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A Systematic Assessment of Socio-Economic Impacts of Prolonged Episodic Volcano Crises

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A Systematic Assessment of Socio-Economic Impacts of Prolonged Episodic Volcano Crises

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of the requirements for the degree
Master of Science in Geosciences
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by
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May 2019

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ABSTRACT

A Systematic Assessment of Socio-Economic Impacts of Prolonged Episodic Volcano Crises

by

Justin B. Peers

Uncertainty surrounding volcanic activity can lead to socio-economic crises with or without an eruption as demonstrated by the post-1978 response to unrest of Long Valley Caldera (LVC), CA. Extensive research in physical sciences provides a foundation on which to assess direct impacts of hazards, but fewer resources have been dedicated towards understanding human responses to volcanic risk. To evaluate natural hazard risk issues at LVC, a multi-hazard, mail-based, household survey was conducted to compare perceptions of volcanic, seismic, and wildfire hazards. Impacts of volcanic activity on housing prices and businesses were examined at the county-level for three volcanoes with a "very high" threat designation from the U.S. Geological Survey (USGS); LVC, (caldera system), Mount St. Helens, WA (stratovolcano), and Kīlauea, HI (shield volcano). A negative relationship was found between volcanic risk perception and preparedness. Additionally, the perception that housing prices declined after volcano alerts was confirmed by econometric modeling.

ACKNOWLEDGMENTS

I would first like to thank my committee chair, Dr. Chris Gregg, for providing me with opportunities to be involved directly with the disaster science community and world-class training. My gratitude extends to my expert committee members, Drs. Michael Lindell, and Andrew Joyner. Dr. Lindell's mastery of statistical methods and socio-cognitive and behavioral science theory underscore the importance in multidisciplinary hazards research. Dr. Joyner's proficiency in big data analytics and enthusiastic expertise in advanced geospatial applications improved the quality of my graduate research.

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CHAPTER 1

INTRODUCTION

The public response to elevated unrest at the Long Valley Caldera (LVC), California, USA, has been a case study of focus in natural hazards studies for decades. Planning documents (Mader 1987), socio-economic studies (Bernknopf et al. 1990), and studies on challenges in risk communication and Volcanic Alert Level Systems (VALS) (Fearnley et al. 2012; Hill et al. 2017) have discussed resentment of the scientific community by the public following a "Notice of Potential Volcanic Hazard," released in 1982. Although no eruption occurred, a temporary local economic crisis radiated from a perceived loss of tourism to the ski destination town of Mammoth Lakes, CA on the southwest rim of the LVC.

Volcanic events (unrest & eruptions) are physical phenomena while volcanic crises are social (Gregg and Houghton 2006). Furthermore, indirect losses are related to, but not entirely dependent on direct, physical losses due to hazard activity (Lindell et al. 2006). Therefore, this study first examined how perceptions of volcanic risk differed from wildfire and earthquake hazards at LVC. Then, economic trends were examined from 1974 to 2016 between three different volcanic regions in the United States—LVC, (caldera system), Mount St. Helens, WA (stratovolcano), and Kīlauea, HI (shield volcano).

In contrast to unrest at LVC, Kīlauea Volcano on Hawaiʻi island has been erupting almost continuously since 1983, and exposure to lava flows has inundated subdivisions (Poland et al. 2015; Neal et al. 2019). Additionally, the May 18, 1980 eruption of Mount St. Helens was the deadliest and costliest volcanic event in U.S. History. Financial losses were estimated at $1.1 billion USD ($3.3 billion adjusted) by the United States International Trade Commission (USITC), (1980). There were also 57 confirmed human casualties(Brown et al. 2017).

Study 1

To understand present community attitudes towards volcanic hazards in comparison to earthquake and wildfire hazards, we conducted a mail-based household survey (ETSU IRB#: c1017.18sd).

Theoretical Background

The perception of a hazard and behavioral responses to disasters are often more influenced by the societal nature of a geographic region rather than geophysical conditions. (Torry et al. 1979; Gaillard and Dibben 2008). Whether or not a person will change their behavior to adopt a protective action, depends on whether are motivated to adjust their lives to confront a potential threat (Weinstein and Nicolich 1993). The prediction that risk perception is the motivation for protective action follows from a number of theories such as Protection Motivation Theory (Rogers 1975; Floyd et al. 2000) and the Protective Action Decision Model (PADM) (Lindell and Perry, 1992; Lindell 2018). The framework of this study was utilized in previous research that has also explored the relationship between personal perception of volcanic risk and the behavioral response of adopting protective actions(Perry and Lindell 1990; Perry and Lindell 2008; Reeves 2018).

Research Objective

Study one examines how psychological variables including risk perceptions and hazard awareness as well as exogeneous variables such as scientific risk indicators (e.g., hazard zone proximity) and demographic variables influence the behavioral response of taking a protective action. This multi-hazard framework could provide insight on how different hazards are perceived in the same region. Additionally, issues in risk communication could be identified.

Study 2

Data on County Business Patterns (CBP) from the Statistics of U.S. Businesses (SUSB), and Housing Price Indexes (HPI) (Bogin et al. 2016) were collected from 1974-2016. These data were analyzed in time series to understand differences in economic trends during prolonged volcanic unrest and eruptions.

Theoretical Background

The indirect losses that often follow natural disasters have been a topic of focus in socio-economic journals for decades. Examples include, regional housing price impacts after earthquake (Murdoch et al. 1993), wildfire (Donovan et al. 2015), flood (Bin and Landry 2008), and hurricane (Ewing et al. 2007). Hazard proximity and impacts on housing prices have been examined for a variety of natural and technological hazards, often with inconsistent results. Generally, property located within or near flood hazard zones is lower than housing prices in less vulnerable areas (Bin and Landry 2008; Zhang and Cheng 2019). Furthermore, housing prices were found to decline regionally following tornado and hurricane events (Ewing et al. 2007) and large earthquakes (Murdoch et al. 1993). Still, some studies have found no significant difference between property values inside and outside of flood zones (Babcock and Mitchell 1980; Damianos and Shabman 1979; Fried et al. 1999; Zhang et al. 2009).

Research Objective

This study examined whether or not volcanic eruptions have a similar effect on economic trends as simply the issuance of a volcanic alert. Since direct losses are not necessary for an economic crisis to occur, (Lindell et al. 2006), this study considers volcanic eruptions and volcanic alerts as separate variables. This study does not attempt to assess the accuracy of volcanic alert levels over time, but rather analyses employ econometric time series regression models to observe economic indicator trends during times of increased volcanic alert levels and potentially hazardous volcanic episodes as separate variables for U.S. counties at risk of exposure to hazards from three volcanoes—LVC, Mount St. Helens, and Kīlauea volcano, along with a non-volcanically active control region, Steamboat Springs, CO.

CHAPTER 2

RISK PERCEPTIONS AND MULTI-HAZARD PREPAREDNESS AT LONG VALLEY CALDERA, CALIFORNIA

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ABSTRACT

Exposure to escalating volcanic unrest can lead to socio-economic crises with or without an eruption, as demonstrated by the post-1978 response to caldera unrest of the Long Valley Caldera, USA. Extensive research in volcano science of the Long Valley Volcanic Region (LVVR) provides an understanding of volcano-seismic activity, but comparatively fewer resources have been dedicated to understanding human processes in response to volcanic hazards and risk there. To understand community attitudes about relevant natural hazard risk issues, we conducted a multi-hazard, mail-based, sample survey research (N=229) study of 1,209 households to compare volcanic hazards with seismic and wildfire hazards in the region. The study utilizes aspects of the Protective Action Decision Model (PADM) to understand how varying degrees of exposure to hazards (e.g., volcano, earthquakes, wildfire) may affect the relationship between risk perceptions and adoption of hazard adjustment/mitigation strategies. A negative relationship was found between risk perception factors and emergency preparedness for volcano hazards. That is, in this dataset, perceptions of higher volcanic risk are reported by those who also tend to adopt fewer protective actions.

