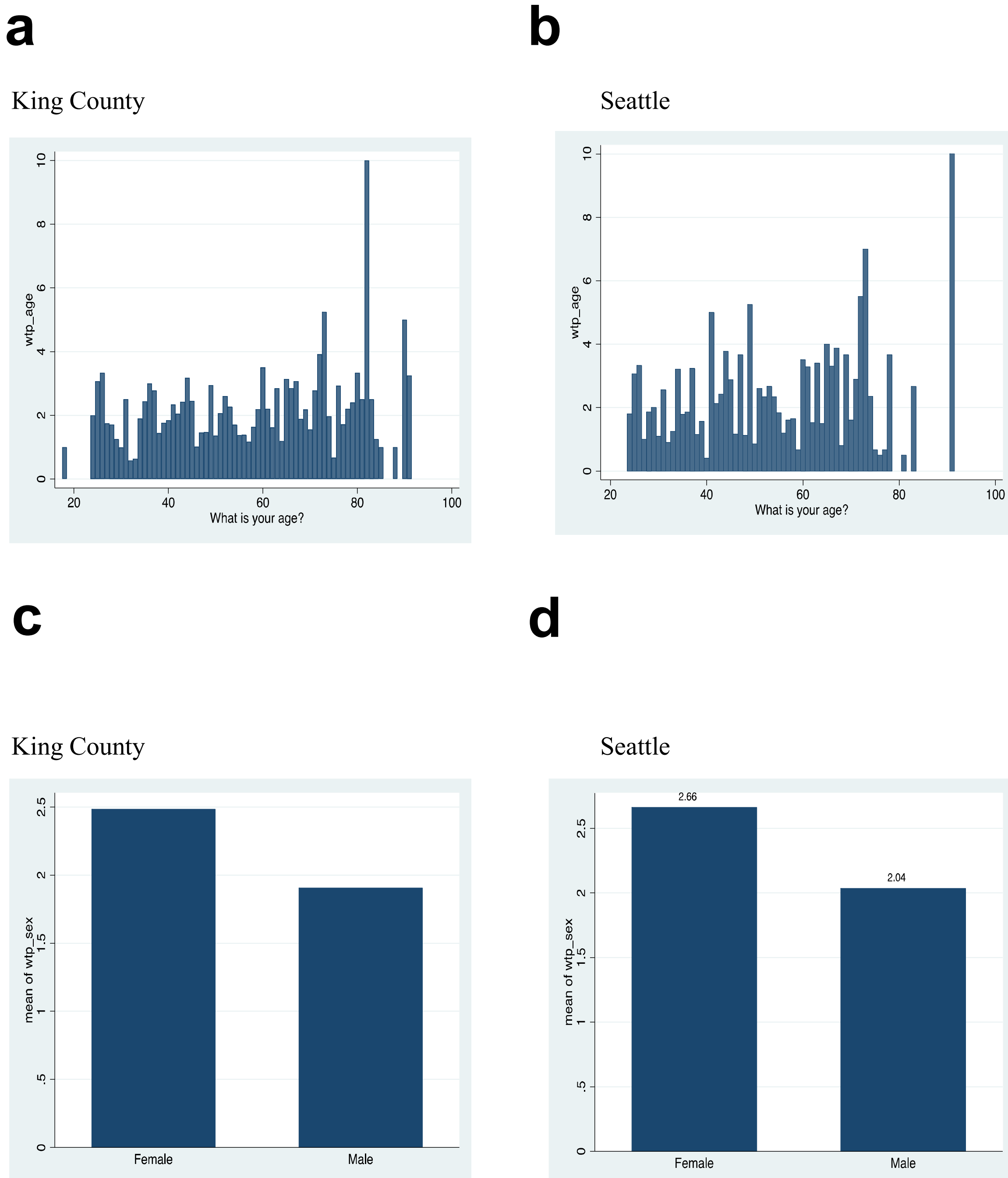

Figure 3.3 WTP by age in King County (a) and Seattle (b), and WTP by sex in King County (c) and Seattle (d)

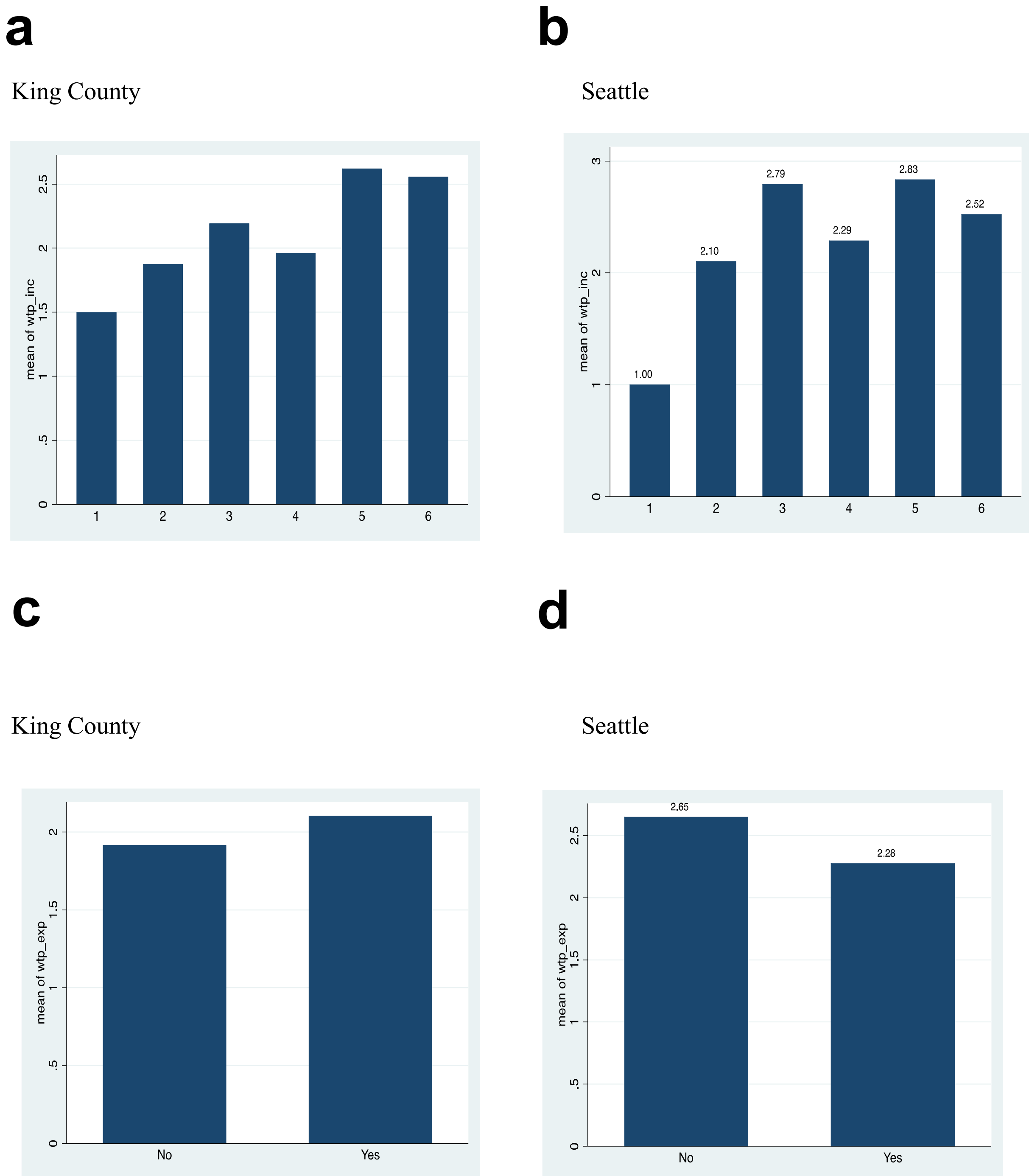

Figure 3.4 WTP by income in King County (a) and Seattle (b), and WTP by earthquake experience in King county (c) and Seattle (d)

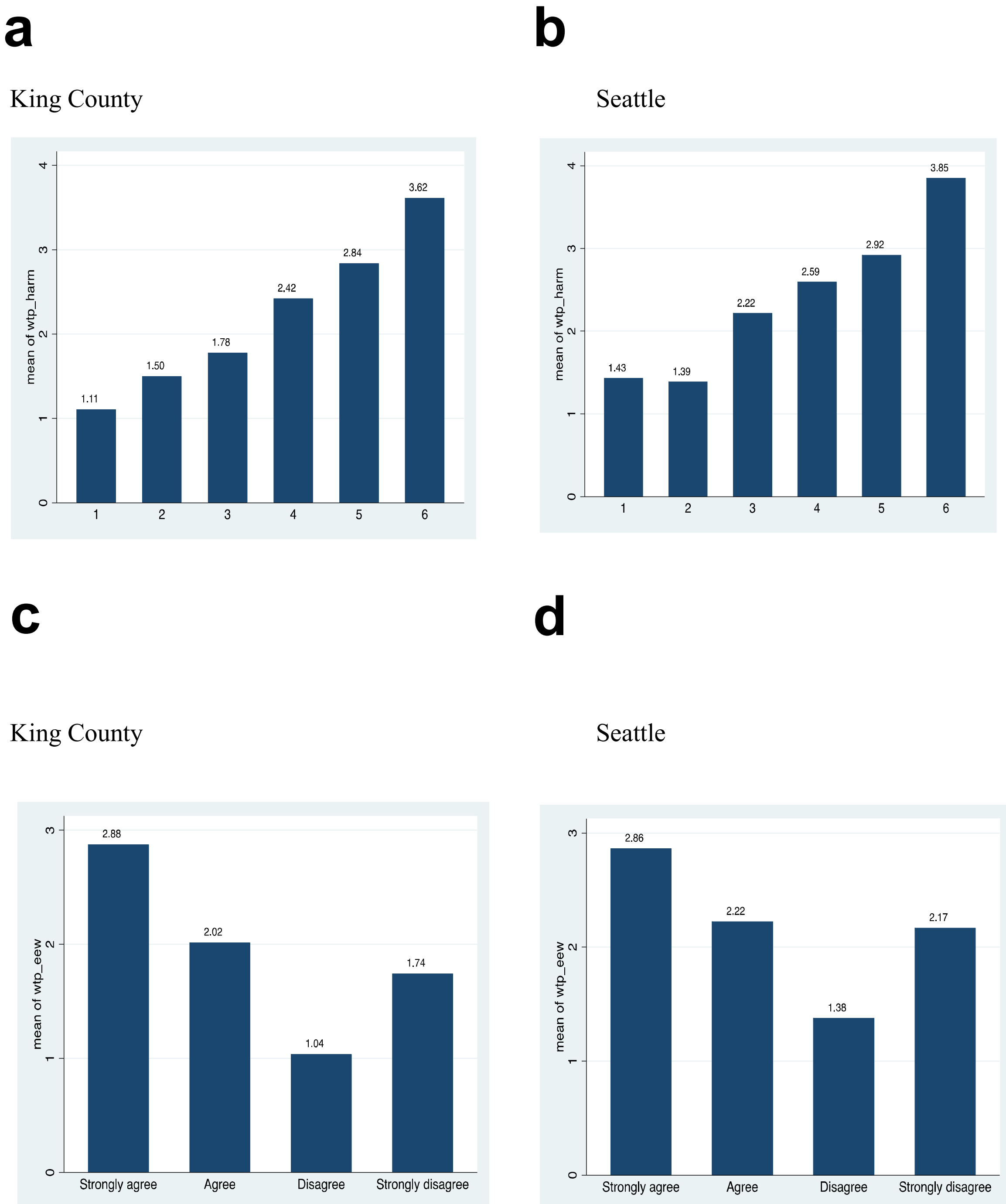

Figure 3.5 WTP by likelihood of harm in King County (a) and Seattle (b), and WTP by perceived effectiveness in EEW in King county (c) and Seattle (d)

Table 3.1 Comparison of demographics between sample and population

	Sendai		Seattle	
	Sample	**Population**	**Sample**	**Population**
Percent female	56%	52%[1)]	37%	51%[2)]
Median age (or age group)	45-49 years	General pop.: 45-49 years[1)] (Pop. of 20+: 50-54 years[1)])	53 years	36.8 years[2)] (Pop. of 20+: 40-44 years[2)])
Median annual household income	7 million yen - less than 8 million yen	5 million yen - less than 6 million yen[3)]	$100,000 - $149,999	$94,974[2)]

1) Source: Sendai City (as of October 2019)
2) Source: U.S. Census Bureau (ACS 2019)
3) Source: Statistics Bureau Japan (2015 census)

Table 3.2 List of variables used in Sendai and Seattle analyses

Variable	Measure
Earthquake experience	Binary for Earthquake experience (Yes = 1, No = 0) * Note that the Sendai version asked about "earthquake damage experience.
Associates "fear" with earthquakes	Binary (1 if selected "somewhat frightened", "very frightened" or "extremely frightened" during most recently experienced earthquake, 0 if "excitement", "very little reaction" or "no reaction"
Awareness (number of topics)	Number of earthquake-related topics one has heard of among: EEW, manmade earthquakes, earthquake swarms, aftershocks, and - Seattle: Cascadia Subduction Zone, "The Big One", Pacific Northwest Seismic Network (Possible response: 0 - 7) - Sendai: Largest class earthquake and tsunami (Japan trench, etc.) (Possible response: 0 - 5)
Preparedness (number of preparations)	Number of emergency preparations at home: Water and non-perishable food, first aid kid, emergency plan, battery operated radio, safe zone identified, earthquake insurance (Possible response: 0 - 6)
Earthquake likely	1: Extremely unlikely (less than 1% chance) 2: Very unlikely (less than 10% chance) 3: Unlikely (less than 33% chance) 4: About as likely as not (33% to 66% chance) 5: Likely (more than 66% chance)
Harm likely from earthquakes	1: Extremely unlikely (less than 1% chance) 2: Very unlikely (less than 10% chance) 3: Unlikely (less than 33% chance) 4: About as likely as not (33% to 66% chance) 5: Likely (more than 66% chance)
Damaging earthquake in lifetime	(Only Sendai) 1: Not in my own lifetime 2: My lifetime 3: Within 10 years 4: Next year
Seismic reinforcement measures are effective	1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree
EEW can protect me, including death	1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree
EEW can prevent deaths	Yes = 1, No = 0 (only in Seattle survey)

EEW can prevent injuries	Sendai: "Injuries would decrease with the warning" (Selected = 1, Not selected = 0) Seattle: EEW would help avoid minor to moderate injuries and/or serious injuries (Selected = 1, Not selected = 0)
Trust	Can you trust most people when dealing with others? (Only in Sendai survey) 1: In most cases, you should be careful 2: Mostly, you should be careful 3: Mostly, you can trust 4: In most cases, you can trust
Fairness	Do you try to take the opportunity to do well, or do you try to act fairly? (Only in Sendai survey) 1: Most of the time, I think I try to take the opportunity to do well 2: Generally, I think I try to take the opportunity to do well 3: Generally, I think I act fairly 4: Most of the time, I think I act fairly
Willingness to pay	- Sendai: "What is the most you would be willing to pay per month for a more accurate and detailed earthquake early warning system than the current one? (Amount: yen)" - Seattle: "What is the most you would be willing to pay per month for an earthquake early warning app on your smartphone or personal computer? Please enter a dollar amount in the range \$0.00 to \$10.00."
Female (sex)	Binary for male (0), female (1) (Responses of "refuse to answer" and "other" were excluded from data.)
Age	Continuous
Location	Sendai: binary (1 = residence in each of the four districts in the city, 0 = non-residents) Seattle: binary (1 = residence in Seattle, 0 = non-residents based on reported zip code of neighborhood)

Table 3.3 Comparison of key variables between Sendai and Seattle

a. Earthquake experience

	Percent of respondents
Sendai	
- Experienced strong shaking with damage	62%
- Experience earthquake in which I felt danger	90%
Seattle	
- Percent of respondents with earthquake experience	88%
- Percent who reported experiencing strong/violent shaking * Strong: heavy furniture moved, negligible damage in well constructed buildings, some chimneys broken * Violent: great damage with partial collapse, buildings shifted off foundations	26%

b. Actual vs. hypothetical response to earthquake
(Percent of respondents in parentheses.)

	Dominant *behavioral* response		Dominant *emotional* response	
	Hypothetical	Actual	Hypothetical	Actual
Sendai	Stop and stay put (34%)	Stop and stay put (42%)	Very frightened (34%)	Extremely frightened (45%)
Seattle	Drop, cover, hold (55%)	Stop and stay put (36%)	Somewhat frightened (48%)	Somewhat frightened (39%)

- Actual behavioral response question: What was your first response during the shaking for that (or your most memorable) earthquake experience?
- Hypothetical behavioral response question: If you were to experience an earthquake when you were indoors, what do you think your first response would be during the shaking?

Response scale
1. Stop what I was doing but stay put
2. Drop, cover, and hold on
3. Protect people, pets or property nearby
4. Turn off gas or open flames
5. Immediately leave the building
6. Other (please specify)

- Actual emotional response question: How did you react to this (or your most memorable) earthquake?
- Hypothetical emotional response question: When you think about being in an earthquake, how do you react?

Response scale
1. No reaction
2. Very little reaction
3. Excitement
4. Somewhat frightened
5. Very frightened
6. Extremely frightened
7. Other (please specify)

c. Risk perception

(Percent of respondents in parentheses. See Table 3.2 for response scale.)