1. INTRODUCTION

Volcanic eruptions, unlike some other geologic hazards such as earthquakes, are often preceded by months to years of clear precursors (e.g. volcano seismicity, increased fumorolic activity, ground deformation and gas emissions) which offer opportunities to reduce volcanic risk, so long as community stakeholders are engaged in the risk management process. Still, exposure to volcano hazards can lead to crises; with or without an eruptive event. Therefore, it is important to distinguish that volcanic events (unrest & eruptions) are physical phenomena, while volcanic crises are social (Gregg & Houghton, 2006). The onset of prolonged volcanic unrest in the Long Valley Caldera (LVC) and the public response centralized around the resort community of Mammoth Lakes in the 1980's emphasized the importance of identifying challenges in risk communication. Records of meetings held by scientists from the United States Geologic Survey (USGS) and the California Office of Emergency Services (CalOES) following the release of a volcano hazard warning suggest confusion about the uncertainty surrounding volcano hazard potential, and resentment of the scientific community by the public (Mader, 1987). A poor economic climate and temporary decline in tourism following the notice shifted concern from public safety to adverse impacts on previously thriving business and housing markets (Mader, 1987). Although the level of volcanic unrest of the LVC has declined since 2001 relative to levels from 1978 to 2000, the volcanic potential remains, so it is important to examine the perception of volcanic risk with respect to natural hazards of which exposure is more frequent and persistent.

The framework of this study was utilized in previous research that has also explored the relationship between personal perception of volcanic risk and the behavioral response of adopting protective actions (Perry & Lindell, 1990; Perry & Lindell, 2008; Reeves, 2018).

Comparatively fewer designs have observed volcano risk perceptions in a high threat, multi-hazard environment (Perry & Lindell, 2008). This study explored the relationship between householder risk perception of and preparedness for volcano, earthquake, and wildfire hazards in communities surrounding the LVC, which has experienced episodic volcanic unrest and faced variations in volcano hazard communication over the past four decades.

2. GEOGRAPHIC SETTING AND SOCIAL CONTEXT

The LVC was formed approximately 760 ka when 600 km3 of magma was ejected during the eruption of the Bishop Tuff. The aftermath of the eruption left a 16 by 32-km depression in Earth's surface, bound by the Sierra Nevada Mountains to the west and the White Mountains to the east. On the southwest rim of the LVC lies Mammoth Mountain, a 3,369 m steep-sided cone volcano formed by a series of dome-building events from 110-60 ka (Hildreth & Fierstein, 2016). The volcano boasts a prominent ski-tourism industry, with the town of Mammoth Lakes positioned on its flank. From the western rim of the LVC, the Mono-Inyo Craters system stretches 40 km northward towards Mono Lake. The southern Inyo craters were formed from 5.5-0.6 ka, and the northern Mono domes were formed from 65-0.6 ka. The Mono-Inyo craters system, along with Mammoth Mountain and LVC, form a complex volcanic system which is commonly referred to as the Long Valley Volcanic Region (LVVR), which collectively occupies areas of two state counties— Mono and Inyo. The most recent eruption in the LVVR occurred at Paoha Island in the middle of Mono Lake, around 1700 A.D. (Bevilacqua et al., 2018). The town of Mammoth Lakes, hosts a permanent population of ~8,000, which fluctuates to over 40,000 during peak tourism (Hill et al., 2017). Some 58% of the total population of Mono County lives in Mammoth Lakes, and 60% of total business establishments in the county are within 10 km of town center (U.S. Census Bureau, 2010). Inyo County population follows a similar distribution, with some 68% of the population residing in and around the immediate proximity of the town of Bishop, in North Inyo County, approximately 65 km from Mammoth Lakes. (Fig. 2.1).

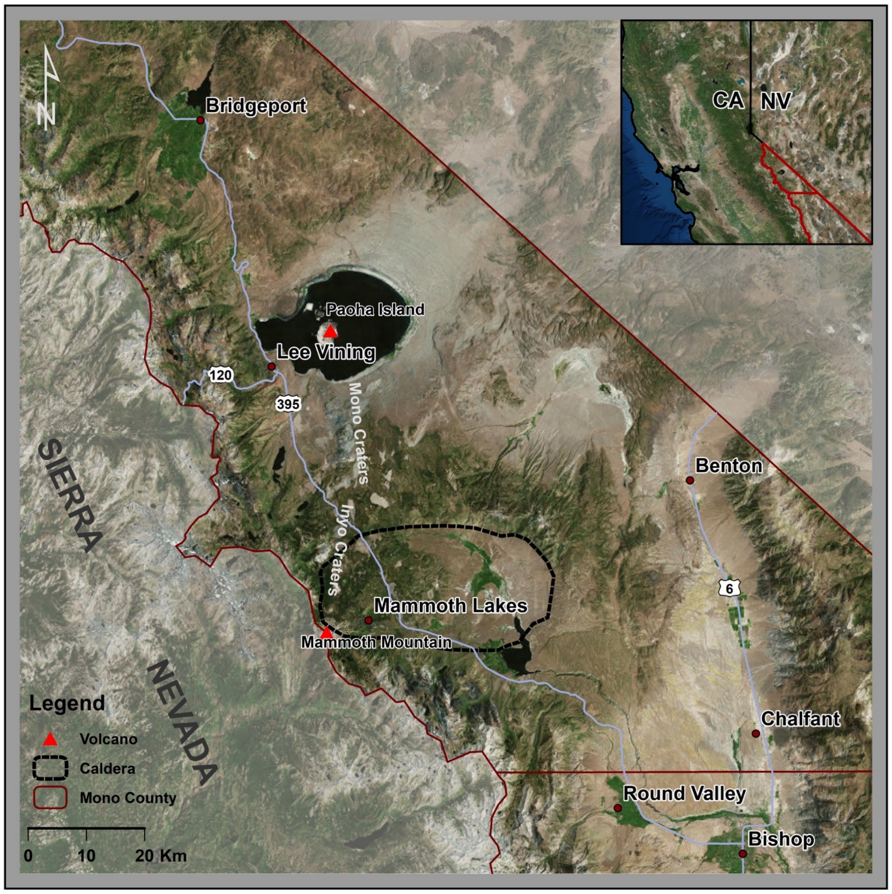


Fig. 2.1: Map of the Long Valley Volcanic Region (LVVR).