	Sendai	Seattle
How likely do you think you are to experience an earthquake here in Washington in the next five years?	About as likely as not (47%)	Likely (44%)
How likely do you think it is that an earthquake will harm you in the next five years?	About as likely as not (60%)	Unlikely (30%)

d. Emergency preparedness

(Percent of respondents in parentheses.)

	Sendai	Seattle
Supply of water and non-perishable food	68%	68%
First aid kit, stocked	49%	73%
Emergency plan	21%	31%
Battery operated radio	60%	52%
Identified safe zone	23%	22%
Earthquake insurance	46%	25%
None of the above	8.8%	11%

Table 3.4

3. Summary of willingness to pay for EEW improvements in Sendai, Japan, in response to the question, "What is the most you would be willing to pay per month for a more accurate and detailed earthquake early warning system than the current one?"

	Percent ¥0	**25th percentile**	**Median**	**Mean**	**75th percentile**	**Maximum**
original WTP	23%	30	300	956	1000	500000
5% upper trimmed WTP	23	5	150	373.2	500	2580

b. Summary of willingness to pay for EEW app in Seattle-King County, WA, in response to "What is the most you would be willing to pay per month for an earthquake early warning app on your smartphone or personal computer? Please enter a dollar amount in the range $0.00 to $10.00. Monthly amount for early warning app: $____.__ __ (Range: 0-10.00). Response options included "I don't know" and "I prefer to not answer" as well.

(n=819)	**Percent $0**	**25th percentile**	**Median**	**Mean**	**75th percentile**	**Maximum (capped at $10)**
WTP (in US$)	33.8%	0	1	2.10	3	10

Table 3.5 Effect of predictors on willingness to pay for Sendai, Japan

	(1) Complete WTP	(2) Median-split WTP	(3) Median-split WTP (logit)	(4) Zero-split WTP	(5) Zero-split WTP (logit)
Sex	22.597	0.075***	0.313***	0.045***	0.260**
	(18.475)	(0.020)	(0.085)	(0.017)	(0.101)
Age	2.724***	0.003***	0.014***	0.002**	0.009*
	(0.865)	(0.001)	(0.004)	(0.001)	(0.005)
Experience	5.564	-0.012	-0.051	-0.004	-0.030
	(18.829)	(0.021)	(0.086)	(0.017)	(0.103)
Fear	8.653	-0.0001	-0.0004	0.005	0.032
	(9.711)	(0.011)	(0.045)	(0.009)	(0.053)
Awareness (number of topics)	-8.692	-0.005	-0.021	0.001	0.006
	(7.202)	(0.008)	(0.033)	(0.007)	(0.039)
Preparedness (number of preparations)	8.423	0.011	0.044	0.019***	0.112***
	(6.064)	(0.007)	(0.027)	(0.006)	(0.033)
Earthquake harm likely	50.917***	0.058***	0.240***	0.037***	0.205***
	(10.672)	(0.012)	(0.050)	(0.010)	(0.057)
Damaging earthquake in lifetime	15.290	0.011	0.046	0.021	0.138*
	(14.431)	(0.016)	(0.066)	(0.013)	(0.079)
Retrofits are effective	-1.427	-0.019	-0.078	-0.022	-0.134*
	(15.284)	(0.017)	(0.070)	(0.014)	(0.081)
EEW can protect me	-34.843***	-0.023	-0.094	-0.059***	-0.353***
	(13.081)	(0.015)	(0.060)	(0.012)	(0.072)
EEW can prevent injuries	-4.842	0.023	0.094	0.044***	0.259***
	(14.680)	(0.016)	(0.066)	(0.013)	(0.079)

Civic trust	23.906*	0.047***	0.194***	0.041***	0.241***
	(12.818)	(0.014)	(0.059)	(0.012)	(0.070)
Fairness	-2.593	0.0002	0.001	-0.005	-0.030
	(13.353)	(0.015)	(0.061)	(0.012)	(0.073)
Ward: Wakabayashi	15.332	0.021	0.088	-0.025	-0.148
	(29.294)	(0.032)	(0.134)	(0.027)	(0.159)
Ward: Taihaku	39.191	0.050*	0.205*	0.005	0.027
	(24.621)	(0.027)	(0.113)	(0.023)	(0.138)
Ward: Miyagino	9.923	0.023	0.096	-0.032	-0.186
	(25.603)	(0.028)	(0.117)	(0.024)	(0.139)
Ward: Izumi	-39.890	-0.035	-0.146	-0.020	-0.120
	(25.060)	(0.028)	(0.115)	(0.023)	(0.140)
Constant	-17.035	-0.112	-2.537***	0.355***	-1.124**
	(103.201)	(0.113)	(0.473)	(0.094)	(0.556)
Observations	2,572	2,737	2,737	2,737	2,737

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

Table 3.6 Effect of predictors on willingness to pay for Seattle, WA

	(1) Complete WTP	(2) Median-split WTP	(3) Median-split WTP (logit)	(4) Zero-split WTP	(5) Zero-split WTP (logit)
Female	0.409*	0.071*	0.348**	0.053	0.289
	(0.222)	(0.036)	(0.176)	(0.035)	(0.186)
Age	0.019***	0.003**	0.013**	0.001	0.007
	(0.007)	(0.001)	(0.006)	(0.001)	(0.006)
Experience (Y/N)	0.001	-0.076	-0.388	-0.038	-0.238
	(0.359)	(0.058)	(0.290)	(0.056)	(0.309)
Fear	0.623***	0.128***	0.605***	0.091***	0.485***
	(0.211)	(0.035)	(0.165)	(0.033)	(0.174)
Awareness (number of topics)	0.043	0.016*	0.074*	0.012	0.061
	(0.057)	(0.009)	(0.045)	(0.009)	(0.047)
Preparedness (number of preparations)	0.042	-0.000	-0.001	0.001	0.008
	(0.069)	(0.011)	(0.054)	(0.011)	(0.057)
Earthquake likely	0.124	0.001	0.009	-0.014	-0.067
	(0.123)	(0.020)	(0.096)	(0.019)	(0.100)
Earthquake harm likely	0.238**	0.046**	0.220**	0.051***	0.262***
	(0.113)	(0.019)	(0.089)	(0.018)	(0.093)
Retrofits are effective	0.007	0.032	0.147	0.025	0.126
	(0.158)	(0.026)	(0.124)	(0.025)	(0.128)
EEW can protect me	0.531***	0.111***	0.519***	0.112***	0.555***
	(0.147)	(0.024)	(0.117)	(0.023)	(0.121)
EEW can prevent deaths	0.233	0.028	0.143	0.036	0.197
	(0.222)	(0.037)	(0.174)	(0.035)	(0.183)

EEW can prevent injuries	0.159	0.149***	0.672***	0.203***	0.902***
	(0.299)	(0.049)	(0.230)	(0.047)	(0.230)
Seattle	0.330	0.037	0.175	0.031	0.158
	(0.210)	(0.035)	(0.165)	(0.033)	(0.174)
Constant	-2.844***	-0.361***	-4.058***	-0.186	-3.452***
	(0.853)	(0.140)	(0.702)	(0.134)	(0.714)
Observations	763	771	771	771	771

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

Table 3.7 Likelihood ratio test results for models treating ordinal variables as continuous vs. categorical (Seattle data)

Model	N	AIC	BIC
Complete WTP			
Continuous covariates	763	3742.114	3807.035
Categorical covariates		3741.839	3853.133
Median-split WTP			
Continuous covariates	771	1004.125	1069.192
Categorical covariates		1005.763	1117.307
Median-split WTP (logit)			
Continuous covariates	771	956.115	1021.183
Categorical covariates		958.4191	1069.964
Zero-split WTP			
Continuous covariates	771	929.791	994.8583
Categorical covariates		930.516	1042.061
Zero-split WTP (logit)			
Continuous covariates	771	889.577	954.644
Categorical covariates		890.425	1001.970

APPENDIX 3.1 MODEL SPECIFICATIONS FOR GENERALIZED LINEAR MODELS

3. Sendai

$WTP_{Trimmed} = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedness) $+ b_5 *$ (likelihood of damaging earthquake) $+ b_6 *$ (likelihood of har from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (trust) $+ b_{11} *$ (fairness) $+ b_{12} *$ (female) $+ b_{13} *$ (age) $+ b_{14} *$ (location)

$WTP_{Median\text{-}split} = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedness) $+ b_5 *$ (likelihood of damaging earthquake) $+ b_6 *$ (likelihood of har from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (trust) $+ b_{11} *$ (fairness) $+ b_{12} *$ (female) $+ b_{13} *$ (age) $+ b_{14} *$ (location)

$WTP_{Zero\text{-}split} = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedness) $+ b_5 *$ (likelihood of damaging earthquake) $+ b_6 *$ (likelihood of har from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (trust) $+ b_{11} *$ (fairness) $+ b_{12} *$ (female) $+ b_{13} *$ (age) $+ b_{14} *$ (location)

2. Seattle

$WTP = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedness) $+ b_5 *$ (likelihood of earthquake) $+ b_6 *$ (likelihood of harm from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (EEW prevents deaths) $+ b_{11} *$ (female) $+ b_{12} *$ (age) $+ b_{13} *$ (location)

$WTP_{Median\text{-}split} = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedness) $+ b_5 *$ (likelihood of earthquake) $+ b_6 *$ (likelihood of harm from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (EEW prevents deaths) $+ b_{11} *$ (female) $+ b_{12} *$ (age) $+ b_{13} *$ (location)

$WTP_{Zero\text{-}split} = b_0 + b_1*$ (experience) $+ b_2 *$ (felt fear) $+ b_3 *$ (awareness) $+ b_4 *$ (preparedne $+ b_5 *$ (likelihood of earthquake) $+ b_6 *$ (likelihood of harm from earthquake) $+ b_7 *$ (effectiveness of seismic reinforcements) $+ b_8 *$ (effectiveness of EEW) $+ b_9 *$ (EEW prevents injuries) $+ b_{10} *$ (EEW prevents deaths) $+ b_{11} *$ (female) $+ b_{12} *$ (age) $+ b_{13} *$ (location)

APPENDIX 3.2 A DOUBLE-HURDLE MODEL APPROACH TO PREDICTING WTP FOR EEW

1. BACKGROUND

Our survey data of reported WTP from Seattle are bounded by a lower limit of $0 and an upper limit of $10 specified in the survey response scale, as shown in Figure 3.6. The upper bound was introduced primarily to limit outlier responses. The decision to limit the maximum allowed amount to $10 was based on the results from the same survey item in previous survey research (Dunn et al., 2016). The question in the three waves of surveys conducted in Washington state for the previous study elicited WTP on a range from $0 to $100. The median WTP of the first two waves was $1 ($0 in third wave), and the mean across the three waves was about $7, ranging from $5.02 to $9.67. The percentage of responses higher than $10 averaged to approximately 8% across the three waves.

> What is the most you would be willing to pay per month for an earthquake early warning app on your smartphone or personal computer? *Please enter a dollar amount in the range $0.00 to $10.00.*
>
> Monthly amount for early warning app: $____.____ (Range: 0.00-10.00)

Figure 3.6 Willingness-to-pay survey item

Approximately 34% of our Seattle respondents reported a monthly WTP for an EEW app on their smartphones as zero dollars (see Figure 3.7). The mean of our continuous WTP variable is $2.10 while the median is $1. For the subset of non-zero WTP responses, the mean is $3.17 and the median is $2.

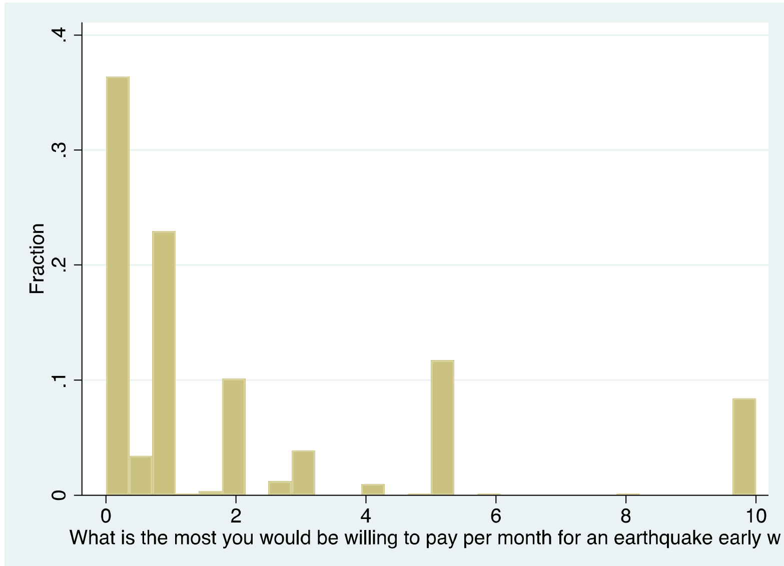

Figure 3.7 Fraction of WTP responses

Respondents might have reported a zero-dollar WTP for various reasons (Freeman III et al., 2014; Hanley et al., 2003). For some respondents, a zero-dollar response might be a way of expressing their aversion to the idea of EEW alerts being a paid service. For some, the requirement that individual recipients of EEW alerts—as opposed to some other entity—pay for the service, might have been the reason. Some of the zero-dollar responses in our data are likely to be protest responses based on such reasons, and as such, they are likely responses that reflect the respondents' lack of intention to pay for this service, rather than an arbitrary number that replaces a negative value unobservable due to left truncation.

In this sense, the willingness to pay elicited in our survey item could be viewed as a two-stage sequence of the following questions for the respondents: 1) "Do I want to pay for this service?" and 2) "If I do, how much should I pay?" Various external and internal factors identified by theoretical frameworks on decision-making are likely to affect both decisions—(1) whether or not to pay, and (2) the amount of payment—as further discussed in Section 3. The same sets of predictors may or may not apply to both decision stages (Martínez-Espiñeira, 2006; Winter and Fried, 2001).

Two-stage models have been adopted in previous studies with similar types of dependent variables, such as decisions about charitable donations, acceptable increases in property taxes for better provision of parks, and payments for state-sponsored programs to reduce wildfire risks (Dickert et al., 2011; del Saz-Salazar and Rausell-Köster, 2008; Winter and Fried, 2001).

2. Double hurdle model

When a subsample consists of observations for which the dependent variable is above a threshold (in our case, WTP above $0), OLS assumptions are violated as the error term no longer has a mean of zero; instead, it contains a component that is a function of $x\beta$. In other words,

$$E(y \mid x) = x\beta + f(x\beta)$$

where $f(x\beta)$ is the error term that is expressed as a function of $x\beta$. (For a detailed discussion on the function, $f(x\beta)$, see Wooldridge (2002), pp. 521-522.) Here, the double hurdle model proposed by Cragg (1971) is applied to address this problem. Fitting an OLS model to such data omits this $f(x\beta)$ component, leading to inconsistent estimates of the coefficients.

The two decisions—(1) the decision to pay or not ($y = 0$ or $y > 0$), and (2) if the decision is to pay (y > 0), the decision of how much to pay—were modeled in two separate steps (Yen and Huang, 1996). The Cragg double hurdle model allows a specification of a set of determinants for the decision to pay or not ("selection model"), and another set of determinants for how much one is willing to pay for those who reported an amount greater than zero ("outcome model"). The two stages in the double hurdle model can be expressed as follows (adapted from Yen and Huang, 1996):

(1) First hurdle (selection model for lower limit of $0):

$s_i^{ll} = z_i\gamma + \eta_i$

$s = 1$ if $z_i\gamma + \eta_I > 0$; and

$s = 0$ otherwise

(2) Second hurdle (outcome model):

$y_i^* = x_i\beta + \varepsilon_i$

where $y_i = s_i^{ll}\, y_i^*$

The selection indicator, s_i, for the lower limit (*ll*) equals 1 if the decision is to pay within the bounded range, and 0 if beyond the bounded range. That is, the lower limit selection indicator for this study was 1 if one decided to a non-zero amount, and 0 if the decision is to pay nothing. It should be noted that an upper limit of $10 was introduced in the survey, but an upper bound was not imposed to the data in the current analysis. While including the $10 responses which accounted for 8% of the sample might have been most suitable for this study, the estimation formula built into the software used for the analysis imposed a truncation at $10, i.e., excluded $10 responses.

The observed outcome variable y_i^* is the level or amount one selects (e.g., amount one is willing to pay); the parameters and predicted y_i are estimated only if s_i=1. The error term for the selection, η_I, has a standard normal distribution, while the outcome error term, ε_I, has a truncated normal distribution with lower truncation at $-x_i\beta$. The log-likelihood given the lower limit is estimated following the truncated normal hurdle model (StataCorp, 2021, p. 224 and 230-231; Cragg, 1971).

If only a lower limit is specified, the parameters for a single selection model and the outcome model are estimated (StataCorp, 2021, p.220).

3. Variables and model specification

For this study, a double hurdle model was adopted with the expectation that it would allow an assessment of a) the determinants of the decision to pay nothing versus anything at all, and b) among those who decide to pay something, the factors that are associated with how much one is willing to pay. In addition to Section 2 of the main text in which the key variables of interest are identified based on a review of the literature, this section further elaborates the rationale behind the set of variables included in the selection and outcome models for the double hurdle model.

3.1 Dependent variable

Our dependent variable, one's willingness to pay for EEW alerts, expresses a behavioral intention which is distinct from preparedness, an actual behavior. However, theories on the relationship between attitudes and behavior, such as the theory of reasoned action (TRA) and theory of planned behavior (TPB), identify behavioral intentions as a key determinant of actual behavior (Fishbein & Ajzen, 1975; Ajzen, 1985). TRA in particular emphasizes behavior intention as a strong predictor of volitional behavior, and posits that such intentions are influenced by attitudes and subjective norms regarding the action (Hale et al., 2002). Several empirical studies and meta-analyses of such studies on the correlation between intentions and actions indeed find high correlations (see, for example, Sheeran et al., 2003; Armitage and Connor, 2001).

For stated preference surveys that elicit one's willingness to pay, it is common to observe responses of "0". The reported "0" may be "true" zeros, indicating a perceived value of zero for the proposed amenity in question. Alternatively, the reported "0" could also be a "protest" zero, which reflects the respondent's rejection of the constructed scenario even if they value the amenity as having a positive value due to, for example, a lack of credibility in the hypothetical scenario or a disagreement of who is responsible for paying for the amenity (Freeman III et al., 2014, p. 388; Hanley et al., 2003).

While protest votes are very different in nature from true zero responses, they are not discernible if (a) respondents choose "0" as their response to express their protest instead of opting out of the question altogether; and (b) if this response is not followed up with a question assessing whether or not the response is out of protest (Freeman III et al., 2014). Based on studies that included follow-up questions assessing protests, the proportion of protest votes among zero-responses appears sizable, with a meta-analysis of 254 studies indicating an average of 18% (Meyerhoff and Liebe, 2010). There is also evidence that web-based surveys may see higher protest zeros than face-to-face ones, likely due to social desirability bias when interacting with the interviewer in person (Nielsen, 2011). It is therefore important to use caution in interpreting the results from models that use willingness to pay amounts that may potentially include protest responses.

3.2 Independent variables

The set of independent variables in the selection model have been chosen based on the literature review presented in Section 2 of the main text. Risk perception, hazard experience and perceived efficacy of protective actions are among important predictors of adopting the respective protective actions, and are included in the three OLS models presented in the main text, along with additional covariates.

Plausibly, these variables may also determine one's initial decision of whether or not to pay for EEW alerts. The decision-making process for taking protective action against natural hazards that many theoretical frameworks of behavioral decision-making such the Protective Action Decision Model (PADM) identify consist of a) a pre-decision stage that is informed by knowledge and experience, external cues, and individual characteristics such as sociodemographic factors, which influences b) an appraisal stage where perceptions of risk and of protective actions are formed, that results in c) a decision, first as intentions and then as actions (Lindell and Perry, 2012). As both the decisions of whether or not to pay for EEW alerts and how much to pay can be characterized as behavioral intentions, the pre-decisional inputs and appraisal variables identified by these theoretical frameworks seemed applicable.

3.2.1 Experience

When respondents are faced with the task of assessing their willingness to pay for a protective action, heuristics may determine their initial thoughts and influence their decisions, especially the decision of whether or not they want to pay anything at all. Prior experience is a source of information that supplies one with the knowledge, emotions, and assessments that are used in deciding the course of protective actions to take, as explained in Section 2 of the main text (Reser and Bradley, 2020; Demuth, 2018). It is a source of mental shortcuts (i.e., heuristics) for assessing objects that involve uncertainties like natural disasters (Norris et al., 1999). The affect heuristic is one example, which in effect substitutes one's feelings towards e.g., a hazardous event action, for a deliberative appraisal of that hazardous event. This substitution often draws from experience or familiarity with the object.

At the same time, cognitive heuristics—for example, the availability of similar examples or the representativeness of the appraisal object—may also expedite one's appraisal of a disaster risk. Prior experience of an earthquake may lead to application of the availability or representativeness heuristic to assess the probability of encountering an earthquake in the future, for example, and thereby affect payment intentions.

Experience was included as a binary indicator for past exposure, as shown in Table 3.2 of the main text.

3.2.2 Risk perception

Risk perception is at least in part affected by one's experience and plays a crucial role in determining intentions for or adoption of protective actions. Many studies have found that risk perception is positively associated with the adoption of protective actions, although some have found mixed, non-significant effects, perhaps due to how risk perceptions are measured and the complexity of their relationships with behavior (Wachinger et al., 2013; Terpstra, 2011; Miceli et al., 2008).

This study adopted (a) assessments of the probability of earthquake occurrence, (b) assessments of the probability of harm from earthquakes (consequence), and affective associations for our risk perception variable, as shown in Table 3.2 of the main text. Given that these three variables were designed to measure the common construct of risk perception, high correlations among these variables were expected, as observed in other studies previously mentioned. When collinearity is present, the effects of highly correlated variables are hard to disentangle as each correlated variable can stand in for the other in predicting the outcome variable (Vanhove, 2021; York, 2012). If signs of multicollinearity were detected, further exploratory analyses such as a principal component analysis were warranted to create a risk perception index to better assess the overall effect of risk perception on WTP (see Chapter 2, Section 4.2 for a discussion of principal component analysis used for risk perception).

3.2.3 Perceived efficacy

In addition, perceived efficacy of a protective measure is also a commonly identified determinant, as explained in Section 2. If based on cognitive heuristics from experience, initial appraisals of risk and efficacy may be quick and so may influence the selection decision.

This study used three perceived efficacy variables pertaining to EEW: (a) perceived efficacy of protecting oneself, including from death; (b) perceived efficacy in prevention of deaths specifically; and (c) perceived efficacy in prevention of injuries specifically. As discussed above regarding the risk perception variables included in this study, these perceived efficacy variables were also likely to highly correlated. If indeed signs of multicollinearity were detected, substituting a perceived efficacy index variable in the models for the separate variables was deemed beneficial in assessing the effect of perceived efficacy on WTP.

Together, the above suggested that earthquake experience, risk perception—including the association of earthquakes with fear—and perceived efficacy were associated with the selection variable for WTP. Specifically, the hypothesized relationships were as follows:

H1: Having earthquake experience is positively associated with both the selection into paying for an EEW app and with the WTP amount.

H2: Risk perception is positively associated with both the selection into paying for an EEW app and with the WTP amount.

H3: Higher perceived efficacy of EEW alerts is positively associated with both the selection into paying for an EEW app and with the WTP amount.

To test the above hypotheses, the double hurdle regression models were specified as follows:

(1) Selection model:

$s_i = \gamma 0 + \gamma 1*$ experience $+ \gamma 2*$ fear $+ \gamma$ 3*harm likely $+ \gamma 4*$ earthquake likely $+ \gamma$ 5*EEW protects $+ \gamma 6*$EEW prevents deaths $+ \gamma*$EEW prevents injuries

where $s_i = 1$ if $z_i\gamma + \eta_I > 0$ and $s_i = 0$.

(2) Outcome model:

$y_i^* = x_i\beta + \varepsilon_i$

where $y_i = s_i y_i^*$ if $s = 1$; and

$y_i = 0$ otherwise

The full set of covariates (x_i) included in the outcome model is consistent with our models in the main text (see Table 3.6) to allow a comparison, and includes: earthquake experience, risk perception (earthquake likely, harm likely, fear), perceived efficacy (EEW protects, EEW prevents injuries, EEW prevents deaths, retrofits prevents deaths), gender (female), age, and residence in Seattle. The analysis is conducted using the *churdle* command available on Stata16.

4. Results

4.1 Descriptive statistics

Table 3.4b in the main text provides the descriptive statistics of the WTP variables including the mean and the median. A comparison of the WTP variable and the subsample whose WTP was greater than $0 is shown in Table 3.9.

Table 3.8 Comparison of WTP for full- and subsample (WTP>0)

	Obs. (Percent of sample)	Mean	Standard deviation	Min.	Max.
Reported WTP	819 (100%)	2.10	2.89	0	10
Reported WTP (WTP > 0)	542 (66%)	3.17	3.04	0.01	10
Obs. for WTP=10	69 (8%)				

In the selection model for the lower limit of zero WTP, prior experience of an earthquake did not predict selection, contrary to Hypothesis 1 (see Table 3.10). Some risk perception and perceived efficacy variables were significant determinants of whether one is willing to pay anything at all. Of the risk perception variables, the association of fear with earthquakes, and perceived likelihood of harm from an earthquake were significant. Perceived likelihood of an earthquake occurrence, which is the other risk variable, did not significantly predict selection. None of these risk perception variables were significant in the outcome model, and therefore hypotheses 2 and 3 were partially supported.

For a better interpretation of the results, marginal effects were computed, as shown in Table 3.11. A one-point increase of the perceived likelihood of harm from an earthquake (five-point scale from “extremely unlikely” to “likely”) increased WTP for an EEW app by 27 cents. Those who associated earthquakes with fear had a WTP amount higher by 61 cents than those who did not.

Perceived efficacy of EEW in protection and in preventing injuries was also a significant predictor of selection. Whether one perceives EEW as being effective for preventing deaths was not significantly associated with selection. In terms of marginal effects, a one-point increase in one’s belief that EEW can provide personal protection in an earthquake (4-point scale from “strongly disagree” to “strongly agree”) was associated with a WTP higher by 53 cents (Table 3.11).

Table 3.9 Double hurdle regression results

The coefficients presented in this table are from the double hurdle model estimation. The selection model (Column 2) shows the associations of the independent variables included in the model with the decision to pay or not pay. The outcome model (Column 1) shows the associations of the full set of independent variables on the WTP amount, given that selection was equal to 1 (i.e., that respondents were willing to pay a non-zero amount). Fear reactions, perceived likelihood of harm from an earthquake, and perceived efficacy of EEW are significant and positive predictors of selection, but none of the variables are significant predictors in the outcome model (Column 1).

	(1) Outcome	(2) Selection
Experience (Y/N)	2.003	-0.097
	(4.429)	(0.175)
Fear	4.185	0.284**
	(2.927)	(0.102)
Awareness (number of topics)	-0.006	
	(0.655)	
Preparedness (number of preparations)	0.408	
	(0.807)	
Earthquake likely	2.819	-0.023
	(1.977)	(0.058)
Earthquake harm likely	1.286	0.173**
	(1.442)	(0.053)
Retrofits are effective	-0.499	
	(1.815)	
EEW can protect me	2.435	0.347***
	(2.016)	(0.069)
EEW can prevent deaths	1.740	0.108
	(2.583)	(0.105)
EEW can prevent injuries	-6.321	0.555***
	(4.333)	(0.139)
Female	2.362	
	(2.620)	
Age	0.226	
	(0.123)	
Seattle	3.809	
	(2.771)	
Constant	-55.879*	-1.558***
	(27.853)	(0.315)
Observations	763	
Log-likelihood	-1514.64	
LR chi2	139.41	
df	13	
Prob > chi2	0.00	

Note: Standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

Table 3.10 Marginal effects of risk perception and perceived efficacy on WTP

The marginal effects shown here indicate the effect of a one-unit increase of the variables of interest on WTP in dollar terms. A one-category increase in perceived efficacy of EEW ("EEW can protect me") was estimated to increase WTP by 53 cents.

Variables	Marginal effect
Risk perception	
Earthquake likely	0.19 (0.15)
Harm from earthquake likely	0.27 (0.16)
Fear	0.59 (0.31)
Perceived efficacy	
EEW can protect me	0.53* (0.14)
EEW can prevent deaths	0.24 (0.23)
EEW can prevent injuries	0.07 (0.33)

Note: Standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

Table 3.12 provides a comparison of predicted WTP for the full sample and the subsample with a positive WTP.

Table 3.11 Predicted WTP for full- and subsample (WTP>0)

	Mean	Standard deviation	Min.	Max.
Predicted WTP	2.12	0.84	0.24	4.95
Predicted WTP (WTP > 0)	3.12	0.74	1.63	6.38

The coefficients of the risk perception and perceived efficacy variables shown in Table 3.10 had very large standard errors. As discussed in Section 3, these may be signs of multicollinearity. The correlation coefficients of many of the three risk perception variables and perceived efficacy variables were also moderate to high and significant as expected, as shown in Table 3.13.

Table 3.12. Correlations of risk perception variables and perceived efficacy variables

	(1)	(2)	(3)
Risk perception			
(1) Earthquake likely	1.00		
(2) Harm from earthquake likely	.48*	1.00	
(3) Fear	.04	.21*	1.00
Perceived efficacy			
(1) EEW can protect	1.00		
(2) EEW can prevent deaths	.27*	1.00	
(3) EEW can prevent injuries	.39*	.15*	1.00

(*) Asterisks indicate a significance level of $p<0.01$.

As described in Section 3, perceived likelihood of earthquakes and harm from earthquakes, and fear associations were adopted as measures of risk perception. For any given individual, these three variables together were expected to represent the individual's perceived risk of earthquakes, and therefore to be correlated. The three variables capturing one's perceived efficacy were also expected to be correlated for similar reasons. In order to better assess the effects of risk perception and perceived efficacy in the absence of collinearity, principal component analyses were conducted. Table 3.14 shows the eigenvalues of each component and proportion of variance explained. The eigenvalues of Component 1for both risk perception and perceived efficacy are over 1 and meet the general rule of thumb in terms of the criteria for selecting components to retain (eigenvalue > 1). Furthermore, the first component of both variables explained slightly over 50% of the variance of the three variables included for each construct.

Table 3.13 Eigenvalues and proportion of variance explained by components

Component	Eigenvalue	Proportion	Cumulative
Risk perception			
Comp1	1.53	0.51	0.51
Comp2	0.97	0.32	0.83
Comp3	0.50	0.17	1.00
Perceived efficacy			
Comp1	1.56	0.52	0.52
Comp2	0.86	0.29	0.81
Comp3	0.58	0.19	1.00

The risk perception variables of likelihood of an earthquake and likelihood of harm from an earthquake loaded heavily on Component 1, as shown in Table 3.15. The variable fear loaded moderately on Component 1 but heavily on Component 2. All three perceived efficacy variables loaded heavily on the first component. From these results, component 1 of each construct is retained and included in the second set of double hurdle models.

Table 3.14 Loadings of principal components on variables of interest

Variables	Components		
	1	2	3
Risk perception			
(1) Earthquake likely	**0.64**	-0.40	0.65
(2) Harm from earthquake likely	**0.70**	-0.05	-0.72
(3) Fear	**0.32**	0.92	0.25
Perceived efficacy			
(1) EEW can protect	**0.65**	-0.14	-0.74
(2) EEW can prevent deaths	**0.48**	0.84	0.26
(3) EEW can prevent injuries	**0.59**	-0.52	0.61

The results of the double hurdle models using the principal components (PC) for risk perception and perceived efficacy are shown in Table 3.16. In the selection model for the lower limit of $0, the principal components for both risk perception and perceived efficacy were positive and significant, indicating a higher probability of a respondent being willing to pay a positive amount with higher risk perception and perceived efficacy.

The results in the outcome model were similar to the pre-PCA results shown in Table 3.10, albeit with smaller standard errors for the risk perception and perceived efficacy principal components. The overall marginal effect of the risk perception PC on WTP was 45 cents (p=.000), and the marginal effect of the perceived efficacy PC on WTP was 35 cents (p=.000).

Table 3.15 Double hurdle regression results with principal components

The coefficients presented in this table are from the double hurdle model estimation using principal components instead of separate indicators for risk perception and perceived efficacy. The selection model (Column 2) shows the associations of the independent variables included in the model with the decision to pay or not pay. The outcome model (Column 1) shows the associations of the full set of independent variables on the WTP amount, given that selection was equal to 1 (i.e., that respondents were willing to pay a non-zero amount). Both risk perception and perceived efficacy of EEW are significant and positive predictors of selection, but not in the outcome model.

	(1) Outcome	(2) Selection
Experience (Y/N)	1.31	-0.20
	(4.68)	(0.17)
Risk perception PC	3.98	0.17***
	(2.09)	(0.04)
Perceived efficacy PC	0.35	0.33***
	(1.31)	(0.04)
Awareness (number of topics)	-0.08	
	(0.71)	
Preparedness (number of preparations)	0.53	
	(0.89)	
Retrofits are effective	0.07	
	(1.93)	
Female	2.50	
	(2.87)	
Age	0.22	
	(0.13)	
Seattle	4.01	
	(3.08)	
Constant	-39.25	0.64***
	(22.92)	(0.16)
Observations	763	
Log-likelihood	-1524.32	
LR chi2	120.03	
df	9	
Prob > chi2	0.04	

Standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

5. Discussion

The results indicated that some of the variables of interest in this study, namely risk perceptions and perceived efficacy, predicted whether one would be willing to pay anything at all for EEW, but they were not significantly associated with variations in the amount of willingness to pay among those willing to pay above $0. The results for the selection model are consistent with the OLS and logit results presented in the main text (see the results from the zero-split WTP models in Table 3.7, Columns 4 and 5).

In the natural hazard decision-making literature, appraisal stage variables like risk perception and perceived efficacy are thought to affect an individual's response to the threat in terms of protective actions (Norman et al., 2015; Floyd et al., 2000). The findings of this Appendix confirm that indeed, perceptions of earthquake risks and efficacy of EEW are associated with adoption intentions for EEW apps represented in terms of whether one is willing to pay for them or not. Further investigation is needed on if and how decisions for such adoption intentions differ from subsequent decisions regarding the intended payment amounts, as the double hurdle model results suggest.