2.1. Volcanic Unrest and Risk Communication

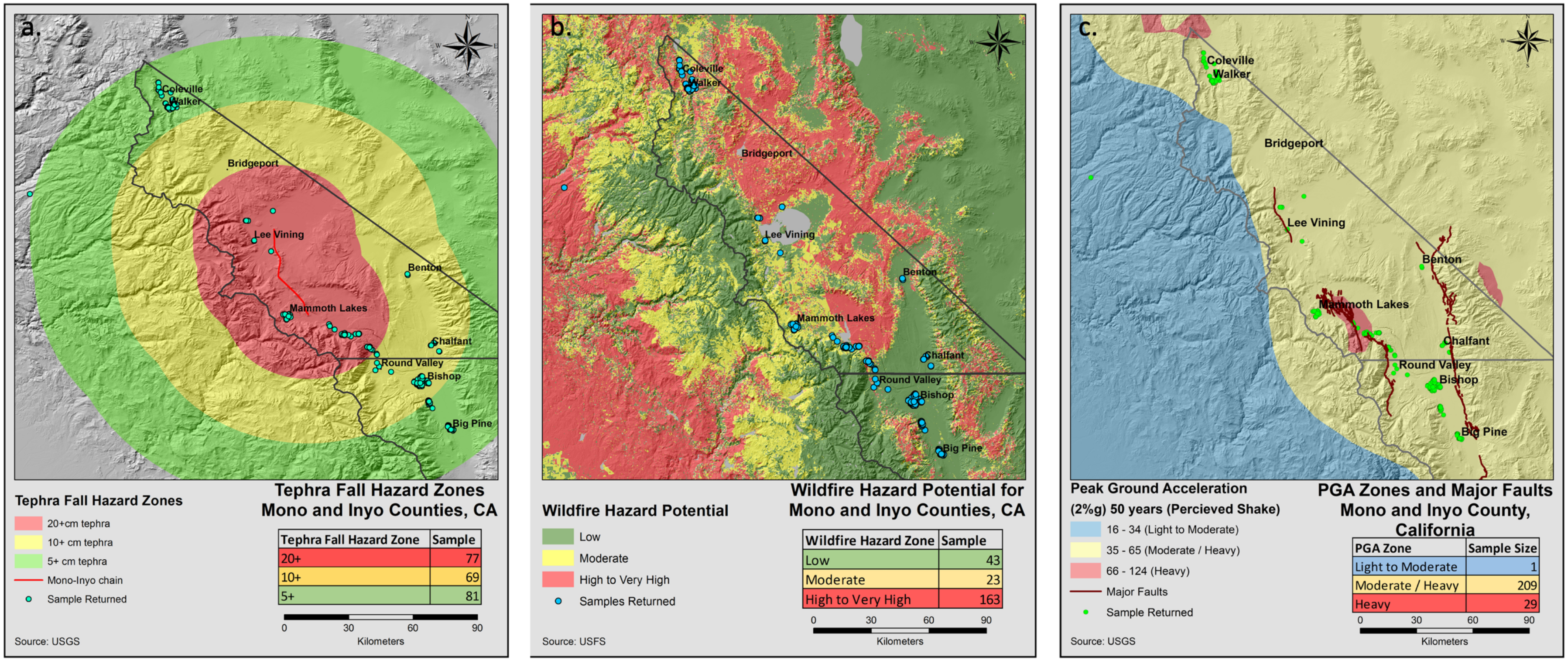
The onset of prolonged volcanic unrest at the LVC began in 1978, with an M=5.8 earthquake 14 km southeast of the caldera (Hill, 2006; Hill et al., 2017). In May 1980, one week after the eruption of Mount. St Helens, four M~6 earthquakes shook the southern rim of the LVC (Hill, 2006, Hill et al., 2017). Numerous shallow earthquake swarms, along with uplift and deformation of the caldera floor amplified concerns in the scientific community of the possibility of an eruption—leading to increased volcano seismic monitoring and response planning by stakeholders at the local, state and federal levels (Clarke & Savage & 1982; Miller, 1989; Hill et al., 2017). These events prompted the release of an earthquake "Hazard Watch" in Mammoth Lakes in 1980, followed by a "Notice of Potential Hazard" for volcanic activity issued for the area in 1982 by the United States Geologic Survey (USGS) under authority of the Disaster Relief Act of 1974 (Bernknoph et al., 1990). At the time, the USGS hazard warning system had three levels. The level of "Notice of Potential Volcanic Hazard," was defined as, "Information on the location and possible magnitude of a potentially hazardous geologic condition. However, available evidence is insufficient to suggest that a hazardous event is imminent or evidence has not been developed to determine the time of occurrence." (Federal Register, 1977; Hill et al., 2017). The threat of volcanic potential was met by confusion in the local community as there was no perceivable physical change in the environment to suggest volcanic activity (Mader, 1987; Hill et al., 2017). The California Office of Emergency Services (CalOES) sponsored a workshop in which locals received presentations on the volcanic potential in their region, and could discuss emergency protocols. Records show that locals in attendance were less concerned with understanding and communicating uncertainty regarding volcanic events, and more interested in potential economic loss related to a decline in tourism (Mader, 1987). As the news of potential volcanic activity in the Long Valley region continued to gather widespread attention, the booming economic development of Mammoth Lakes seen through the 1960's and 1970's came to a halt and decline, sparking distrust between the public and the scientific community (Mader, 1987).

An intense earthquake swarm on January 7, 1983 provided a seismic velocity profile which further proved the existence of, and constrained the geometry of, the large magma body beneath the LVC (Luetgert & Mooney, 1985). The tremors increased public safety awareness—leading to the authorization and creation of an alternate escape route, named Mammoth Scenic Loop. Mono and Inyo counties established an Incident Command System to coordinate emergency planning efforts between agencies, and many locals purchased earthquake insurance (Mader, 1987). Attendance to regular meetings held by USGS and county officials dropped by May, 1983, and public concern about volcano hazards again shifted from safety to loss of business (Mader, 1987). Seasonal unemployment reached as much as 20% and taxable sales dropped 3.2% in Mono County compared to a California state-wide increase of 9.6%. The local Bank of Mammoth reported approximately half a million dollars in loan delinquencies in 1983 (Mader, 1987). Two members of the Mono County Board of Supervisors that advocated the construction of the Mammoth Scenic Loop were voted out of office by November, 1983 (Mader, 1987; Hill et al., 2017). Despite the local economic crisis, tourism was at near record high levels for the 1983 to 1984 ski season and continued to increase through the mid 1980's (Mader, 1987).

Strong volcanic unrest continued with the onset of CO_2 gas emissions from the flanks of Mammoth Mountain in 1990 following an 11-month earthquake swarm (Hill et al., 2017). Fumorolic activity contributed human fatalities (one in 1998 and three on April 6, 2006) and tree kills (Brown et al., 2017; Hill et al., 2017). From 2000 to 2011, low level unrest was detected as inflation of the resurgent dome, minor seismicity, and continued fumorolic activity (Hill et al., 2017). Caldera inflation and resurgent dome uplift increased after 2011 and continues today.

2.1. Hazard Zones and Proximity

The LVVR crosses over Mono and Inyo County boundaries as do volcanic ashfall (tephra) hazard zones, Peak Ground Acceleration (PGA) earthquake hazard zones, and wildfire hazard zones (Fig. 2.2). For earthquake hazards, proximity to epicenters in the region can also be examined.



Tephra Fall Hazard Zone	Sample
20+	77
10+	69
5+	81

Wildfire Hazard Zone	Sample
Low	43
Moderate	23
High to Very High	163

PGA Zone	Sample Size
Light to Moderate	1
Moderate / Heavy	209
Heavy	29

Fig. 2.2: Three hazard maps of the Long valley region, a) volcanic ashfall zones, b) wildfire hazard potential, and c) Peak Ground Acceleration (PGA).

3. THEORETICAL BACKGROUND

Whether or not a person will change their behavior to adopt a protective action depends on whether they are motivated to adjust their lives to confront a potential threat. Weinstein and Nicolich (1993) describe that high levels of risk perception are presumed to lead to higher levels of protective action, which would imply a positive correlation between risk perception and preparedness. Furthermore, a person that takes high levels of protective action to decrease risk may in turn express lower levels of risk perception—indicating a negative correlation. The prediction that risk perception is the motivation for protective action follows from a number of theories such as Protection Motivation Theory (Rogers, 1975; Floyd, Prentice-Dunn, & Rogers, 2000) and the Protective Action Decision Model (PADM) (Lindell & Perry, 1992; Lindell, 2018).

As there is substantial uncertainty in predicting volcanic activity, there is arguably more uncertainty in predicting human behavior. To account for such uncertainty, this study utilizes the following psychological and exogeneous variables derived in part from the PADM (Lindell, 2018; Lindell & Perry, 2012) to conduct a systematic examination of the social context of risk perceptions of volcano hazards, compared to wildfire and earthquake hazards.

3.1. Expected Personal Consequences

Risk perception is a multi-dimensional concept, composed of factors that contribute to a person's expectation that a threat will impact them in some way. As noted above, social scientists look at correlations between risk perceptions and precautions to examine the accuracy of perceived risk, and whether or not these perceptions prompt behavioral responses. Expected personal consequences, or perceived personal risk are related to personal experiences with hazard events. If a person has not been exposed to a particular hazard, it is unlikely that they will perceive a risk associated with an event of that nature (Paton et al., 2006). Expected impacts could include death or injury, damage to real property, and general disruption to daily activities (Lindell and Perry, 2012). Previous research in natural hazards and disasters has found that risk perception is generally positively correlated with and can predict protective action responses to earthquake (Lindell & Perry, 2012), volcanic (Perry & Lindell, 1990) hazards. However, in some circumstances, there may not be any causal association between perception and behavioral responses, rather social structure constrains behavior (Gaillard & Dibben, 2008).

3.2. Hazard Intrusiveness and Affective Responses

Hazard intrusiveness refers to the frequency in which a respondent thinks about a potential threat or discusses it with others (Ge, Peacock & Lindell, 2011; Lindell & Prater, 2000). Perception of risk has been found to be influenced by unrealistic optimism—a cognitive bias in which people believe themselves to be less vulnerable to exposure than others, and are therefore less likely to adopt preparedness measures (Shepperd, Klein, Waters, & Weinstein, 2013; Weinstein, 1980). Affective response refers to the degree to which a respondent feels anxious, nervous, or worried about a threat (Lindell et al., 2016; Wei & Lindell, 2017). These variables have been found to be correlated with the adoption of hazard adjustments for earthquakes, hurricanes, and volcanic eruptions.

3.3. Response Efficacy

Self-efficacy, which describes an individual's self-appraisal of their capability for taking action, influences people's receptiveness to information and likelihood of adopting risk reduction behaviors (Dunning, 1999). Response efficacy refers to how well a person thinks that the actions that they have taken to protect them and their property from a threat. Response efficacy is postulated to be an essential component of protective action adoption in expectancy valence models which attempt to describe why a person may be motivated to behave a certain way. These include Protection Motivation Theory which postulates that people protect themselves on perceived threat levels, probability of occurrence, efficacy of the preventative behavior, and self-efficacy (Rogers, 1983), and Person Relative to Event Theory which emphasizes the influence of increased threat levels on preparedness behavior (Mulilis & Duval, 1997). Many natural hazard studies have reported that response efficacy is positively related to hazard adjustment adoption (Perry & Lindell, 2008; Lindell & Prater, 2002; Terpstra & Lindell, 2013).

3.4. Hazard Experience, Proximity, and Tenure

Hazard experience is commonly correlated to hazard proximity (Lindell & Perry, 2012). However, proximity to a hazard does not always suggest hazard awareness. For example, one third of the local population near Mount St. Helens was not aware that it was a volcano before its eruption in 1980 (Lindell & Perry, 1993). Furthermore, perception of a hazard and behavioral responses to disasters are more influenced by the societal nature of a geographic region rather than geophysical conditions. (Gaillard & Dibben, 2008; Torry, 1979). Past tenure, or the length of time a person has lived in a place, has been positively correlated with emergency preparedness (Wei & Lindell, 2017) and hazard proximity (Lindell & Hwang, 2008). Lindell and Hwang (2008) also hypothesized that tenure would be negatively related to perceived personal risk, however results showed no significant correlation.

3.5. Hazard Adjustments

3.5.1. Emergency and Evacuation Preparedness

Hazard adjustment refers to a protective action that a person adopts in response to a threat. Protective actions can be non-hazard specific such as stocking general emergency preparedness items in the home (e.g. food rations, water, medications, flashlights) and evacuation planning for specific hazards, among others. Hazard-specific adjustments include purchasing respiratory protection for volcanic ash, maintaining a defensible space around the home as a buffer from wildfire, or purchasing earthquake insurance. It is common in multi-hazard surveys (e.g., Lindell & Hwang, 2008; Perry & Lindell, 2008) to create hazard-specific preparedness variables. Generally, hazard studies indicate that household preparedness levels are low (Bourque et al., 2012; Lindell & Perry, 2000; Wei & Lindell, 2017).

3.5.2. Information Seeking

Information search is a fundamental element of hazard adjustment. Whether or not a person chooses to seek additional, or different, information on a risk begins to move them through the process of choosing whether or not to adopt a protective action (Lindell & Perry, 2012). Risk information search may be influenced by a number of factors including; risk perceptions, affective responses, demographics, and personal perceptions about information channels (Griffin et al., 1999; Wei & Lindell, 2017). When a risk is perceived as imminent, people actively engage in the search for more information about hazards and protective actions from a variety of information channels (Lindell & Perry, 2012).

3.7. Research Objective

The variables outlined in this theoretical framework were chosen to best examine relationships between theoretically interrelated psychological and physical variables as they affect emergency preparedness and information search. These variables include personal risk perceptions, hazard intrusiveness, affective responses, and response efficacy, as well as exogeneous variables such as scientific risk indicators (e.g., hazard zone proximity), past tenure and hazard experience, and demographic variables. Fig. 3 graphically summarizes the model used to analyze this information and provides context for the structure in which the results will be reported in this paper.

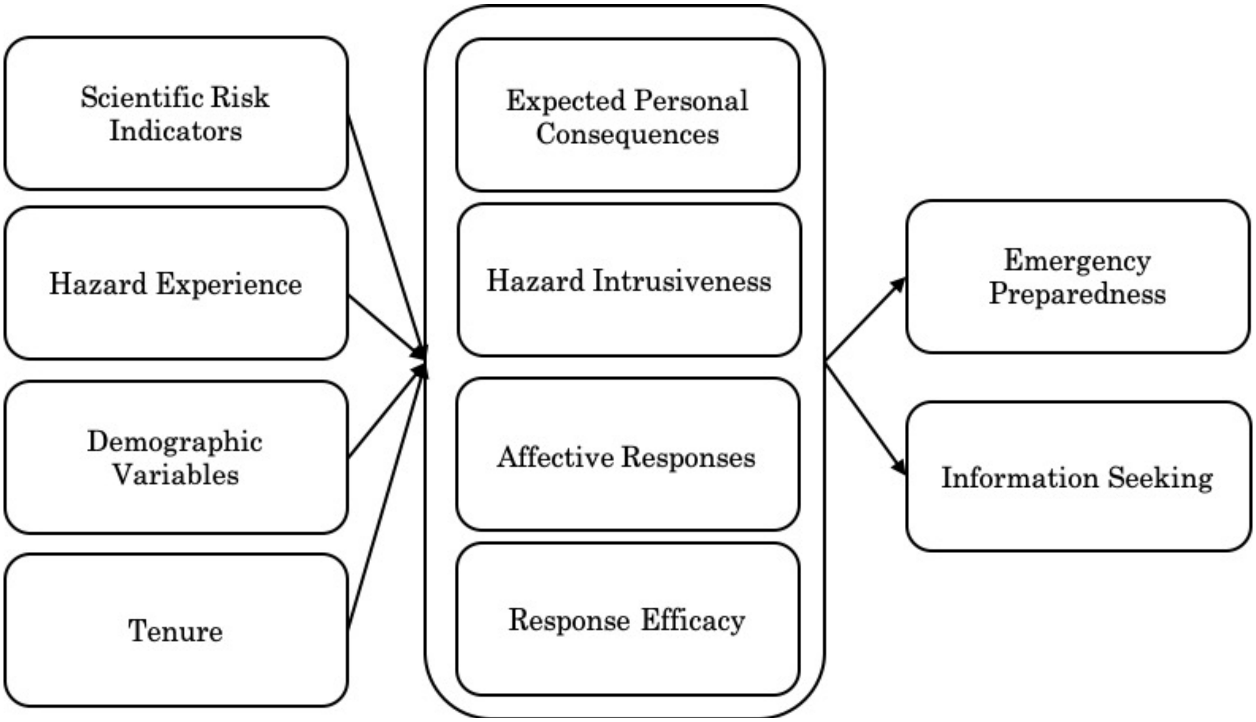


Fig. 2.3: Path diagram representation of the theoretical framework.

4. MATERIALS AND METHODS

4.1. Survey Procedure

This study utilized a mail-based questionnaire distributed to 1,209 households between February and June, 2018. The questionnaires were modelled after those used by Greene et al. (1981), Perry and Greene (1983), Lindell and Whitney (2000), Davis et al. (2006), Perry and Lindell (2008), Apatu et al. (2015), Wei and Lindell (2017), and Reeves (2018). Households were randomly selected from three tephra hazard zones (Fig. 2a). Beginning on February 22, each household was sent a packet of materials including the questionnaire, an Informed Consent Document (ICD), and a pre-addressed postage paid return envelope. The ICD included information about the study, instructions, and contact information of the investigators. Some 89

(7.4%) of packets were returned as undeliverable or otherwise rendered unusable. A total of 229 usable questionnaires were returned for a response rate of 18.9%.