How the WTP variable was measured could also have affected these results. Approximately 33% of the respondents who reported a non-zero WTP said they were willing to pay $1, and those who reported a WTP up to $1 comprised 43% of the total sample. It is possible that the prompting for a WTP amount elicited strong preferences for whether one wanted to pay anything or nothing, but a third of those who were willing to pay a non-zero amount reported the smallest round value to express that they were willing to pay only a small amount. While we allowed up to two decimal points in the responses and did get responses such as $0.01, the frequency of $1 responses was high. Similar patterns are observed at $2 and $5 as shown in

Figure 3.7, although the frequencies of these responses were lower. A small pile of responses of the maximum allowed amount is also observed, and unlike the $0 responses that we assume are "true" responses, at least some of the $10 responses may have represented censored amounts greater than $10 from respondents who greatly valued EEW.

These responses may also have been the result of (a) the convenience of a round number, (b) anchoring effects arising from many paid smartphone apps charging $0.99, $1.99 or $4.99 to download, and/or (c) a symbolic choice for low, medium, or high WTP. In the survey literature, round-value responses for survey items eliciting continuous values have been found to be reflective of respondent fatigue, reluctance or attempts to expedite responses or reduce response burden, which makes this explanation plausible (Gideon et al, 2017; Wilson and Abdirizak, 2017; Fricker and Tourangeau, 2010). Our non-significant coefficient estimates may be, at least in part, the result of noise introduced by such symbolic or convenient approaches taken by respondents to expedite response time, when faced with the complex task of reporting a willingness to pay amount.

6. Conclusion

We fitted a double hurdle model to account for multiple zero WTP responses in our data. We found that risk perception and perceived efficacy significantly predicted whether one was willing to pay anything at all (WTP > 0). However, the effects of those variables on subsequently determining the amount of WTP are inconclusive. Further research is needed on if and how decisions for adoption intentions differ from decisions on the intended payment amounts as the double hurdle model results suggest.

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Chapter 4. PUBLIC ATTITUDES TOWARD PROTECTION MEASURES AGAINST EARTHQUAKE RISKS IN WESTERN WASHINGTON: A CHOICE EXPERIMENT STUDY

Abstract

Western Washington state lies within the Cascadia Subduction Zone (CSZ), a "megathrust" fault that can cause high-magnitude earthquakes. Preparedness at the individual and community levels is critical for mitigating losses and ensuring a quick recovery in the event of a damaging earthquake. Because a critical factor in raising overall preparedness levels is public awareness and receptivity, this study investigated resident attitudes and adoption intentions regarding protection measures against earthquake risks. Further, the study developed estimates of willingness-to-pay for seismic protection measures. To this end, a random sample of households (N=2,443) in King County, WA was invited to participate in an online survey that included questions about perceived earthquake risks and effectiveness of earthquake early warning (EEW) and seismic retrofits, as well as a choice experiment to assess the public's WTP for such measures. The choice model estimates indicate that perceived efficacy and risk perception are significant predictors of the probability of choosing a protection measure over no action, controlling for other factors such as income. The mean WTP estimates are, however, indistinguishable from zero. When communicating to the public about earthquake preparedness, it is therefore important to emphasize the impact protection measures can have on reducing the potential damages caused by earthquakes, along with the courses of protective action that warning recipients can take.

1. INTRODUCTION

The western coast of Washington state lies within the Cascadia Subduction Zone (CSZ). This "megathrust" fault stretching along the coasts of Vancouver Island, Washington, Oregon and northern California poses risks of high-magnitude earthquakes. Such big earthquake events are rare as the last known one in the region was 300 years ago. However, there is alarming evidence that suggests big earthquake events have happened at an interval of 400 to 600 years in the last 3,500 years (PNSN, 2020). Given the population density in the urban areas along Interstate 5 which runs parallel to the coastline of these states, a high-magnitude earthquake in the region will undoubtedly have devastating consequences as witnessed in large-scale events elsewhere. For example, the 2011 Tohoku earthquake of Japan (magnitude 9 event) is estimated to have caused an economic loss of about US$ 150 billion, displacing more than 330,000 people from their homes and resulting in about 16,000 fatalities (Nakayachi & Nagaya, 2016). The magnitude-8.8 Chile earthquake of 2010 cost that nation an estimated US$ 40 billion, causing over 800,000 victims of death, injury and displacement combined, of which about 520 were fatalities (Elnashai et al., 2012).

In light of such catastrophic consequences, the development of earthquake early warning (EEW) systems has been an ongoing enterprise in many countries, with high-risk countries like Japan and Mexico already having a public alert system in place (McBride et al., 2021). In the United States, the state of Washington, along with Oregon and California, has been collaborating with the United States Geological Survey (USGS) to develop and implement an EEW system. ShakeAlert, the EEW system developed for the West Coast, was launched by USGS for the general public in these states in 2021. The goal of this system is to provide advance alerts of imminent shaking to institutional and public users, thereby reducing the economic and social impacts that high-magnitude earthquakes can have in the region (Given et al., 2018). Washington residents now received alerts of imminent earthquakes via Wireless Emergency Alerts (WEA). Ensuring the timeliness and accuracy of such alerts requires sufficient funding in equipment and research, for which the initial cost is estimated to be around $40 million, and an additional $30 million in annual operation costs (Given et al., 2018). Public support for an EEW system is critical if such public funds are to be allocated to such a high-cost project.

Evidence in the literature suggests that low-cost protection measures are more likely to be adopted than resource-intensive measures (Onuma, 2017; Terpstra & Lindell, 2013; Lindell et al., 2009; Lindell & Prater, 2002). EEW alerts delivered to phones require minimal investment from the recipients, which may in part explain the supportive attitudes toward it as a preparedness measure observed in many regions, including Washington state (Becker et al., 2020; Nakayachi et al., 2019; Dunn et al., 2016).

In contrast, the adoption of protection measures that require more substantial investments of money, time, and effort, such as installations of seismic retrofits, tends to be slower (Terpstra and Lindell, 2013; Lindell et al., 2009). Only a few earthquake-prone regions or countries have adopted mandates for retrofits to date (e.g., Los Angeles, New Zealand). In Western Washington, seismic retrofitting is still a recommendation, and hence the risks of losses from building collapse and damages in the event of a strong earthquake remain high. In order for initiatives pushing for such a mandate to gain traction in the policy arena, the public's strong support is crucial (Prater and Lindell, 2000).

Previous studies have shown that people's perceptions of how effective a protective measure is can determine their intention for or actual adoption of the measure, as further discussed in the next section. Effectively communicating information with the public on the effectiveness of earthquake protection measures, such as the reliability of the EEW system and effectiveness of retrofits, therefore can induce public support for preparedness.

Understanding of earthquake risks and related policies in the region are changing while new technologies for providing protection against earthquake risks are emerging. The aim of this study was to facilitate a better understanding of how earthquake protection measures are perceived in the region in terms of effectiveness and adoption intentions. To do so, a survey was conducted in 2018 in King County, WA, home to the Seattle metropolitan area. The survey included a stated preference component to elicit the respondents' mean willingness to pay for installing protective measures at their place of residence, as an indicator of attitudes toward such measures and adoption intentions.

The analysis in this study focused on two aspects of public perceptions regarding earthquake protection measures. First, variables that make it more probable for individuals to hazard mitigation measures over not taking any action were identified. Second, the willingness-to-pay (WTP) for protection measures were estimated using data collected from a choice experiment survey. In the next section, a review of the literature on the predictors of choice probabilities and adoption intention is presented, followed by a description of the survey and choice experiment, estimation results, and a discussion of the results.

2. Literature and hypotheses

The protective actions that individuals and households voluntarily take against a natural hazard like earthquakes are influenced by a variety of factors. Of those, this study closely examines the effects of hazard experience, the perceived probabilities of risk, perceived effectiveness of preparedness measures, and available resources (Han et al., 2017; Dunn et al., 2016; Joffe et al., 2016; Onuma et al., 2016; Kirschenbaum, 2002; Lindell & Perry, 2000; Lindell & Whitney, 2000; Kunreuther, 1996).

2.1 Hazard experience

Hazard experience is among the most commonly included variables in models. Experience is a source of information that provides people with knowledge and emotions about the event (Reser and Bradley, 2020; Demuth, 2018; Becker et al., 2017; Weinstein, 1989). It is often explained in association with risk perception. A link between experience and risk perception may be heuristics, or mental shortcuts, for assessing risk can arise from one's hazard experience (Tversky & Kahneman, 1974). Individuals likely use cognitive and affective heuristics and rely on their experience to resolve the uncertainty involved in assessing natural hazard risks. Anchoring leads people to assess risks in a way that is biased toward their initial estimate. Earthquake experience can affect the initial estimate and therefore influence one's assessment of future risks. Such effects of heuristics on risk perception, then, can be a possible explanation of the mechanism by which experience influences protective action. For example, residents that live in high-risk areas that have not experienced an event for an extended period of time may have lower risk perception and overall preparedness for the natural hazard, as suggested by some studies (Perry & Lindell, 2008; Gregg et al., 2004).

Some studies indicate that experience is positively associated with preparedness (Castañeda et al., 2020; Onuma et al., 2017; Kirschenbaum et al., 2017; Lindell and Hwang, 2008). Partial effects are found by some studies, such as experience predicting preparedness intentions but not implementation (Miranda et al., 2021). There is also evidence that suggests that in addition to a direct effect, the effect of experience on preparedness is moderated or mediated by other factors (Lindell and Prater, 2000). Some studies report weak or non-significant effects of experience (Weber et al, 2018; Dunn et al., 2016; Martin et al., 2009) Such studies suggest that experience may affect adoption of protective measures through other variables, such as perceived risk and efficacy, that may not have been present in their models. Given the evidence that earthquake experience serves an important role in the decision of taking protective action, this study hypothesized that experience of an earthquake increases the probability of the adoption intention of an EEW system as well as structural retrofits.

2.2 Risk perception

The subjective appraisal of risk, or risk perception, resulting from one's experience and knowledge, can serve as guidance on what to do about the risk (Mileti & O'Brien, 1992; Greene et al., 1981). Many empirical studies find that a higher level of perceived risk is associated with increased protective behavior or intentions. Research in hurricane risks suggests that people are more likely to evacuate from a hurricane if they expect personal threats such as damages to their homes or injuries or deaths of family members (Demuth et al., 2016; also see Huang et al., 2016 for a meta-analysis). A survey of west coast residents also shows that individuals with a higher perceived likelihood of being harmed by an earthquake have a higher willingness to pay for an earthquake early warning system app (Dunn et al., 2016). The findings of a study in Portland, OR also indicate that people with higher earthquake risk perceptions are more likely to support mitigation programs that reduce earthquake risks (Flynn et al., 1999).

Therefore, an individual’s perception of earthquake risk in Washington as well as their perceived likelihood of being harmed by an earthquake was hypothesized to be significant predictors of their intention to adopt EEW and retrofits.

2.3 Perceived efficacy

Another essential determinant of behavioral intentions regarding natural hazards is the perceived level of effectiveness, or efficacy, of a protective action in preventing personal and property loss (Botzen et al., 2013; Terpstra & Lindell, 2013; Lindell et al., 2009; Lindell & Prater, 2002; Paton & Johnston, 2001). Evidence suggests that people might base their decisions to adopt mitigation measures on perceived effectiveness more so than the required resource investments, preferring measures with a high certainty of protection to those that provide partial protection even at a higher cost (Botzen et al., 2013; Lindell, 2012). Some findings indicate that perceived efficacy as well as resource requirements affect decisions to adopt more resource-intenstive measures like retrofits (Zou et al., 2020).

In Western Washington, most residents have limited information on the effectiveness of EEW due to its recency and their limited exposure to earthquakes since ShakeAlert has become available. The perceived efficacy of ShakeAlert would also depend on the protective actions that people are able to take upon receiving the alerts (Nakayachi et al., 2019). This also suggests that communication about protective action recommendations is important (McBride et al., 2021).

Based on the evidence presented in these previous studies, it was hypothesized that those who perceived EEW and retrofits to provide protection were more likely to show intentions of adopting the measures.

2.4 Protection action adoption intention

The Theory of Reasoned Action (TRA) posits that stronger beliefs that a given behavior will result in positive outcomes or prevent negative outcomes lead to a more favorable attitude toward the behavior (Fishbein, 2008). It follows, then, that perceptions of adopting protection measures would predict intentions and actual behaviors. Many hazard-related studies have directly asked about protective action intentions, with phrasing such as "How likely is it that you would…?" (Scovell et al., 2021; Goldberg et al., 2020; Jasour et al., 2018; Demuth et al., 2016; Osberghaus, 2015; Botzen et al., 2013; Kievik and Gutteling; 2011). Some of these studies have used responses to such intention questions as a binary dependent variable (e.g., 1 for planned implementation, 0 for no plans), in order to estimate the probability of an alternative being chosen using binary outcome models (Osberghaus, 2015). These choice probabilities for hazard protection measures that are based on stated intentions are informative and useful because the independent variables in such models can be interpreted for their effect on the probability that a protection measure is (or will be) adopted.

In addition, whether or not the public thinks favorably of protective measures against seismic risk in Western Washington may be what they would be willing to pay for it. Given that the nature of the EEW system developed for the U.S. is one of a non-market public good, a positive WTP would be an indication that it has economic value to recipients. This economic value, in theory, reflects the change in one's wellbeing arising from the provision of EEW, which in turn conveys information about one's preference (Bateman et al., 2002). One way to elicit this value is through a stated preference survey, where respondents are given choices that come with a specific price and asked to make choices based on the price and their preference. Choice experiments ask respondents to compare a menu of options that contain varying levels of a set of attributes and make choices based on the level of each attribute and the price of each option. The baseline alternative of maintaining the status quo is also usually offered. The resulting estimates of WTP from and choice experiments therefore provide representations of welfare (Bateman et al., 2002).

If a standard demand curve with a negative slope for EEW and structural retrofits is assumed, the probability of a respondent choosing these measures over taking no action can be reasonably expected to decrease as price increases (see Asgary et al., 2007 for evidence of a downward sloping demand curve for EEW). In addition, previous research has also found that residents of Washington state were willing to pay a non-zero amount for an EEW app on their smartphones (Dunn et al., 2016). Therefore, negative price coefficient and a positive mean WTP for protection measures are hypothesized.

3. Survey administration

A survey was administered to a randomly drawn King County sample (N=399) from May to June 2018 to assess WTP for earthquake preparedness measures. Following a Dillman approach (Dillman et al., 2014), multiple mailings were sent in order to increase response rates. Initial invitation letters that were mailed out to 2,443 randomly selected addresses explained the purpose of the survey and provided the URL and an access code for the online survey, which was unique to each respondent. Also enclosed in each letter was a one-dollar bill as an incentive to boost response rates. This was followed by three reminder postcards, each of which was sent approximately one week apart to all survey recipients, regardless of whether or not they had already completed the survey (see e.g., Mercer et al., 2015; Singer and Ye, 2013; James and Bolstein, 1990 for effect of monetary incentives and follow-up mailings on response rates). One recipient requested to be removed from the survey after receiving the invitation letter and was removed from the sample. The online survey platform was implemented and hosted by the Social Development Research Group at the University of Washington. The procedures and contents of the study conducted in Seattle, Washington were reviewed and approved by the institutional review board of the University of Washington (IRB ID: STUDY00002942).

The response rate including those who submitted partial responses to the survey was 17.6%. We report the response rate including partial completions (RR2) according to the American Association for Public Opinion Research (AAPOR) guidelines as the following:

$$\text{RR2} = \frac{(\text{Complete surveys} + \text{Partial surveys})}{(\text{Complete}+\text{Partial})+(\text{Refusal}+\text{No contact}+\text{Other})+(\text{Unknown if household or occupied}+\text{Other unknown})}$$

where the denominator is essentially the total number of survey invitations sent out (AAPOR, 2016). We received a total of 429 survey submissions out of the 2,443 invitations sent out. Of these, 399 were complete submissions, among whom 246 reported not having any retrofit measures installed at home.

4. Choice experiment

The stated preference questions were presented in a choice experiment format. Each option represented one earthquake preparedness measure, instead of varying levels of attributes as commonly seen in the literature. Respondents were presented two *choice sets*, each of which consisted of choices between protective measures. Across the two choice sets, the only component that varied was the earthquake hazard description, consisting of an earthquake probability and the associated magnitude: each respondent was randomly assigned to two of three earthquake probabilities: 14%, 26%, and 14-18% which corresponded to the probability of an M9 earthquake (14% and 14-18%) and M6.5+ earthquake (26%) in WA in the next 50 years (Frankel et al., 2015). For example, one respondent may have seen a choice set under the 14% condition, and then under the 26% condition, while another respondent may have answered two choice sets under the 26% and 14-18% conditions, respectively. The rationale behind this setup was to bring to the respondents' attention different aspects of the earthquake risks in the region, rather than to present the earthquake probabilities as being different. Figure 4.1 (a) shows how the earthquake probabilities and options were presented for each set.

Within a choice set, the first task was to choose among the two options below based on monthly costs, with Option A (EEW) being the less expensive choice:

- Option A: An EEW with automatic gas shutoff[5] but no seismic retrofit
- Option B: *Partial* seismic retrofit without EEW with automatic gas shutoff

A follow-up question of whether the respondent preferred their choice between Options A and B or to take no action at no monthly cost, as below:

Taking into account your choice above, which of the following would you prefer?

- The option I chose above (at the indicated price).
- Neither option for earthquake preparedness (no monthly cost to my household).