4.2. Measures

4.2.1. Dependent Variables

A preparedness index was created from the average responses for a series of protective actions taken (No=0; Yes=1). The framework of this survey allowed for the creation of unique preparedness indices for each of the three hazards studied. Respondents were asked about short and long-term hazard adjustments. For short-term adjustments, they were asked, “Do you have any of the following emergency items in your home: (a1) battery powered radio with spare batteries, (b1) at least 4 gallons of water in plastic containers, (c1) a complete first-aid kit, (d1) 4 day supply of dehydrated or canned food for your entire family, (e1) at least one week supply of prescription medicines, (f1) disposable breathing protection (mask) for ash and dust in the air, (g1) off grid electric power (gas-powered generator or solar-powered). For long-term adjustments, they were asked, “Have you taken any of the following precautions for the place where you live: (a2) clear cut a 100 foot defensible space around your home, (b2) installed fire resistance on roof/structures, (c2) strapped water heaters, tall furniture, and heavy objects to the building walls, (d2) secured your home’s structure to its foundation, (f2) learned where and how to shut off water, gas, and electric utilities. Additionally, respondents were asked, “Have you planned where to go if you need to evacuate from home?” and “Have you planned what route to take if you need to evacuate from home?” The earthquake preparedness index included items a1-e1, g1, and c2-g2, which had an internal consistency reliability of $\alpha = .73$. For wildfire preparedness, items a1-g1, a2, b2, and f2 were included ($\alpha = .72$). The volcano preparedness index included items a1-g1, c2, d2, and f2 ($\alpha = .73$). Each hazard preparedness index also included responses on evacuation planning, “Have you planned where to go [what route to take] if you need to evacuate from home.” To assess information search, respondents were asked, “How likely is it that in the near future you will seek information about hazards and protective actions for: (a) wildfires, (b) earthquakes, (c) volcanic activity?” Each item was rated on a five -point Likert scale (from Not at all likely= 1 to Very great extent=5).

4.2.2. Independent Variables

The index of expected personal consequences was constructed by asking respondents “How likely do you think it is that in the next 10 years there will be a(n) (earthquake, wildfire, or volcano hazard) that will cause: (a) major damage to property in your community, (b) major damage to your home, (c) injury or illness to you or members of your immediate family, (d) disruption to daily activities such as working and shopping.” The mean ratings on a 5-point Likert scale (from Not at all likely= 1 to Very great extent=5) were combined into an expected personal consequences scales for earthquake risk ($\alpha = .89$), wildfire risk ($\alpha = .76$), and volcano risk ($\alpha = .97$).

To assess hazard intrusiveness, respondents were asked two separate questions about “How often do you think to yourself [talk to other people] about: (a) wildfires, (b) earthquakes, (c) volcanic activity?” Mean scores of hazard intrusiveness in time (daily = 1, weekly = 2, monthly = 3, yearly = 4, and never = 5) were computed for wildfires ($\alpha = .82$), earthquakes ($\alpha = .77$), and volcanic activity ($\alpha = .74$). Questions considering affective responses asked, “To what extent does the possibility of (wildfires, earthquakes, or volcanic activity) make you feel: (a) nervous, (b) fearful, (c) worried?” Responses on a 5-point Likert scale (from Not at all likely = 1 to Very great extent=5) were combined for each hazard to create scales with reliability estimates of α=.96, .97, and .98, for wildfire, earthquake, and volcano hazards, respectively.

In addition, perceptions of response efficacy were assessed by asking respondents "To what extent do you think that the actions you have taken will protect you and your family from death, injury, or illness from; and, "To what extent do you think that the actions you have taken will protect your property from damage from: wildfires, earthquakes, and volcanic activity." Responses were anchored by a 5-point Likert scale ranging from Not at all = 1 to Very great extent = 5. The resulting response efficacy variable had a reliability of α = .80 for wildfires, α = .76 for earthquakes, and α = .84 for volcano hazards. Past hazard experience was assessed through responses (No=0; Yes=1) to the following questions "Is any of the following true about your experience with (wildfires, earthquakes, or volcanic activity): your immediate family's property has been damaged, you or an immediate family member has been injured, property of someone else you know personally has been damaged, someone else you know personally has been injured?" The mean of these items produced a scale with a reliability of α = .80for wildfires, α = .78 for earthquakes, and α = .84 for volcano hazards.

Demographic variables included gender (Male = 0; Female = 1); age; and tenure in the Mono-Inyo County area, current community, and current residence. Ethnicity was measured as White (0) and Minority (1), which included Hispanic, African American, Asian/Pacific Islander, Native American, Mixed, or Other as the number of respondents with non-white ethnicity was small. Marital status was indicated as married, divorced, single, or widowed and recoded to Not Married (= 0) or Married (= 1). Education level was measured by Less than high school (= 1), High school (= 2), Some college/vocational school (= 3), College Graduate (= 4), and Graduate school (= 5). Respondents were asked to select their yearly household income from Less than $15,000 (= 1), $15,000-30,000 (= 2), $30,000-45,000 (= 3), $45,000-60,000 (= 4), and More than $60,000 (= 5). Household size was computed by adding the number of members in each of the three age groups less than 18 years, 18-65 years, and Over 65 years.

4.3. Statistical Analysis

Two multiple regression-based models were used to understand which variables were significant predictors of the emergency preparedness and information seeking hazard adjustments. To test the effect of residence in a hazard zone, all respondents received a code for their respective federally designated hazard zone from models for tephra fall (Miller & USGS, 1989), wildfire hazard potential (Dillon, Menakis & Fay, 2015), PGA, and earthquake proximity (Fig. 2) (USGS, 2017). Analysis of Variance (ANOVA) models tested the effects of residence in these hazard zones or proximity to the hazard source. Pearson correlations were tested at 95% and 99% confidence levels to evaluate the relationships among all independent and dependent variables in the models.