[5] The rationale behind providing "EEW-activated gas shutoff" as an EEW-related option was that fire is known to have been the leading cause of seismic damage in the U.S. and Japan. Some gas valves that were fortified with seismic shut-offs were found to have reduced ignition during the 1994 Northridge earthquake (Strauss & Allen, 2016).

The second task in the choice set consisted of the following, with Option D being the most expensive option of Options A (equal to C), B, and D:

- Option C: identical to Option A, including the monthly cost
- Option D: *Full* seismic retrofit without EEW with automatic gas shutoff

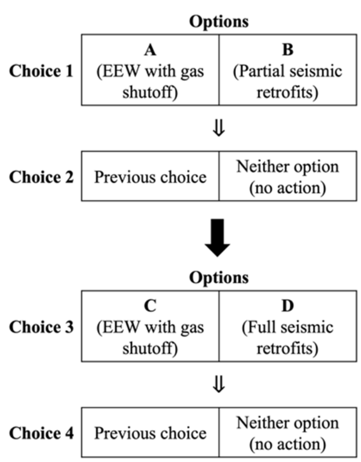
Once again, a follow-up question asked respondents to choose between their choice (C or D) or no action at no cost. The monthly costs that each respondent saw were based on their reported monthly rent or home value category, such that those in a lower rent category saw lower monthly costs for the options overall. Figure 4.1 (b) graphically illustrates this choice process in each choice set consisting of four choices.

The probability of a **magnitude 9 (M9) earthquake** affecting Washington state **in the next 50 years is estimated to be 14%** (that is, a one-in-seven chance).

To prepare for earthquakes at your residence, suppose you could adopt one of the options below:

Description:	**Option A:** *Includes an early warning system with automatic gas shutoffs. Does not include seismic retrofits at home.*	**Option B:** *Includes partial seismic retrofits at home. Does not include an early warning system with automatic gas shutoffs.*
Features include:		
Early warning system with automatic gas shut off	Yes	No
Seismic retrofits at home	None	Partial
Monthly cost to household	${**15/20/30/45/50/55/60**}	${**20/30/45/60/75/90/105**}

a. Sample choice card



b. Choice experiment flowchart

Figure 4.1 Choice experiment flowchart and sample choice card

This survey data allows for discrete choice modeling. A dichotomous variable can be generated for whether a respondent accepts (coded as 1) or rejects (coded as 0) a specific option (e.g., an EEW with automatic gas shutoff) for a given monthly cost, or *bid*. Using this binary variable as the dependent variable, we can estimate the probability of one choosing a specific option, from which a mean WTP for that option can be estimated.

5. Methods

5.1 Discrete choice model

One of the underlying assumptions of choice models is that people's choices reflect their utilities; that is, given a set of choices, decision makers select the choice that maximizes their utility (Train, 2009, p. 14). The assumption for this study is that when respondents were presented with the options of taking no action and protective measures, they made the choices that they perceived as increasing their utility the most. The utility that an individual derives from an option, or *alternative*, can be expressed as follows (the formulas and explanation hereafter are adapted from Train, 2009, pp. 15-16; StataCorp, 2021, p. 73):

$$U_{ia} = V_{ia} + \varepsilon_{ia} \quad (1)$$

U stands for utility, and is expressed in terms of the individual i (i = 1, 2, …, N; each individual respondent in the survey for this study) and alternative a (a = 1, 2, …, A; no action, EEW with automatic gas shutoff, partial- and full retrofits for this study). This utility includes two components: an observed component V_{ia} and an unobserved, stochastic component, ε_{ia}. Because this unobserved term is unknown to the researcher, it is assumed to have a random distribution, and therefore utility model is known as a random utility model. The observed component V_{ia} is what is in the data, i.e., information collected from the choice experiment survey on the variables of interest.

A utility function like equation (1) can be written for each alternative, and an individual is assumed to choose the alternative that is associated with the highest utility U_{ia} among the alternatives. This also means that the probability of an individual *i* choosing alternative *a* over, say, alternative *b* is the probability that U_{ia} is greater than U_{ib}, expressed as the following:

$$P_{ia} = P(U_{ia} > U_{ib} \text{ for all b not equal to a})$$

$$= P(V_{ia} + \varepsilon_{ia} > V_{ib} + \varepsilon_{ib} \text{ for all b not equal to a})$$

$$= P(\varepsilon_{ia} - \varepsilon_{ib} > V_{ib} - V_{ia} \text{ for all b not equal to a})$$

Given that ε_{ia} is unobserved and assumed to be random, its distribution can be written as $f(\varepsilon_{ia})$ in the cumulative probability of the individual choosing *a* over *b*, as below:

$$P_{ia} = \int I(\varepsilon_{ia} - \varepsilon_{ib} > V_{ia} - V_{ib}\ for\ all\ b \neq a)\, f(\varepsilon_i) d\varepsilon_i \qquad (2)$$

I in equation (2) is a function to indicate whether or not the expression inside the parentheses is true (1 if true, 0 otherwise). Discrete choice is modeled differently based on how $f(\varepsilon_i)$ is specified. For example, if it is assumed to follow an iid extreme value distribution, a logit model is estimated. Given the use of a binary outcome variable for choice of an option, logit is widely used for analyzing choice experiment data (Train, 2009).

The choice model is tested using conditional logit and estimated using maximum likelihood procedures. The log-likelihood function used to estimate the parameters is as follows (adapted from Bateman et al., 2002):

$$\log L = \sum_{a=1}^{A} \sum_{i=1}^{N} y_{ia} log \left[\frac{\exp(V_{ia})}{\sum_{i=1}^{N} \exp(V_{ia})}\right]$$

where i (i = 1, …, N) is each individual respondent in the survey for this study; the alternatives are denoted a (a = 1, 2, …, A; no action, EEW with automatic gas shutoff, partial- and full retrofits for this study); and y_{ia} is the indicator variable for choice (1 if respondent i chose option a).

5.1.1 The assumption of IIA

The basic assumption of the conditional logit model is independence from irrelevant alternatives (IIA). The unobserved component of utility, ε_I, is assumed to be independent of one another (Train, 2009). That is, the probability of choosing alternative a over b is independent of the characteristics of other alternatives. Therefore, whether IIA is a plausible assumption depends on whether or not the unobserved components might be correlated (StataCorp, 2021). In terms of choice probabilities, IIA implies that the ratio P_{ia}/P_{ib} stays constant even if other alternatives become available to reduce the absolute probabilities of alternatives a and b.

The IIA assumption is an essential part of the conditional logit choice model. The probability of individual i choosing alternative a as seen in equation (2) is estimated by a conditional logit choice model as equation (3):

$$P_{ia} = \frac{e^{V_{ia}}}{\sum_{j=1}^{A} e^{V_{ij}}} \quad (3)$$

Equation (3) indicates the ratio of P_{ia}/P_{ib} is the ratio of e^{Via}/e^{Vib}. As no other alternatives enter e^{Via}/e^{Vib}, the probability ratio remains unaffected by the presence of other alternatives (StataCorp, 2021). Along with the IIA assumption, fixed coefficients are assumed by the conditional logit model; that is, coefficients do not vary across individuals.

5.2 Alternative- and case-specific variables

Choice models typically include two types of independent variables: alternative- and case-specific variables. The variables that can be characterized as attributes of the alternatives (e.g., price of each alternative) are called alternative-specific variables. Case-specific variables are characteristics of the individual (e.g., age, income) that do not vary across alternatives, but instead, vary across individuals, or cases. Given this distinction of the independent variables, the observed component of equation (1), V_{ia}, can be expressed as follows (adapted from StataCorp, 2021):

$$U_{ia} = X_i\beta + (z_iA)' + \varepsilon_i \quad (4)$$

$$V_{ia} = q_{ia}\alpha + r_i\delta_a + d_a \quad (5)$$

Equation (4) is a random utility model as seen in equation (1) but expressed in terms of alternative- and case-specific variables. $X_i\beta$ is the vector of alternative-specific variables and their coefficients, i.e., the price of each alternative that each respondent saw in this choice experiment; z_iA is a vector of case-specific variables and their coefficients, i.e., the covariates of interest, such as experience, risk perception, and perceived efficacy; and ε_i is the random component that is assumed to have an iid extreme value distribution. Equation (5) is the observed component of equation (4): a vector of alternative-specific variables is indicated as q_{ia} for individual i and alternative a, with α as coefficients, which for the choice experiment in the current study, was simply the price of each alternative (q_{ia}) and its coefficient (α) for respondent

i. Case-specific variables for individual i are expressed in vector form as r_i, with δ_a consisting of the coefficients of the case-specific variables for each alternative. The term d_a indicates the vector of alternative-specific constants.

Since case-specific variables are constant across alternatives for any given individual, they can only enter the model as interaction terms with each alternative except for the base alternative (StataCorp, 2021; Bateman et al., 2002). The conditional logit choice model command, *cmclogit* of Stata16 does this automatically and is used for this analysis.

5.3 Willingness-to-pay (WTP)

Choice experiments are commonly used to estimate how much an individual is willing to sacrifice for a marginal change in an attribute, or the *willingness-to-pay* for (WTP) for a marginal change in an attributed (Holmes et al., 2017). This marginal rate of substitution (MRS) between a change in, say, attribute 1 and payment can be expressed as below (ibid.):

$$\text{MRS} = (\partial V_{ia} / \partial q_{ia1}) / (\partial V_{ia} / \partial b_{ip}) \qquad (6)$$

where V_{ia} is the observed component of person i's utility from alternative a, as seen in equation (5); q_{ia1} is the level of attribute 1; and b_{ip} is the coefficient for the price (p) of each alternative. Equation (5) is essentially the ratio of the marginal utility of the attribute of interest and the marginal utility of money. Therefore, equation (6) can be rewritten as below (ibid.):

$$\text{Marginal WTP} = - \beta_{ia1} / \beta_p$$

which indicates that the marginal WTP is the ratio of the coefficient of the attribute of interest and the price coefficients.

In the choice experiment adopted for the current study, alternatives were made up of different protective measures instead of varying levels of attributes. Therefore, instead of an attribute coefficient, the linear combination of case-specific coefficients multiplied by the value of the respective case-specific variables plus the constant is used as the numerator in computing the marginal WTP. The linear combination is performed (1) using the sample mean of each variable (sample mean approach); and (2) using the values of each individual and then averaging across all individuals (individual value approach).

6. DATA AND VARIABLES

6.1 Dependent variable

As discussed in Section 4, whether or not a respondent accepted a specific bid amount for an earthquake protection measure was the dependent variable. Specifically, we used the binary indicator for each alternative, coding this "choice" variable as 1 if a particular alternative was chosen, and 0 otherwise.

The survey used in the current study presented two choice sets to respondents under randomly assigned earthquake probabilities and associated earthquake magnitudes, as described in Section 4. Each choice set consisted of first choosing between EEW, partial retrofits, or no action, followed by a choice between EEW, full retrofits, or no action. In the current study, the alternative chosen for each choice in a choice set is coded as 1 for choice (0 otherwise). The structure resembles that of a repeated choice setup (panel data), but because the models controlled for variations in earthquake probabilities as further discussed in Section 6.2.2, data is analyzed using conditional logit models.

6.2 Independent variables

6.2.1 Alternative-specific variables

The bid amount (monthly cost to household) entered the model as the only variable that varied across alternatives. Under the IIA assumption of the conditional logit model, this price coefficient was assumed to be fixed across individuals.

6.2.2 Case-specific variables

As previously discussed in Section 6.2, prior experience of a hazard, risk perception, and perceived efficacy of a protection measure are key factors that have been identified by theory and empirical findings as determinants of protective behavior intentions. In this study, hazard experience was included as a binary variable of whether or not an individual had experienced an earthquake. To account for the multifaceted nature of risk perception, two aspects of risk perception were included: the likelihood of an earthquake in Washington state, and the likelihood of being harmed from an earthquake. An additive index of the two variables was used as the risk perception variable for the models. Perceived efficacy was measured for both EEW and structural retrofits given that the set of alternatives presented to respondents was made up of both. Table 4.1 lists the case-specific variables used in the study.

Table 4.1 List of independent, case-specific variables

Variable	Question	Coding	Categories/Range
Experience	How many earthquakes have you experienced?	Binary (0, 1)	Yes/No
Risk perception	Sum of two indicators below	Ordinal (2-14)	
• Perceived likelihood of earthquake	How likely do you think you are to experience an earthquake here in Washington in the next five years?	Ordinal (1-7)	1-"Extremely unlikely (less than 0.1% chance)" to 7-"Extremely likely (more than 99% chance)"
• Perceived likelihood of harm from earthquakes	How likely do you think it is that an earthquake will harm you in the next five years?	Ordinal (1-7)	1-"Extremely unlikely (less than 0.1% chance)" to 7-"Extremely likely (more than 99% chance)"
Efficacy of EEW	"How much do you agree with the following statement? I would be better able to protect myself from earthquake risks, including death, with an earthquake early warning (a few seconds to ten seconds of warning)."	Ordinal (1-4)	1-"Strongly disagree" to 4-"Strongly agree" (No midpoint in scale)
Efficacy of retrofits	How much do you agree or disagree with the following statements? "Structural hazard mitigation, such as reinforced buildings, reduces the risk of death from earthquakes."	Ordinal (1-4)	1-"Strongly disagree" to 4-"Strongly agree" (No midpoint in scale)
Age	What is your age?	Continuous	18+
Sex	What is your sex?	Categorical	1-Female1, 2-Male
Income	What is your yearly household income?	Ordinal (1-6)	1-"Less than $25k" to 6-"$200k or more"

7. RESULTS

7.1 Descriptive statistics

7.1.1 Demographics

The mean age of the respondents in the sample was 49.5 (SD = 15.3) and the median age was 49. The proportion of males in the sample was higher at 55.4% than females (44.7%). The proportion that reported having a bachelor's degree or higher was 74.2%; 36.9% held a bachelor's degree, and 28.7% a master's or professional degree. Close to 57% reported a yearly household income higher than $100,000. Slightly over sixteen percent (16.3%) of respondents reported their annual household income as $49,999 or under, while 26.8% were in households earning "$50,000 to $99,999"; 27.5% were in the median category of "$100,000 to $149,999"; 13.1% reported that their household earned "$150,000 to $199,999" and 16.3% reported a household annual income of "$200,000 or more".

Of those included in this analysis, 69.8% reported owning their current place of residence, while 30.2% were renters. Those that reported "other" forms of living arrangement were excluded from the analysis as the choice experiment used one's amount of rent or home value for the price of the options.

Table 4.2 shows the comparison of the demographics between the sample for this study and the general population of King County, WA (U.S. Census Bureau QuickFacts 2019[6]). The median age of the sample was higher than that of King County in part because the eligibility for the survey was limited to those 18 and over. While the invitations to the survey were sent out to randomly to selected households within King County, respondents were more highly educated, with a higher median income, and more likely to be male and to own their own home than the King County population. It should be noted that actual participation was voluntary and therefore some degree of self-selection bias was likely involved in our results.

[6] Quick Facts 2019 currently available from the U.S. Census Bureau used in Table 4.2 include estimates updated as of July 2019 (median age, % of females) and ACS 2014-2018 estimates (median income, % with bachelor's degree or higher, home ownership).

Table 4.2 Comparison of sample to King County, WA population

	Sample	King County
Median age (in years)	49 (min: 18, max: 91)	36.8
% of females	44.7	49.7
% holding bachelor's degree or higher	74.2	51.4
Median income	"$100,000 to $149,000"	$89,418
Home ownership	69.8%	57.1%

7.1.2 Choice of protective measure

Nearly 60% of respondents in the sample chose to take no action over EEW with automatic gas shutoff, partial retrofits, or full retrofits. For the choice between Options A (EEW), B (partial retrofits), or no action as shown in Figure 4.1, a total of 60.5% of respondents chose no action across the two choice sets presented. This was followed by EEW (24.4%) and partial retrofits (15.0%). For the choice between Options C (EEW), D (full retrofits), or no action, 58.7% of respondents selected no action. The percentage of respondents that chose EEW and full retrofits was 21.5% and 19.7%, respectively. Figure 4.2 gives a graphical illustration of these percentages.

Figure 4.2 Percentage of respondents choosing each alternative

7.1.3 Earthquake experience and risk perception

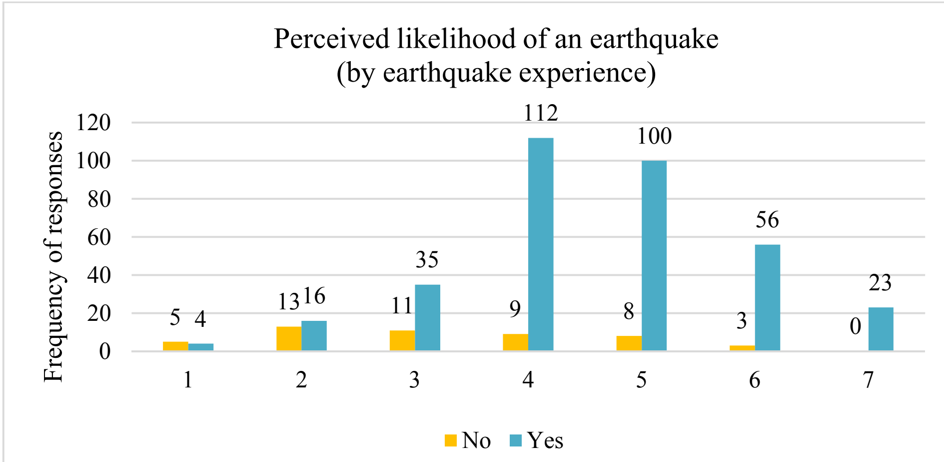
Of the respondents included in the analysis, 15.6% reported not having previously experienced an earthquake, as shown in Table 4.3.

Risk perception by earthquake experience was also informative for our analysis. Figure 4.3 shows the cross tabulation of the risk perception variables, *likelihood of earthquake* and *likelihood of harm from earthquake*. It was clear that a higher percentage of respondents with no earthquake experience ("None") said they were "extremely unlikely" or "very unlikely" for both risk perception measures. In addition, most respondents perceived the likelihood of earthquakes to be a toss-up or "likely" (see histograms labeled "Total"). Overall responses for perceptions of likelihood of personal harm from an earthquake were lower than the responses for likelihood of earthquake, as can be seen in the "Total" graphs of Figures 4.3 (a) and (b).

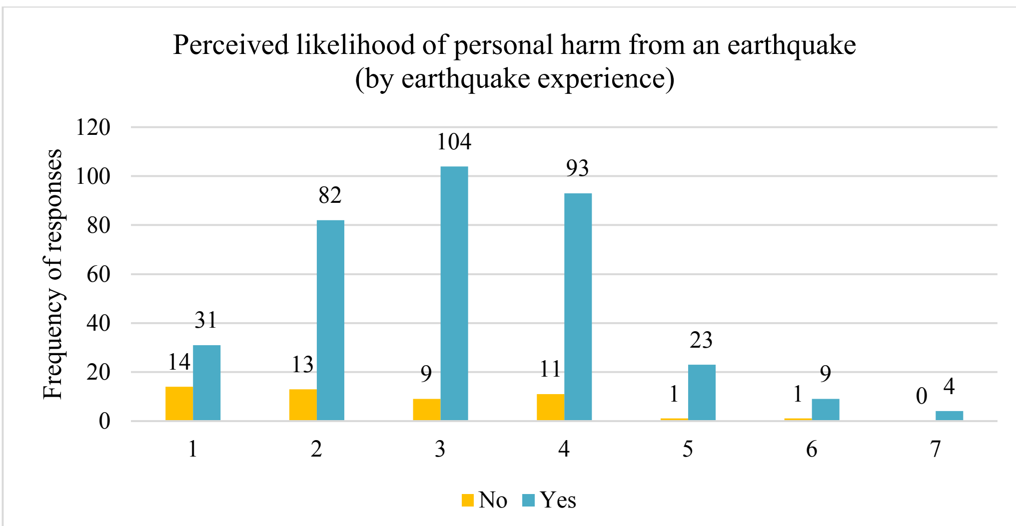
Table 4.3 Earthquake experience and subjective perceptions of earthquake risk and harm

Variable	Percentage
Earthquake experience	
No	15.2
Yes	84.8
How likely is an earthquake?	
Extremely unlikely (less than 0.1% chance)	2.5
Very unlikely (less than 10% chance)	8.2
Unlikely (less than 33% chance)	12.4
About as likely as not (33% to 66% chance)*	30.6
Likely (more than 66% chance)	26.2
Very likely (more than 90% chance)	13.6
Extremely likely (more than 99% chance)	6.5
How likely is personal harm from an earthquake?	
Extremely unlikely (less than 0.1% chance)	12.2
Very unlikely (less than 10% chance)	22.9
Unlikely (less than 33% chance)*	27.2
About as likely as not (33% to 66% chance)	27.5
Likely (more than 66% chance)	5.9
Very likely (more than 90% chance)	3.1
Extremely likely (more than 99% chance)	1.2

* Median response categories



a. Perception of likelihood of an earthquake in WA in the next five years by experience (Yes/No)



b. Perception of likelihood of personal harm from an earthquake in the next five years

Figure 4.3 Risk perception by earthquake experience

Response scale: (1) Extremely unlikely (less than 0.1% chance); (2) Very unlikely (less than 10% chance); (3) Unlikely (less than 33% chance); (4) About as likely as not (33% to 66% chance); (5) Likely (more than 66% chance); (6) Very likely (more than 90% chance); (7) Extremely likely (more than 99% chance)

7.1.4 Perceived efficacy

The median response category for perceived efficacy of EEW was “3-Agree.” About 53% of the respondents in the sample chose this category, and 30% chose “4-Strongly agree.” The median category for perceived efficacy of retrofits was also “3-Agree,” with 58% percent of respondent making this choice. An additional 39% chose “4-Strongly agree.”

7.2 Choice model results

7.2.1 Choice probabilities

The results indicated a near-zero effect of price on the choice probability of an alternative over taking no action (Table 4.4). The price coefficient was negative but very close to zero (-0.005) for the choice model with alternative- and case-specific models (note that the alternative-specific variable-only model is shown in Table 4.4, Column 1 for a comparison). This coefficient, however, was not significant. This indicated that the price of each alternative that was presented to respondents did not have an effect on the probabilities of the respondents choosing each of the alternatives over taking no action, contrary to the hypothesis. Perceived efficacy was found to be a significant determinant; the perceived efficacy for EEW significantly determined the choice probability for EEW with automatic gas shutoff (Column 2), and the perceived efficacy for retrofit significantly determined the choice probability for full retrofits (Column 4), but not partial retrofits (Column 3). Risk perception was significantly and positively associated with the choice probability of only full retrofits relative to taking no action and not the other two alternatives (Column 4).

The predicted percentage of individuals choosing each alternative (predicted probabilities) are shown in Table 4.5. Approximately 59% of the respondents were predicted to choose no action over the other alternatives from the model (Column 2; the predicted probabilities from the alternative-specific covariate-only model are provided in Column 1 for a comparison.). The percentage of individuals predicted to choose EEW with automatic gas shutoffs was 23%. Approximately 10% of respondents were predicted to choose full retrofits, and partial retrofits were least likely to be chosen, at 7.6%.

In contrast to the hypothesized effect of experience, the results did not show a significant or positive relationship. In fact, the signs of the non-significant coefficients for the experience variable were negative for all alternatives, indicating that the probability of choosing other alternatives in Table 4.4 over taking no action were lower for those with earthquake experience.

Risk perception was found to be significant and positive as hypothesized only in predicting the choice probability for full retrofits relative to taking no action. As shown in Table 4.6 (Column 1), the marginal effect of the risk perception variable used in the model (an additive index, summing "likelihood of earthquake" and "likelihood of harm from an earthquake") was a 0.035 decrease in the probability that one would choose "no action" and a 0.012 increase in the probability that the option of full retrofits is chosen, all else equal. The coefficients of the EEW and partial retrofit options were not statistically significant.

Perceived efficacy of the alternatives in providing personal protection was a significant and positive predictor for the choice probability of the respective alternatives, as hypothesized in Section 2 (Table 4.4). An increase in perceived efficacy of EEW, for example, was associated with an increase in the choice probability for EEW (Column 1). The choice probability for full retrofits was also significantly associated with higher perceived efficacy of retrofits (Column 3).

Table 4.6 shows the marginal effect of the key predictors on choice probabilities. A one-category increase of the risk perception variable was associated with a 0.035 decrease in the probability of one choosing no action, but with a 0.012 increase in the probability of choosing full retrofits (Column 1). A unit-increase of perceived efficacy of EEW was estimated to decrease the probability of choosing "take no action" by 0.109, and to increase the probability of choice for EEW by 0.097 (Column 2). Perceived efficacy of EEW was not significantly associated with either of the retrofit options. The marginal effect of perceived efficacy of structural retrofits on choice probabilities for full retrofits was 0.062 (Table 4.6, Column 3). The marginal effect estimate for partial retrofits was not significant.

The earthquake probabilities that were varied across choice sets were not found to be significant determinant of choice probabilities for each alternative. Among the demographic variables, only income was a significant predictor of choice probabilities.

Table 4.4 Choice model estimation results

The coefficients indicate the changes in the choice probabilities of each alternative relative to taking no action, estimated using conditional logit (the log of the odds ratio changes from a unit increase of each variable, holding all other variables constant). One coefficient was estimated for the alternative-specific variable *Bid (price)* indicating the effect of a one-unit change in the price of each alternative on the choice probability of each alternative over taking no action, holding all other variables constant. The coefficient estimates for each case-specific variable indicate the effect of a unit change of the variable on the choice probability for each alternative.

Variables	(1) No-covariate model	(Base alternative: No action)		
		(2) EEW w/ gas shutoff	(3) Partial retrofits	(4) Full retrofits
Bid (price)	-0.001		-0.005	
	(0.004)		(0.006)	
Earthquake hazard				
14% (M9)		0.245	-0.021	0.119
		(0.228)	(0.281)	(0.252)
26% (M6.5+)		0.216	0.020	0.087
		(0.241)	(0.290)	(0.272)
14-18% (M9)			(Base category)	
Experience (Yes)		-0.222	-0.748	-0.670
		(0.487)	(0.517)	(0.529)
Risk perception		0.141	0.164	0.219*
		(0.090)	(0.085)	(0.090)
Efficacy of EEW		0.656*	0.194	0.385
		(0.268)	(0.271)	(0.231)
Efficacy of retrofits		-0.017	0.539	0.852*
		(0.298)	(0.470)	(0.374)
Age		-0.007	-0.013	-0.020
		(0.012)	(0.016)	(0.015)
Sex		-0.171	0.472	0.675
		(0.347)	(0.400)	(0.381)
Income		0.293*	0.374*	0.410**
		(0.139)	(0.147)	(0.153)
Constant		-4.342*	-5.735*	-7.643***
		(1.866)	(2.478)	(1.958)
EEW	-0.821***			
	(0.234)			
Partial retrofits	-1.237***			
	(0.339)			
Full retrofits	-0.870*			
	(0.424)			
Obs. (cases)	944		820	
Obs. (individuals)	236		205	
Log-pseudolikelihood	-911.642		-718.415	
Wald chi2	0.12		43.94	
df	1		28	
Prob > chi2	0.733		0.028	

Notes
1) Robust standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)
2) Alternate rows shaded to improve visibility

Table 4.5 Predicted probabilities of choice for each alternative

The estimates show the predicted probabilities of choosing each alternative based on the results presented in Table 4.4. Each of the estimates shown in Column 2 is the percentage of respondents predicted by the model to choose the respective alternative. The estimates shown in Column 1 correspond to the "No-covariate model" in Column 1 of Table 4.4.

Alternatives	Model	
	(1) Alt-specific covariate-only	(2) Alt- and case-specific covariates
No action	0.579*** (0.030)	0.594*** (0.030)
EEW with automatic gas shutoff	0.239*** (0.025)	0.229*** (0.025)
Partial retrofits	0.078*** (0.011)	0.076*** (0.011)
Full retrofits	0.103*** (0.012)	0.101*** (0.013)

Note: Robust standard errors from Delta method in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

Table 4.6 Marginal effect of key variables on predicted choice probabilities

The marginal effects of key variables on the choice probability for each alternative are presented here. Each estimate indicates the effect of a unit increase (i.e., the marginal effect) of the variable on the probability of one choosing the respective alternative.

Alternatives	Marginal effect		
	(1) Risk perception	(2) Perceived efficacy of EEW	(3) Perceived efficacy of retrofits
No action	-0.035* (0.015)	-0.109* (0.043)	-0.062 (0.060)
EEW with automatic gas shutoff	0.015 (0.014)	0.097* (0.040)	-0.033 (0.045)
Partial retrofits	0.007 (0.005)	-0.001 (0.015)	0.033 (0.027)
Full retrofits	0.012* (0.006)	0.013 (0.015)	0.062* (0.025)

Note: Robust standard errors from Delta method in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

7.2.2 Willingness-to-pay (WTP)

The WTP estimates are shown in Table 4.7. From both the sample mean approach and the individual value approach, the estimated WTP for each alternative was negative and large in magnitude, with a large standard error. The WTP estimates, therefore, were not distinguishable from zero.

Further exploratory analyses for the EEW option were conducted using contingent valuation methods. The results from both a parametric approach and a non-parametric approach for contingent valuation are shown in Appendix 4.2. Parametric estimation results for the alternative EEW with automatic gas shutoffs using the contingent valuation method were similar to the findings from the choice models: WTP was negative with large standard errors. Estimation using the log of the price variable yielded a small positive amount, but this was still indistinguishable from zero. Non-parametric estimations that did not include the set of covariates used in this study are offered only for exploratory purposes, as indications of WTP for those who decided to pay a positive amount. The non-parametric models estimated the WTP of non-zero payers to be between $17 and $19.

Table 4.7 Willingness-to-pay (WTP) estimates for EEW, partial retrofits, and full retrofits

The WTP estimates presented below were calculated as linear combinations of the estimated coefficients (Table 4.4) and the observed values of the case-specific variables, divided by the price coefficient. The sample mean approach used the mean values for each case-specific variable in the model (averaged over all respondents) for the linear combination. The individual value approach used the values of the case-specific variables observed for each respondent, The estimates show that the WTP for the alternatives is not distinguishable from zero.

	WTP		
Model	EEW	Partial retrofits	Full retrofits
Sample mean approach	-182.69 (293.02)	-270.01 (439.89)	-183.59 (358.63)
Individual value approach	-216.59 (279.17)	-311.99 (402.13)	-229.05 (295.23)

Note: Standard errors from Delta method in parentheses

8. Discussion

The results suggested that those who perceived an EEW system as being effective for protection and those who perceived earthquake as more likely to harm them were more receptive to adopting an EEW system as a hazard mitigation measure. These results are consistent with and add to prior findings in the literature that find risk perception and perceived efficacy to be important determinants of behavioral intentions, as discussed in Section 2.3.

The negative price coefficient seen in Table 4.4 was consistent with the initial assumption of a downward sloping demand curve for hazard mitigation measures. However, the WTP estimates were effectively zero; they were negative, large in magnitude, and had large standard errors.

The zero WTP for adopting resource-intensive protection measures as presented in the choice experiment is consistent with the literature, as discussed in Section 1. The alternatives presented in the choice experiment, namely EEW with automatic gas shutoff, partial and full retrofits, were protection measures that not only required a monetary payment, but also presumably required some expertise, effort, and possibly cause some inconvenience by temporarily disrupting one's residence for installation. The sample used for this study consisted of respondents who had not previously implemented any retrofits, which may have been indications of either lower motivation or lower ability to adopt resource-intensive measures. Given that most respondents would have had little prior knowledge of how much resource would be required, a zero WTP may have been a reflection of their reluctance of adopting the proposed measures.

In a previous study (Dunn et al., 2016), respondents were prompted to report how much they would be willing to pay for an EEW app on their smartphone. The median willingness to pay was $1, and two-thirds of the respondents were willing to pay a non-zero amount. The difference between adopting an EEW-activate gas shutoff at home and installing an EEW app on a phone might be due to the level of difficulty associated with each of these two measures. If installing an EEW system at home appeared substantially more difficult and resource-intensive due to the lack of information about such a system that was not available at the time, respondents may have chosen to take no action regardless of the other variables. In contrast, installing an app on a smartphone is a common activity that most people find quite manageable and affordable. This perceived ease and affordability of installing an EEW app might have encouraged more respondents to be receptive to paying for EEW and led them to report a non-zero WTP amount.

In addition, the framing of the survey item asking respondents to make choices among alternatives may also have influenced responses. A tenet of prospect theory (Tversky and Kahneman, 1992; Kahneman and Tversky, 1979) is that reference points matter, and preference tends to be for the certainty of the status quo (reference point) rather than an uncertain outcome that may or may not result in a loss (Levy, 1992). Theories on mental accounting also suggest that household expenditures are grouped into various categories and even when the absolute amount of expenditure may be the same, expenditures from different categories can be perceived differently (Shefrin and Thaler, 2004; Thaler, 1999).

The survey item asked respondents if they were willing to, for example, install EEW with automatic gas shutoff at an *additional* monthly cost. Respondents may have seen the monthly payments as premiums to be paid for uncertain outcomes (i.e., potential monetary loss) because the probability of a damaging earthquake within the time that they are residing in their current home is highly uncertain. The significantly positive risk perception coefficient in the model for full retrofits (Table 4.4, Column 3) is an indication that indeed, those who perceived earthquake risks to be lower were less likely to pay the premium for full retrofits. When such uncertainty in outcome was combined with a price mismatch as discussed below in Section 8.1, respondents may have chosen not to pay this premium for protection measures, resulting in an effectively zero WTP estimate.

At the same time, in understanding the zero WTP estimates, consideration should be given to potential measurement issues. A few possible alternatives for the zero-dollar estimates of WTP that consider measurement issues are offered as below.

8.1 Unintentional neglect of price

One possible measurement-related explanation of price being a non-significant predictor of choice probabilities is that respondents may have disregarded prices in making a choice in order to express their preferences. Such disregard may have been intended or unintended. Unintended or subconscious neglect of information in a survey item and *satisficing* to produce a response may occur when respondents are faced with response burdens (Krosnick, 1991). Sufficient attention and cognitive efforts are required for respondents to comprehend questions and evaluate options and when either falls short, measurement errors may result (de Bruijne and Oudejans, 2015). Studies in survey research have indeed indicated that when respondents had trouble understanding the question due to factors such as complex logical structures and unfamiliar or technical wording, data quality were compromised (Lenzner et al., 2011; Graesser et al., 2006; Cannell et al., 1981).