5. RESULTS

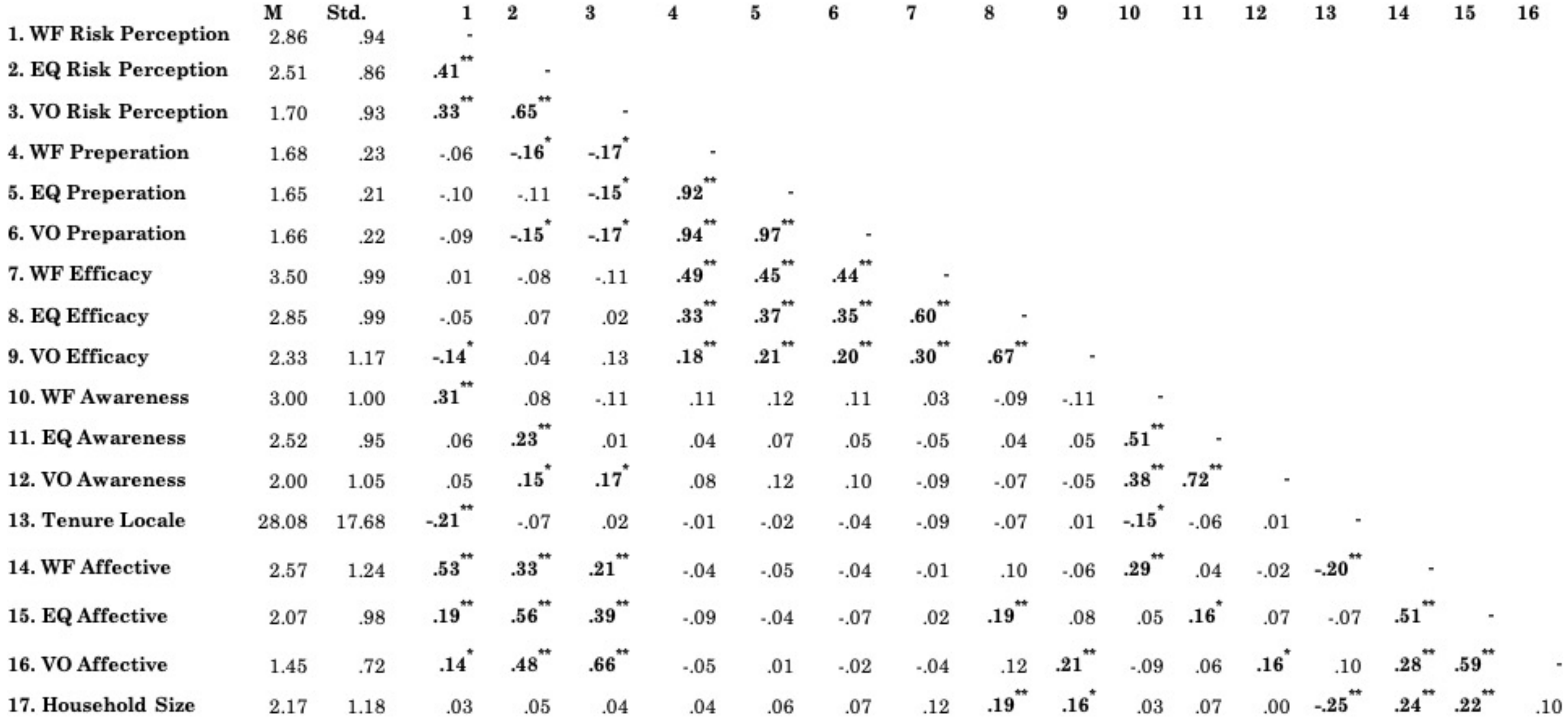
5.1. Correlation Analysis

The correlations of the hazard adjustments with the psychological variables showed that emergency preparedness had a significant negative correlation with expected personal consequences (r = -.17) for volcano hazards, but was not significantly correlated with wildfire or earthquake preparedness. Volcano hazard preparedness (r = .20), wildfire preparedness (r = .49), and earthquake preparedness (r = .37) were all significantly correlated with response efficacy. Information seeking was significantly correlated with expected personal consequences for volcano (r = .34), wildfire (r = .41) and earthquake (r = .30) hazards. Information seeking for volcano (r = .25) and earthquake (r = .21), but not wildfire hazards, was also significantly correlated with response efficacy. Information seeking for volcano (r = .37), wildfire (r = .43), and earthquake hazards (r = .33) were significantly related to affective response. Last, preparedness for volcano (r = .14), wildfire (r = .15), and earthquake (r = .13) hazards was significantly related to experience with wildfire hazards.

The correlations of the dependent variables with the demographic variables showed that information seeking for volcano hazards and protective actions had a significant negative correlation with community tenure (r = -.15). Wildfire information seeking had negative correlations of r = -.30, -.34, and -.25 for time lived locally, within the same community, and in the same residence, respectively. For earthquake information seeking, local, community, and residential tenure were negatively correlated—r = -.23, -.25, -.16, respectively. Information seeking for wildfire hazards was significantly correlated with education level (r = .19). Additionally, information seeking for wildfire (r = .20) and earthquake (r = .19) was significantly correlated with households with more children less than 18 years old. Preparedness for wildfire (r = .14) and earthquake (r = .16) hazards, but not volcano hazards, were significantly correlated with only one demographic variable, income. Finally, preparedness (r= -.17, -.16, -.17) for volcano, wildfire, and earthquake preparedness had negative relationships with female gender. However, information seeking for wildfire (r = .18) and earthquake (r = .17), but not volcano hazards, had positive correlations with female gender.

Significant inter-item correlations among the risk perception variables show that expected personal consequences is significantly related to hazard intrusiveness (r = .17, .31, and .26) for volcano, wildfire, and earthquake hazards, respectively. Response efficacy is related to affective responses for volcano (r = .21) and earthquake (r = .19). Affective responses were correlated with expected personal consequences (r = .66, .53, .56) for volcano, wildfire, and earthquakes, respectively. Hazard experience was also significantly correlated with expected personal consequences (r = .16, .17) for wildfire and earthquake hazards, but not volcano hazard. Affective responses were related to volcano (r = .16) and wildfire (r = .20) experience, and hazard intrusiveness was related to experience with wildfires (r = .30) and earthquakes (r = .14). Additionally, response efficacy was significantly related (r = .23) with wildfire experience, but not to volcano and wildfire experience.

Table 2.1: Means, standard deviations and correlations for variables. *95% confidence, **99% confidence.



	M	Std.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. WF Risk Perception	2.86	.94	-															
2. EQ Risk Perception	2.51	.86	.41**	-														
3. VO Risk Perception	1.70	.93	.33**	.65**	-													
4. WF Preperation	1.68	.23	-.06	-.16*	-.17*	-												
5. EQ Preperation	1.65	.21	-.10	-.11	-.15*	.92**	-											
6. VO Preparation	1.66	.22	-.09	-.15*	-.17*	.94**	.97**	-										
7. WF Efficacy	3.50	.99	.01	-.08	-.11	.49**	.45**	.44**	-									
8. EQ Efficacy	2.85	.99	-.05	.07	.02	.33**	.37**	.35**	.60**	-								
9. VO Efficacy	2.33	1.17	-.14*	.04	.13	.18**	.21**	.20**	.30**	.67**	-							
10. WF Awareness	3.00	1.00	.31**	.08	-.11	.11	.12	.11	.03	-.09	-.11	-						
11. EQ Awareness	2.52	.95	.06	.23**	.01	.04	.07	.05	-.05	.04	.05	.51**	-					
12. VO Awareness	2.00	1.05	.05	.15*	.17*	.08	.12	.10	-.09	-.07	-.05	.38**	.72**	-				
13. Tenure Locale	28.08	17.68	-.21**	-.07	.02	-.01	-.02	-.04	-.09	-.07	.01	-.15*	-.06	.01	-			
14. WF Affective	2.57	1.24	.53**	.33**	.21**	-.04	-.05	-.04	-.01	.10	-.06	.29**	.04	-.02	-.20**	-		
15. EQ Affective	2.07	.98	.19**	.56**	.39**	-.09	-.04	-.07	.02	.19**	.08	.05	.16*	.07	-.07	.51**	-	
16. VO Affective	1.45	.72	.14*	.48**	.66**	-.05	.01	-.02	-.04	.12	.21**	-.09	.06	.16*	.10	.28**	.59**	-
17. Household Size	2.17	1.18	.03	.05	.04	.04	.06	.07	.12	.19**	.16*	.03	.07	.00	-.25**	.24**	.22**	.10

5.2. Linear Regression

Linear regressions of the emergency preparedness and information seeking measures onto the five risk perception variables and eight demographic variables for each hazard individually are summarized in Table 2.1. Each regression model was significant at the 95% confidence level. Response efficacy was the most consistently significant independent variable ($p < .05$) in all three models for volcano, wildfire, and earthquake preparedness, as well as in the information seeking models for volcano and earthquake hazards. Expected personal consequences was a significant predictor for volcano preparedness and wildfire information seeking. Hazard intrusiveness was a significant predictor for seeking information about volcano and earthquake hazards. Affective response was a significant predictor for information seeking about volcano and wildfire hazards. For emergency preparedness, risk perception factors accounted for 13% of the variance for volcano (R2 = .19; adjusted R2 = .13), 34% of the variability for wildfire (R2 = .38; adjusted R2 = .34), and 21% of the variability for earthquake (R2 = .19; adjusted R2 = .21) hazards.

Table 2.2: Regression results for multi-hazard preparedness and information seeking models.

Variables	Volcano					Wildfire					Earthquake				
Preparedness Model	*b*	SE	Beta	t	Sig.	*b*	SE	Beta	t	Sig.	*b*	SE	Beta	t	Sig.
Expected Personal Consequences	-.07	.02	-.28	-2.97	.00	-.01	.02	-.03	-.37	.71	-.02	.02	-.07	-.89	.38
Hazard Intrusiveness	.02	.02	.11	1.54	.13	.01	.02	.05	.71	.48	.02	.02	.07	1.00	.32
Affective Responses	.03	.03	.10	1.01	.31	.01	.01	.03	.42	.68	-.02	.02	-.09	-1.08	.28
Response efficacy	.05	.01	.24	3.32	.00	.14	.02	.57	9.22	.00	.09	.02	.41	6.16	.00
Hazard Experience	.11	.18	.04	.61	.54	-.03	.08	-.02	-.37	.71	.00	.05	.00	-.03	.98
Adusted R^2			.13					.34					.21		
df			179.00					194.00					190.00		
Information Seeking Model															
Expected Personal Consequences	.20	.13	.14	1.48	.14	.33	.13	.21	2.60	.01	.18	.13	.11	1.33	.18
Hazard Intrusiveness	.20	.09	.16	2.38	.02	.17	.11	.12	1.59	.11	.20	.10	.14	2.01	.05
Affective Responses	.33	.17	.18	1.99	.05	.24	.10	.20	2.50	.01	.23	.12	.16	1.87	.06
Response efficacy	.29	.08	.26	3.67	.00	.06	.10	.04	.62	.54	.27	.09	.20	2.88	.00
Hazard Experience	1.37	.99	.09	1.38	.17	-.21	.52	-.03	-.41	.69	.29	.35	.06	.82	.41
Adjusted R^2			.20					.22					.19		
df			189.00					192.00					189.00		

5.3. Spatial Analysis by Hazard Zone and Proximity

No significant spatial relationships were found between the variables explored in this study for volcano, earthquake, or wildfire hazard zones. However, earthquake-specific preparedness was significantly correlated ($r = .19$) with distance from recent earthquake epicenters during the time frame of this study. Additionally, earthquake proximity was a significant predictor for all emergency preparedness models, but not for the information seeking models.