The choice experiment used in this study was information heavy, as shown in Figure 4.1. It included information on earthquake magnitude, earthquake probabilities associated with a time frame, and protection measures that were unfamiliar to respondents[7]. It then asked respondents to assess the alternatives and choose one, taking into consideration the price of each in addition to

[7] The EEW-activated gas shutoff option was hypothetical because such a thing was not available in the region at the time of the survey, and therefore, respondents would have been unfamiliar with this option. In addition, we used a subset of the sample that had not installed retrofits in their homes, and therefore respondents would have not been familiar with the retrofit options either.

the background information. Although some findings in the literature have suggested that respondents in choice experiments do take prices into account in making their choices (Carlsson et al., 2007), how and to what extent the differences in prices affect choices, especially in an information-heavy context, is uncertain. It is possible that faced with a cognitive overload, respondents may have neglected to incorporate the difference in prices into the decision.

8.2 Protest responses

Intended disregard of the information in the choice experiment is also possible and commonly observed in stated preference surveys (Meyerhoff and Liebe, 2010). In the current study, about 60% chose to take no action over EEW, partial, or full retrofits, as mentioned in Section 7.1.2. While such responses may be “true” zeros that indicate a perceived value of zero for the option, the responses could also have been a form of protest, showing the respondent’s rejection of the constructed scenario in the choice experiment even if they associated an option with a positive value. If several observations in the survey data are characterized by such protest reactions, the alternative-specific price variable may be estimated as having little effect on choice probabilities.

Unless follow-up questions explicitly ask about the motivations for zero-responses, it is not possible to distinguish from survey data which responses are true zeros and which are protest zeros. Studies that did include such follow-up questions have found the proportion of protest votes among zero-responses to be sizable (Meyerhoff and Liebe, 2010). It has also been suggested that web-based surveys may see higher protest zeros than face-to-face ones (Nielsen, 2012).

Under this uncertainty in the responses, respondents may have expressed protest against the hypothetical scenario (Freeman III et al., 2014, p. 388; Hanley et al., 2003). That is, they may have disliked the proposed prices of the options, or believed that the hypothetical scenario of a high-magnitude in Washington state was unlikely. The latter possibility is less likely; one of the risk perception variables used in the study was the perceived likelihood of an earthquake in Washington in the next five years, to which about 77% of responses ranged from “4-About as likely as not (33% to 66% chance)” to “7-Extremely likely (more than 99% chance).”

The possibility of a mismatch between the proposed prices and the respondents’ perceived value is plausible. Especially for the respondents who were renters, a monthly payment to install fixtures to the property that they were temporarily renting may not have been appealing or the prices may have appeared too high. Even some homeowners who responded to the survey may have been willing to pay a lower price overall for the alternatives, and may have chosen to take no action in the choice experiment.

8.3 Study limitations and caveats

In addition to potential sources of measurement errors discussed in this section, a few limitations and caveats of this study should be noted. First, the WTP amounts from this experiment were derived from prices that were artificially set for each alternative based on the individual respondents’ monthly rent or home value. This format created artificial bounds; the actual WTP of each individual when facing different prices may vary. However, by linking the price levels that were presented to the respondents to their housing costs instead of applying the same costs to everyone, the differences in resource availability could be accounted for to some extent. In addition, once more information on the effectiveness of an EEW system becomes available to the public, WTP may change as public perceptions adjust with the new information.

Second, caution must be taken in applying the findings herein to the general population. The sample used in this survey characterized by (1) the sample demographics shown in Table 4.2, and (2) residents of homes that do not have structural retrofits or residents who have no knowledge of them. As explained in Section 3, survey invitations were sent out to a random address-based sample, but recipients of the invitations self-selected into taking the survey, resulting in some differences from the general King County demographics, as shown in Table 4.2.

9. Conclusion

Using a choice experiment, this chapter investigated the effects of earthquake experience, risk perception, and perceived efficacy of protection measures on the choice probabilities of EEW-activated gas shutoffs and seismic retrofits. Respondents' willingness-to-pay amounts for such measures were also estimated, although the estimates were effectively zero.

The results suggest that when communicating to the public about seismic risks, accurate and reliable information on the risks in terms of the probability of a damaging earthquake in the region, and the probability of individuals being harmed in one should be provided. In addition, it is important to emphasize the impact hazard mitigation measures can have on reducing the potential damages and harm caused by earthquakes, and how the benefits of the system can be maximized. The results of this study indicated that a better understanding of such factors may increase uptake of such measures. The residents of Washington state already seem to be receptive to the adoption of EEW system from previous research (Dunn et al., 2016) while seismic retrofits still remain a recommendation instead of a mandate. It is up to engineers, policy makers and implementers to ensure that the public receives accurate and timely information about what to expect in the event of an earthquake, and how they can prevent losses.

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EDIANS (MDS), AND CORRELATION COEFFICIENTS OF VARIABLES

M	Md	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
.60	1	1.00														
.23	0	-.14*	1.00													
.15	0	-.08*	-.05	1.00												
.20	0	-.09*	-.05*	-.03	1.00											
30	40.66	-.51*	.02	.10*	.24*	1.00										
.33	0	-.01	.01	.00	-.00	.03	1.00									
.34	0	.00	-.00	-.00	-.00	-.03	-.51*	1.00								
.33	0	.01	-.01	-.00	.01	.01	-.49*	-.50*	1.00							
.85	1	.03	.01	-.04	-.04	.06*	.03	.01	-.05	1.00						
7.45	8	-.04	.04	.01	.02	.01	-.02	-.02	.04	.32*	1.00					
3.10	3	-.07*	.07*	.02	.03	-.02	-.01	-.02	.04	-.05*	.01	1.00				
3.36	3	-.04	.00	.04	.05*	-.06*	.03	-.01	-.02	-.13*	-.16*	.20*	1.00			
49.45	49	.06*	-.02	-.05	-.06*	.12*	.02	.01	-.03	.29*	.15*	-.13*	-.13*	1.00		
1.56	2	.01	-.05	.03	.03	.01	-.03	.05	-.02	-.12*	-.28*	.02	.10*	-.01	1.00	
3.83	4	-.07*	.04	.05	.05*	.16*	.02	-.03	.01	.07*	-.12*	.04	-.05	-.15*	.19*	1.00

oice across both choices (A/B/No action, C/D/No action) and both choice sets are reported.
nce of correlation coefficient at $p<0.01$ level. Recommendations in the literature for significance-level adjustments for lowering the probability
ypotheses have been considered (Glickman et al., 2014) and the significance level at 0.01 which allows 1.4 false positives in the 136 pairwise
een chosen.

APPENDIX 4.2 DICHOTOMOUS CHOICE CONTINGENT VALUATION

While the setup of the stated preferences questions followed the format of a choice experiment, each option did not include varying levels of attributes. Choices of respondents could be modeled as a contingent valuation in which each respondent chooses to "Accept" or "Reject" a protective action based on price, or "bid" for exploratory purposes, given the negative and non-significant WTP estimates. For example, consider the case of a hypothetical respondent who made a choice among the options seen below in Figure 4.4:

Figure 4.4 Example of options in first task for a hypothetical respondent

Option A	Option B	
(EEW-activated gas shutoff)	(Partial seismic retrofits)	Take no action
$15	**$20**	**$0**

If the respondent's choice was Option A, she was effectively reporting a WTP of at least $15 to install an EEW-activated gas shutoff system. Similarly, if she chose Option B, her WTP for partial seismic retrofits was at least $20. Choosing to take no action indicated that her WTP for either EEW or partial seismic retrofits is below $15 and $20, respectively, including the possibility of a WTP of $0. For any of the three protective measure options that were presented in the sets (namely, EEW, partial retrofits, and full retrofits), it was possible to treat one's choice of a protective measure as an "Accept" or "Reject" response for a given monthly cost. It was also reasonable to assume that the respondent's WTP relative to the monthly cost presented were as follows:

- "Accept" : WTP ≥ Monthly cost
- "Reject" : 0 < WTP < Monthly cost; or

$$\text{WTP} = 0$$

This survey data allowed for a close-ended and single-bounded contingent valuation analysis. A dichotomous variable could be generated for whether a respondent accepted (coded as 1) or rejected (coded as 0) a specific option (such as an EEW-activated gas shutoff) for a given monthly cost, or bid. Using this binary variable as the dependent variable, the probability of an "Accept" response could be approximated, from which a mean WTP for that specific option could be estimated. Such dichotomous data was analyzed using parametric and non-parametric estimation.

Methods

Parametric estimation of WTP

The probability that one accepts a bid, in which case one's WTP, denoted as X, for a specific protective measure is at least, if not more than, the amount of the bid, x, can be expressed as follows.

$$Pr(Y\text{=Accept''}) = Pr(Y\text{=``Accept''} \mid x) = Pr(X \geq x)$$

Y is the binary dependent variable for whether a respondent accepts or rejects an option, given bid amount x. The probability of a respondent accepting a bid given the bid value of x is equal to the probability that the respondent's maximum WTP is greater than bid x.

Since the probability of "Accept" is defined as such, the probability of one's WTP being less than or equal to a specific bid is the cumulative density function (CDF or $F(x)$) of the WTP distribution. The probability of one's WTP being greater than the specified bid amount is simply

$$Pr(X > x) = 1 - F(x) \qquad (1)$$

With no covariates in the model. For the parametric estimation of WTP, assumptions must be made about the underlying probability distribution. For dichotomous choice contingent valuation that uses a binary dependent variable, a logistic distribution is a reasonable and frequently made assumption (Bateman et al., 2002; Giraud et al., 2001; Buckland et al., 1999). A no-covariate logistic regression that estimates the expected value of *Y* without any covariates other than the bid amount x_i is expressed as Equation (2). The notations and formulas are adapted from Buckland et al. (1999).

$$E(Y_i) = Pr(\text{“Accept”} \mid x_i) = \frac{1}{1+e^{-\beta(x_i-\mu)}} \qquad (2)$$

Equation (2) is the logistic probability of a respondent accepting bid x_i. In the formula, WTP is expressed as μ. This expression indicates that the term βμ (from when the linear component -β(x_i – μ) is expanded) is the constant. Equation (2) can be rewritten as equation (3) using the estimated coefficients from the logistic regression, *b* and *m* for β and μ:

$$\hat{y}_i = \frac{1}{1+e^{-b(x_i-m)}} \qquad (3)$$

The estimated probability of accepting bid amount x_i (i = 1, …, total number of bids), written as $\hat{y}_i$, is the dependent variable. The estimated parameters are *b*, which is the coefficient of the bid variable x_i, and *m*. The estimated constant, *bm*, can be rewritten as b_0 such that $bm = b_0$, and therefore, $m = b_0/b$. Since a logistic distribution is symmetric, *m* is both the mean and median WTP. The variance and covariance for this WTP point estimate, var(m) and cov(b, m), can also be estimated.

The model for the linear component of equation (3), $-bx_i - m$, is as follows for this study:

$$y = b(\text{Bid}) + b_0$$

With covariates in the model. For a WTP model with covariates other than the bid, equation (3) is modified as below:

$$\hat{y}_i = \frac{1}{1+e^{-b_0-(\sum_i b_i x_i)}} \quad (4)$$

Instead of bx_i from equation (3), the summation of all covariates multiplied by their coefficients is used. The estimated constant in equation (4) is b_0.

The linear component of equation (4) is as follows:

$y = b_0 + b_1$(bid) + b_2(earthquake prob. 14%) + b_3(earthquake prob. 26%) + b_4(earthquake experience) + b_5(earthquake likely) + b_6(harm likely) + b_7(EEW can protect) + b_8(retrofit can protect) + b_9(age) + b_{10}(sex) + b_{11}(income)

In this case, there are two ways to estimate of mean WTP (Buckland et al., 1999). A method commonly used in the literature is to average over all covariates except the bid variable.

Specifically, the mean of each covariate except the bid variable is multiplied by the respective coefficient, summed over along with the constant, and divided by the bid coefficient, as equation (5):

$$\text{WTP} = -\frac{\sum \bar{x}_i \hat{b}_i}{\hat{b}_1} \tag{5}$$

Here, $\bar{x}_i$ is the sample mean of each covariate, and $\hat{b}_i$ is the estimated coefficient corresponding to each covariate. The denominator is the estimated bid coefficient, b_1. While it is a simple way to estimate the mean WTP, this method is potentially biased in that the WTP amount computed this way is that of the "average person" in the sample who likely does not exist in the sample.

An alternative way to compute the mean WTP is to use each respondent's response values for the covariates instead of using the mean values for each covariate. Using this method, averaging across all respondents yields an estimate of the mean WTP of the sample.

Dealing with negative WTP. The logistic distribution assumes a continuous and symmetric distribution with tails that extend below 0 and above some upper threshold, such as one's income level. When using a logistic regression model, therefore, negative WTP amounts may result. While this characteristic may be useful in some studies, it is not desirable for many contingent valuation studies that seek to assess the value of an increased level of some nonmarket "good" that presumably has either no value or a positive value to respondents.

One way to restrict the estimated WTP to non-negative values is left truncation (Buckland et al., 1999; Bateman et al., 2002). This involves rescaling the probabilities of the distribution after truncating the logistic curve at $x = 0$. Another option that is simpler and is often sufficient for resolving the concern for negative WTP is a logarithmic transformation of the bid, x. Simply put, the natural log of the bid amounts, $ln(x)$, can be used in lieu of the actual bids for the probability of "Accept", as below:

$$E(Y_i) = \frac{1}{1+e^{-\beta[\ln(x_i)-\mu]}} \quad (6)$$

$$\hat{y}_i = \frac{1}{1+e^{-b_0-(b_i \ln(x_i)+\sum_j b_j x_j)}} \quad (7)$$

Equation (6) simply replaces the bid variable x_i from the no-covariate model, equation (2), with its natural log, $ln(x_i)$. Equation (7) shows the formula for the estimated probability model with covariates, where the log of the bid variable is expressed as $ln(x_i)$ and other covariates are denoted $b_j x_j$ (j=1, …, k for a total of k covariates). The estimated parameters are the beta coefficients, as seen in equation (4). From the log-logistic model of equation (7), the mean and median WTP are calculated as the following (Giraud et al., 2001; Hanneman, 1984):

$$\text{Mean WTP} = -e^{-b_0/b_i} \cdot \frac{\pi/b_i}{\sin(-\pi/b_i)} \quad (8)$$

$$\text{Median WTP} = e^{-b_0/b_i} \quad (9)$$

Here, the notation π is the constant of 3.141592, and the formula for mean WTP is the result of the numerical integration of the *pdf* in order to get the CDF as seen in equation (1). The mean WTP is sensitive to distributional assumptions and outliers that change the distribution, as seen in equation (8) which contains a component derived from a logistical distribution. By contrast, median WTP is not as sensitive to outliers or distributional assumptions as the mean (Bateman et al., 2002; Giraud et al., 2001; Kerr, 2000).

Nonparametric estimation of WTP

Estimating the parameters using econometric modeling as described in the previous section requires assumptions about the probability distribution. Using parametric models allows the researcher to adhere to the economic theory on WTP measurement and account for the randomness, or components that are unobservable to the researcher. However, the distributional assumptions made in parametric modeling renders the mean WTP estimate to be rather sensitive as previously mentioned.

Nonparametric estimation is an alternative approach. It takes the response probability as an unknown function of the bid amount and estimates the function at only the discrete bid levels in the form of step function (Carson & Hanemann, 2005). Generally, this approach results in an empirical estimation of the survival function of the WTP responses which results in lower-bound mean and median WTP estimates (Bateman et al., 2002; Kriström, 1990).

For single-bounded WTP responses from contingent valuation surveys, the survival function consists of point estimates at the bid levels presented in the surveys. The empirical estimate of the survival function at bid levels b_i (i = 0, 1, …, total number of bid levels I) is the following (Bateman et al., 2002):

$$\hat{S}(b_i) = \frac{n_i}{N_i} \qquad i = 0 \text{ to } I \tag{10}$$

Equation (10) is simply the survival function of bid levels, expressed as the ratio of the number of people accepting bid level i (denoted n_i) to the total number of respondents in the sample that got the bid level b_i (denoted N_i). Note that bid levels range from 0 to I; b_0 indicates the bid level of “0” and it is assumed that everyone is willing to pay at least zero (non-negative WTP assumption). Therefore, $S(b_0) = 1$.

A property of survival functions is that they are non-increasing. Simply put, the survival function should be non-increasing as the bid level increases. However, when plotting the point estimates of the survival function from contingent valuation survey responses, this property may be violated for some bid levels. A simple way to resolve this issue is through pooling adjacent bid levels where violation of the non-increasing property is seen (Bateman et al., 2002).

$$\hat{S}(b_i) = \hat{S}(b_{i+1}) = \frac{n_i + n_{i+1}}{N_i + N_{i+1}} \quad i = 0 \text{ to } I \qquad (11)$$

The pooling of adjacent bids is achieved by following Equation (11). Supposed that a non-increasing survival probability is detected at bid level 2, for example, because the survival probability at b_2 is greater than that of b_1. Pooling is achieved by taking the sum of the number of people accepting b_1 and b_2, and dividing that by the number of people presented with b_1 and b_2. This pooling process can be continued until non-increasing survival probabilities are achieved.

The median WTP under this method is the bid level at which the survival probability is 0.5. The mean WTP is the area under the survival function, calculated as Equation (12) below (Bateman et al., 2002):

$$\text{Mean WTP} = \bar{C} = \sum_{i=1}^{I} \hat{S}(b_i)[b_i - b_{i-1}] \qquad (12)$$

Estimating the WTP using this nonparametric approach produces lower bound estimates because the survival probability corresponding to the higher bid, b_i, is used for the segment between b_i and b_{i-1}.