6. DISCUSSION

6.1. Risk Perceptions and Hazard Adjustments

This study provided a unique opportunity to discuss examples of the correct interpretations of correlations between risk perceptions and protective action adoption as outlined by Weinstein and Nicolich (1993) and how to interpret these correlations.

6.1.1. Emergency Preparedness

The most notable finding of this paper is that expected personal consequences were negatively correlated with volcano-specific emergency preparedness ($r = -.17$). Furthermore, regression analysis (Table 2.2) shows that expected personal consequences was a significant predictor in the volcano hazard preparedness model. Consistent with the analysis of Weinstein and Nicolich (1993), it would be inappropriate to interpret this negative correlation between volcanic risk perception and preparedness as indicating that higher levels of risk perception caused people to refrain from taking emergency preparedness actions. Instead, it is quite possible that the causality runs in the reverse direction—the adoption of more emergency preparedness actions caused people to experience lower levels of expected personal consequences. Furthermore, suggesting the presence of a bias, wildfire hazard experience is positively correlated with wildfire risk perception, and preparedness and earthquake hazard experience is significantly positively related to earthquake risk perception. These same results are of no significance for volcano hazards.

Bernknoph et al. (1990) surveyed resident and non-resident property owners in the LVC on their risk perceptions of earthquake and volcano hazards preceding and following each hazard notice. They observed an increase in the perceived risk of death and property damage following each hazard announcement. The results showed that while perception of personal injury returned to near background levels by 1984 for both hazards, the perception of property damage from each hazard persisted. They reported that 30% more respondents indicated the lowest level of perceived risk of property damage from a volcano than from an earthquake. This result is similar to differences in mean response ratings observed between volcano and earthquake hazards for the expected personal consequences in this study. The mean response rating for earthquake risk perception was some 38% higher than volcanic risk perception. Additionally, the mean response rating for wildfire risk perception was the highest of the three—some 41.8% greater than levels indicated for volcano risk perception.

6.1.2. Information Search

In contrast to the significant negative relationship between volcano risk perception and preparedness, this study found a strong, significantly positive correlation between wildfire risk perception and information search (r = .41). Regression analysis shows that expected personal consequences is a significant predictor in information search for wildfire risks, but not for earthquake or volcano risks. Here, the positive correlation can be interpreted as higher levels of wildfire risk perception causing a behavioral response to adopting more protective actions. This is not surprising when considering that this survey was mailed in February, 2018, after the most destructive wildfire season recorded in the history of California with 5,053 km^2 burned and nearly 12 billion dollars of insurance claims (Aon Benfield, 2017)

6.2. Other Variables

Risk perceptions can change over time as people learn new information about a hazard, and encounter varying risk over time (Weinstein & Nicolich, 1993). Some 61.2% of respondents indicated that they had lived in the region for greater than 20 years, which puts them in the range of time of elevated unrest levels at LVC. Furthermore, 42.9% lived in the area for over 30 years, indicating that their perceptions of volcanic hazards could have been influenced by events that took place locally during the 1980's. Although past tenure was significantly negatively correlated with wildfire expected personal consequences and wildfire hazard intrusiveness, it was not a significant predictor in any regression models.

Response efficacy was a significant predictor in each model except for wildfire information seeking. Not surprisingly, response efficacy was also highly correlated with emergency preparedness, similar to results reported by Perry and Lindell (2007) and Lindell and Prater (2002).

The correlations between earthquake proximity and hazard preparedness for each hazard, along with being a significant predictor in all emergency preparedness models, suggests that householders in the LVVR are aware of local earthquake activity, even when this is at low levels of seismicity. These findings are consistent with Lindell and Hwang (2008) as well as Rajapaksa et al. (2016).

7. CONCLUSIONS

The results from this study's correlation and regression analyses show not only that volcanic risk in the LVVR is perceived differently than earthquake and wildfire risk, but also that volcanic risk perceptions may not be accurate. This is a noteworthy finding—especially considering the regional social context in the LVVR. Given the similarities of this study's findings to those of Bernknoph et al. (1990), along with documented issues in volcano risk communication stemming from the uncertainty surrounding volcanic unrest (Mader, 1987), these results could be used to further investigate issues in risk communication and perception of information channels, specifically caldera unrest. Positive relationships between level of exposure and hazard adjustments for wildfire hazards; and between level of exposure and risk perception of earthquake hazards are not unexpected, due to the relative imperceptible physical effects of prolonged volcanic unrest.

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CHAPTER 3

AN ECONOMETRIC EVALUATION OF THE EFFECTS OF VOLCANIC ALERTS AND ERUPTIONS ON HOUSING PRICES AND BUSINESS PATTERNS

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ABSTRACT

Social and economic vulnerability can result from direct and indirect losses caused by volcanic unrest and eruption. In this study, indirect losses from volcanic eruptions and volcanic alert levels are examined as independent variables. We explore economic vulnerability as a function of these variables using econometric time series analysis. Regional economic impacts of volcanic activity on housing prices and business patterns were examined for three different types of volcanos with a "very high" threat designation from the United States Geological Survey (USGS)—Long Valley Caldera (LVC), CA (caldera system), Mount St. Helens, (MSH) WA (stratovolcano), and Kīlauea, HI (shield volcano). To understand how local economic trends compared to regions that are not volcanically active, yet are largely economically dependent on tourism, we use Steamboat Springs, CO as a control community as it is a major winter ski-tourism destination much like Mammoth Mountain in LVC, but it is not geologically part of any volcanic system. Analyses indicate there are significant negative relationships between housing prices during 1) episodic lava flow crises at Kīlauea volcano from 1983 to 2016 and 2) increased hazard alert levels at LVC from 1982 to 1983 and 1991 to 1997. Economic trends in volcanic regions were also more highly variable than the control region. Findings suggest that indirect

losses resulting from volcanic eruptions and increased volcanic alert levels should be examined independently to more completely understand volcanic impacts in economic vulnerability and risk assessments as well as risk management strategies.

1. INTRODUCTION

Studies on the impacts of natural and technological hazards in hazard and disaster sciences are generally focused on determining and assessing direct losses resulting from physical damages of hazardous events through empirical and probabilistic models. However, socio-economic crises can occur with or without direct impacts of a hazardous event, as was evidenced from public response to elevated unrest of Long Valley Caldera (LVC), California, USA beginning in 1978. The indirect losses that often follow natural disasters have been a topic of focus in socio-economic journals for decades. Examples include, regional housing price impacts after earthquake (Murdoch, Singh, & Thayer, 1993), wildfire (Donovan, Champ, & Butry, 2007), flood (Bin & Landry, 2008), and hurricane (Ewing, Kruse, & Wang, 2005). All of these studies have one important element in common that differ from the framework of our research—they were conducted after a specific physical natural disaster event occurred, and a socio-economic crisis ensued. In contrast, this study more broadly explores longer term indirect loss data using decadal time series analyses to look at impacts with and without direct impacts from physical volcano events.