The variance of mean WTP estimate from equation (12) can be calculated in two steps:

1. Calculate the variance of the population mean WTP (C) as below:

$$\text{var(C)} = \sum_{i=0}^{I}(b_i - \bar{C})^2\,(\hat{S}(b_i) - \hat{S}(b_{i+1}))$$

2. Calculate the variance of the estimated mean WTP ($\bar{C}$) as the variance of C divided by the sample size, N as below:

$$\text{var}(\bar{C}) = \frac{var(C)}{N}$$

One of the biggest limitations of this method, however, is that the covariates other than the bid variable do not directly enter the model, similar to the no-covariate, constant-only parametric estimation.

Results

Parametric estimation of WTP

The parameters from both a no-covariate model and a model with a full set of covariates including sociodemographic variables were estimated as equations (3) and (4).

The bid coefficient, *b*, of the no-covariate model was negative, as expected, and significant as shown in Table 4.8, Column 1. A negative bid coefficient was the marginal effect of an increase in bid amount on the logistic probability of one accepting the bid decreases. The constant, b_0, was negative (-0.727) and not significant. Specifically, using the coefficients in Column 1, Equation (4) can be rewritten as below:

$$\hat{y}_i = \frac{1}{1+e^{0.727+0.006(Bid)}} \tag{13}$$

The predicted probability of a respondent accepting a bid of, say, \$50 would then be about 0.22 according to Equation (13).

The bid coefficient, b_1, from the model with the full set of covariates was also negative and significant, at the 90% level (Table 4.8, Column 2). The constant, b_0, was negative and non-significant. Similar to Equation (13), Equation (4) can be rewritten by substituting the coefficients in the linear combination component of the exponent.

Among the covariates, likelihood of getting harmed by an earthquake, perceived effectiveness of EEW, perceived effectiveness of retrofits, and income were significantly associated with the probability of choosing EEW. As expected, all of the coefficients corresponding to these covariates were positive, confirming that a heightened perception of risk and effectiveness, as well as income increased the probability of one choosing to pay something for EEW.

The mean WTP for both models estimated from these results are shown in Table 4.9. The WTP for EEW estimates from the no-covariate model and the full model were not significantly different from zero. As discussed in the previous section, a different model that restricted a negative WTP outcome was used to resolve this.

A log-logistic model was estimated to tackle the negative WTP by taking the log of the bid amounts and using that in lieu of the actual bid amounts as the bid variable in the model. The logged bid coefficients and constants from both the no-covariate model and the full model were negative but non-significant except for the constant of the full log model (Table 4.8, Columns 3 and 4). The WTP estimates of the log-logistic model models are shown in Table 4.10. The WTP from the no-covariate model was now $18.86 and $0.01 from the full model, both with large standard errors indicating effectively zero WTP.

Table 4.8 Parametric model estimates of coefficients on bid acceptance probability

	(1)	(2)	(3)	(4)
Covariates	No covariate	With covariate	No covariate (log bid)	With covariate (log bid)
Bid	-0.006	-0.010		
	(.006)	(0.010)		
Earthquake prob: 14%		0.206		0.208
		(0.159)		(0.155)
Earthquake prob: 26%		-0.028		-0.029
		(0.189)		(0.212)
Earthquake experience (Y/N)		0.332		0.332
		(0.405)		(0.407)
Risk perception		0.108		0.108
		(0.082)		(0.072)
EEW is effective		0.514**		0.515*
		(0.168)		(0.204)
Retrofits are effective		0.075		-0.071
		(0.245)		(0.249)
Age		-0.008		-0.008
		(0.010)		(0.009)
Sex		-0.213		-0.213
		(0.271)		(0.251)
Income		0.226*		0.232
		(0.108)		(0.126)
Log(Bid)			-0.24	-0.399
			(0.24)	(0.350)
Constant	-0.727*	-3.753**	-0.10	-2.779
	(.325)	(1.354)	(0.90)	(1.909)
Obs. (cases)	770	660	770	660
Obs. (individuals)	385	330	385	330
Log-pseudolikelihood	-447.615	-360.406	-447.303	-360.019
Wald chi2	0.88	34.39	1.30	19.75
df	1	10	1	10
Prob > chi2	0.349	0.000	0.002	0.057

Robust standard errors in parentheses (*** p<0.001, ** p<0.01, * p<0.05)

Table 4.9 Willingness to pay for EEW estimates from logistic models

Model	WTP	S.E.	95% Confidence interval Lower	Upper
No covariates	-123.83	185.57	-487.54	239.88
Full				
Sample mean approach	-62.50	99.73	-257.97	132.96
Individual value approach	-75.73	69.54	-212.02	60.56

Table 4.10 Willingness to pay for EEW estimates from log logistic model

Model	WTP	S.E.	95% Confidence interval Lower	Upper
No covariates	18.86	524.37	-1008.87	1046.60
Full model	0.01	0.07	-0.12	0.14

Nonparametric estimation of WTP

WTP was also estimated using a nonparametric approach to provide a comparison with the parametric estimation results. Survival functions described in the previous section were used. This method did not allow for accounting the two choice sets varied by earthquake probabilities and magnitudes. We therefore estimated the results from each set separately and compare the results.

The survival functions of the data collected from the first sets, following equation (10), are shown in Table 4.11. As can be seen in the column for $S(b_i)$, the "survival" probabilities from the survey data were not non-increasing. The method of pooling adjacent bid levels following equation (11) was used, as shown in the next column. Three iterations of pooling were required to achieve non-increasing probabilities.

Table 4.11 Survival function by bid level (Set 1)

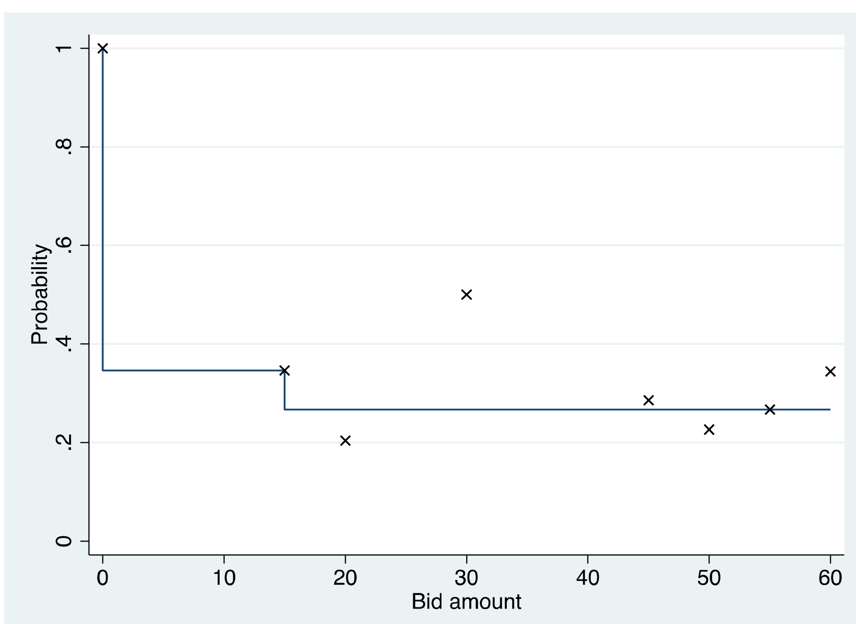
b_i	N_i	n_i	$S(b_i)$	$S(b_i)$ (pooled)
0	-	-	1	1
15	26	9	0.35	0.35
20	49	10	0.22	0.27
30	8	4	0.5	0.27
45	7	2	0.29	0.27
50	84	19	0.23	0.27
55	150	40	0.27	0.27
60	61	21	0.24	0.27
Total	385	105		

Figure 4.5 illustrates the data in Table 4.11. Note that all respondents were assumed to be willing to pay $0 and therefore the probability at bid amount $0 was set as 1. The step curve shows the pooled survival probabilities for each bid level. The original, unpooled probabilities are shown with X marks. The median WTP in this case is where the probability is 0.5, and therefore is $0. The mean WTP is calculated as equation (12), and is simply the area under the survival step curve.

$$\text{Mean WTP} = (0.35 * 15) + (0.27*45) = 17.40$$

Compared to the mean WTP of $4.67 that was computed from the no-covariate parametric model, the mean WTP from the nonparametric model was quite high. It should be noted that the mean WTP using the survival probabilities was the WTP for people who were willing to pay something because it was assumed that everyone was willing to pay at least zero, and those who were not willing to pay above zero were not accounted for in the model.

Figure 4.5 Survival probability by bid level (Set 1)



A nonparametric WTP estimation was done with the second sets following the same procedure. Table 4.12 shows the survival probabilities by bid level. Similar to the results in Table 4.11, the survival probabilities violated the non-increasing property and therefore were pooled.

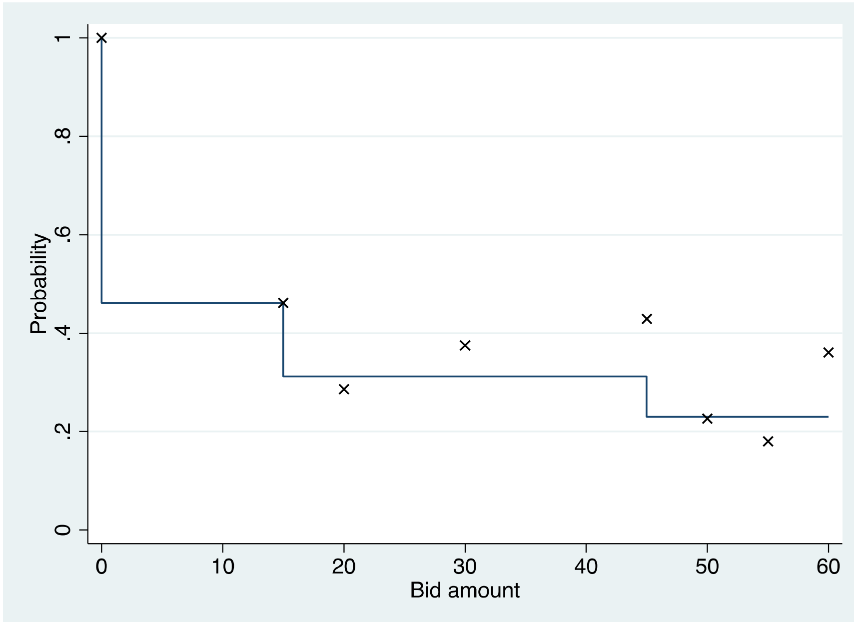
Table 4.12 Survival function by bid level (Set 2)

b_i	N_i	n_i	$S(b_i)$	$S(b_i)$ (pooled)
0	-	-	1	1
15	26	12	0.46	0.46
20	49	14	0.29	0.31
30	8	3	0.38	0.31
45	7	3	0.43	0.31
50	84	19	0.23	0.23
55	150	27	0.18	0.23
60	61	22	0.36	0.23
Total	385	100		

Table 4.12 is graphically shown in Figure 4.6. As with Figure 4.5, the unpooled survival probabilities are marked with Xs. The median WTP was also zero for Set 2 responses. The mean WTP was as follows:

$$\text{Mean WTP} = (0.46*15) + (0.31*30) + (0.23*15) = 19.65$$

Figure 4.6 Survival probability by bid level (Set 2)



The negative price coefficient was consistent with the initial assumption of a downward sloping demand curve for hazard mitigation measures and the estimates from the choice models. However, the WTP estimates remained negative and non-significant. The log-logistic model with the full set of covariates indicated a small WTP amount with a large standard error. The no-covariate, constant-only models that was estimated suggested WTP amounts of about $18; the parametric WTP estimate was $18.86 but did not differ significantly from zero. The nonparametric WTP estimates for the two sets of choices that individuals made averaged to $18.53. However, the no-covariate, constant-only models were estimated for comparison purposes only, as they allowed a comparison of the parametric estimate to the estimate from the nonparametric model that did not incorporate covariates other than the bid amounts. The WTP estimates was effectively zero and inconclusive.

Chapter 5. CONCLUSION

The studies herein examined the effects of hazard experience, risk perception, perceived efficacy of protection measures, and metacognitive confidence in perceived efficacy on people's intentions to pay for such measures to mitigate earthquake risks. The decision process leading up to one's forming of intentions to adopt protection measures against natural hazards involves the individual's consideration of external cues including social and environmental factors, and personal experience that inform the appraisal of the risks and available protective action options (Keller et al., 2012; Morgan et al., 2002). The mechanisms by which these factors influence adoption intentions can be quite complex (Eiser et al., 2012). This dissertation aimed to cast light on the role of hazard experience as a pre-decisional variable, and perceptions of risk and efficacy as appraisal variables on determining one's willingness to pay for earthquake protection measures as the behavioral intention variable.

Chapter 2 confirmed that the importance of perceived efficacy as a determinant of intended payment amounts for structural retrofits also applies to Western Washington. Metacognitive confidence of perceived efficacy did not have moderating effects as hypothesized in the region, adding evidence to the small, but growing body of literature on the effects of metacognition on protective action decisions for natural hazards. This chapter is one of the first studies to apply the metacognitive model to examine the relationship between perceived efficacy of protective measures and people's intentions to pay for the protective measures. The results found that in King County, WA, metacognition in perceived efficacy did not play a role in predicting behavioral intentions. However, the results open up a new avenue of research in metacognition and disaster preparedness. Further investigation would be beneficial on whether the role of metacognition in preparedness decisions as it pertains to perceived efficacy and possibly other predictors is indeed small, or if further methodological considerations as discussed in the chapter would suggest other possible relationships.

As an example, future studies could compare the effects of metacognition pertaining to past protective behavior decision versus a hypothetical protective behavior decision. This study found no moderating effect of metacognition for perceived efficacy of retrofits, which respondents had not implemented in the past. However, another study (Goldberg et al., 2020) found metacognition to have a moderating effect on past hurricane evacuation decisions in determining future intentions to evacuate. Findings from a meta-analysis have suggested that attitudes and actual behavior were more strongly correlated when one had (1) direct experience of an attitude object; and (2) higher confidence that they were correct in their attitude about an object (Glasman and Albarracín, 2006). Considering these factors, an area for investigation is the effects of metacognition on protective behavior or intentions based on different attitude objects.

Chapter 3 provided an international comparison of people's perceptions of earthquake risks and EEW between the city of Sendai, Japan and Seattle, WA, adding to the important disaster research literature of international comparative studies on extreme events. Despite the differences in terms of the numbers of and intensities of earthquakes in the two cities and availability of EEW, the variables of interest, namely perceived likelihood of harm and perceived efficacy of EEW, were found to be important determinants of WTP for EEW in both cities. This study also tested and presented the results of a double hurdle model, a method commonly adopted for research in decision-making related to other topics but rarely in disaster research. The results suggested that protective action decisions, measured as WTP for an EEW app in the King County area, may be two-staged; that is, people may first decide whether they are willing to pay for or adopt a protective measure, and subsequently, decide on the amount to pay or the extent of adoption.

Based on these findings, future studies on whether the decision to take protective action is also a two-stage decision are recommended, with special attention to the measurement of variables. Specifically, when investigating household decisions to adopt protective measures, two factors can be considered in this context: (1) whether the first question they consider is to adopt protective measures at all, followed by how much or to what extent they should adopt them, and (2) if the decisions are indeed two-staged, whether or not the same set of variables can be used as predictors in both decisions. In addition, variables should be adapted to suit local contexts if and when possible. As discussed in the main text of the chapter, for example, the finding that fear association with earthquakes was not a significant determinant of WTP in Sendai raised questions of whether a ceiling effect took place, i.e., the highest response category was not high enough given the intensities and consequences of recent earthquakes in the region.

Chapter 4 used a choice experiment to examine how the key variables of interest influenced choice probabilities of resource-intensive protective measures and people's WTP for such measures. Unlike many other studies in disaster research, this study was designed to specifically examine the effects of covariates on the choice probabilities and compute the WTP from that. The chapter confirmed the importance of perceived efficacy in protective action decisions in the region; it was a significant determinant of the probability that King County residents would choose to adopt a resource-intensive protective measure over taking no action. The results also verified that in King County, people are likely to choose no action over resource-intensive protective measures, and that they are not willing to pay for such measures. This zero WTP estimate may be reflective of people's reluctance for adopting resource-intensive protection measures, which is consistent with findings in the literature. If resource requirements indeed serve as impediments to protection measure adoption in Western Washington as suggested by these results, it indicates a need for policy action to promote voluntary or mandatory uptake of such measures to ensure the public's safety in the event of a high-magnitude earthquake.

The aim of this dissertation was to promote a better understanding of public attitudes toward hazard preparedness. The three studies included in this dissertation were designed and conducted with the goal of improving our understanding of how individuals' preparedness decisions are shaped. Taken together, the findings of this dissertation indicated that people's intentions to pay for costly hazard mitigation measures were low, and that perceived efficacy was a strong determinant of intentions to pay in King County, WA. For natural hazards to gain attention in the political realm and reach the policy agenda-setting stage, focusing events serve a crucial role, revealing current and potential future risks and the areas that need to be addressed by policy (Birkland and Schwaeble, 2019; Birkland, 1997, p. 49). Given the generally low intentions of households to voluntarily adopt resource-intensive hazard mitigation measures, attention must be given to how individual actors can be persuaded to adopt protection measures in the absence of recent focusing events of high-magnitude earthquakes in the region.

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