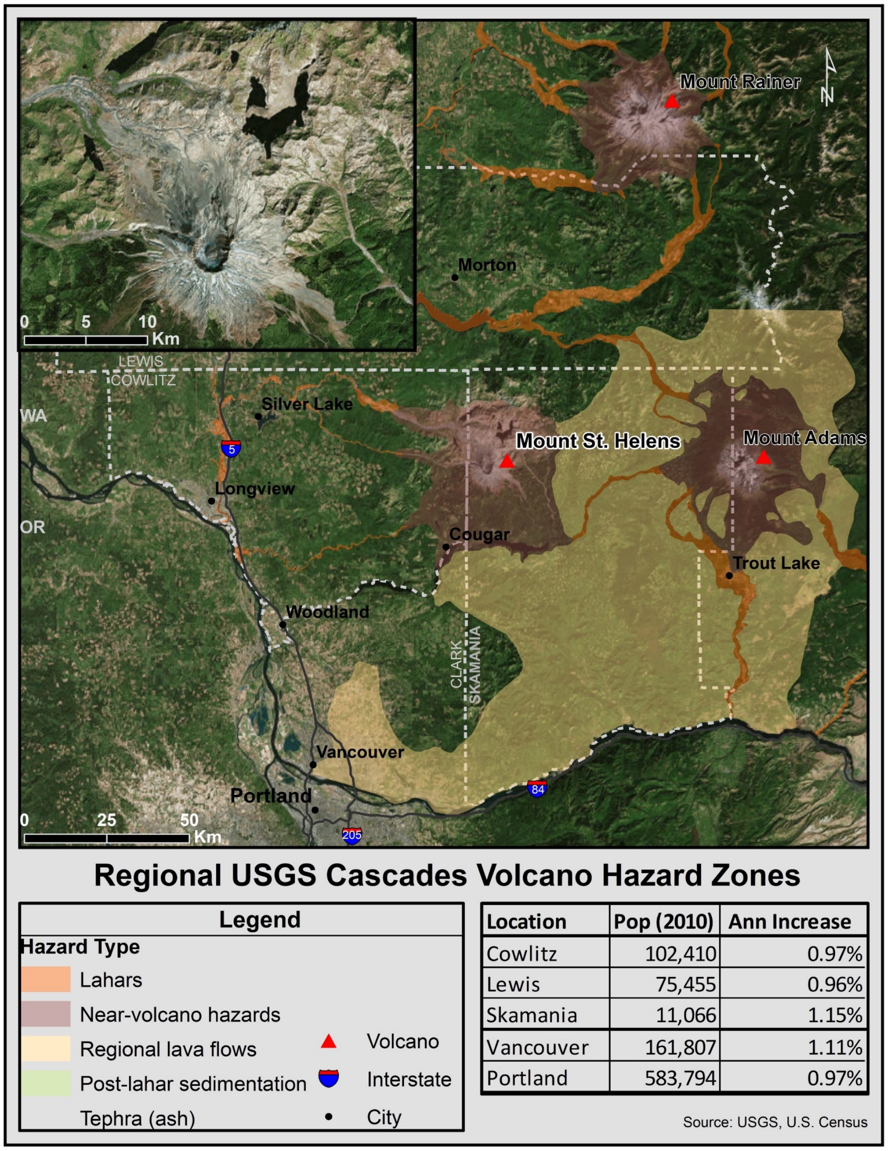
Indirect losses are related to, but not entirely dependent on direct, physical losses due to hazard activity (Lindell, Prater & Perry, 2006). For example, earthquakes, tsunami and volcanic eruptions often adversely affect structures such as roads, buildings, and utilities and precipitating indirect losses such as lost revenue from lodging and eating establishments (Gregg & Houghton, 2006). In contrast, elevated alert levels of a potential impending hazard such as the threat of hurricane landfall or volcanic eruption can lead to both direct and indirect losses due to human response to the threat of, rather than contact with a hazard (Lindell et al., 2006).

Consequently, this study compares the impacts of volcanic alerts issued from different U.S. Geological Volcano (USGS) volcano observatories on local housing prices and businesses. It is important to establish that the issuance of a volcanic alert does not mean that an eruption is imminent, or even that there will be a perceptible change in the environment around a volcano. Rather, a volcano alert is a public statement issued about the status of a volcano—standardized across all U.S. volcano observatories in 2006 by a four-level Volcanic Alert Level System (VALS) (Gardner & Guffanti, 2006). Furthermore, VALS were historically not standardized prior to 2006, so they were inconsistent between observatories, beginning with the development of the first VALS following the 1980 eruption of Mount Saint Helens. This study does not attempt to assess the accuracy of volcanic alert levels over time, but rather analyses employ econometric time series regression models to observe economic indicator trends during times of increased volcanic alert levels and potentially hazardous volcanic episodes as separate variables for U.S. counties at risk of exposure to hazards from three volcanoes—LVC, Mount St. Helens, and Kīlauea volcano. Quite simply, we try to answer the question of whether or not the presence of information about volcanic potential in the form of a volcanic alert has a similar effect on local economic trends (e.g., number of employees and residential housing sales) compared to regions that have experienced numerous direct losses (e.g., property and infrastructure damage) volcano crises?

2. STUDY REGIONS

2.1. Mount St. Helens

Mount St. Helens (MSH) is one of many active strato-volcanos in the Cascade Range. As the region's population increases and develops land closer to and within Cascade volcano hazard zones (Fig. 3.1), the potential for direct and indirect losses increases risk associated with both eruption and elevated VAL due to unrest.



Location	Pop (2010)	Ann Increase
Cowlitz	102,410	0.97%
Lewis	75,455	0.96%
Skamania	11,066	1.15%
Vancouver	161,807	1.11%
Portland	583,794	0.97%

Source: USGS, U.S. Census

Fig. 3.1: Map showing the Mount St. Helens region and USGS designated Cascades volcano hazard zones.

On May 18, 1980 a M 5.1 earthquake triggered the collapse of the north flank of MSH (Global Volcanism Program [GVP], 1980). The debris avalanche permitted the eruption of a lateral blast which sent ash up to 23 km into the stratosphere, and nearly instantaneously destroyed everything within 10 km of the explosion (GVP, 1980). Debris flows of mud, melted ice, and volcanic material (lahars) began within minutes of the blast—filling river channels and causing major flooding, which damaged critical infrastructure and personal property more than 120 km away (Lipman, Mullineaux, & USGS, 1982). For over 9 hours, the eruption vigorously fed a vertical ash plume which deposited 1.08 km^3 of ash over 11 states and nearly 57,000 km^2 (Lipman et al., 1982). Mount St. Helens was the costliest and deadliest volcanic eruption in U.S. history. Estimated financial losses were $1.1 billion USD ($3.3 billion adjusted; United States International Trade Commission (USITC), 1980). There were also 57 confirmed human casualties (Brown et al. 2017).

Volcanic activity at MSH continued with intermittent explosions and dome building eruptions until October 28, 1986. Relatively smaller eruptive episodes occurred from December 7, 1989 to January 6, 1990 and from November 5, 1990 to February 14, 1991 (GVP, 2013). On October 1, 2004, the volcano began an eruptive episode which lasted until January 27, 2008. Volcano-seismic activity has remained at background levels since 2008.

Despite catastrophic volcanic potential, the regional economy in the footprint of MSH (see Fig. 3.1) has benefited from tourism to the volcano— accelerated by the establishment of Mount St. Helens National Monument in 1982. As of 2015, some 15% of employment was represented by the travel and tourism industry in Cowlitz, Lewis, and Skamania counties that border the monument area (Headwaters Economics, 2017).

2.2. Long Valley Caldera (LVC)

Calderas are formed when a volume of magma is emptied from its shallow reservoir, causing the volcanic edifice to collapse, leaving a depression in the surface. The modern 16 by 32 km LVC (see Fig. 3.2) was formed when 600 km^3 of magma was violently expelled about 760 ka during the eruption of the Bishop Tuff (Hill, 2006; Hill, Mangan, & McNutt, 2017). In comparison, the volume displaced during the May 18, 1980 eruption of Mount St. Helens was 2.79 km3 (Brantley, Myers, & USGS, 2000). The greater Long Valley Volcanic Region (LVVR) consists of a series of lava dome complexes called the Mono-Inyo Craters that stretch 40 km from Mammoth Mountain on the southwest rim of LVC northward to Mono Lake. The most recent eruption in the LVVR was at Paoha Island in 1790 CE, in Mono Lake at northernmost end of the Mono-Inyo Craters in Mono county (Bevilaqua et al., 2018).

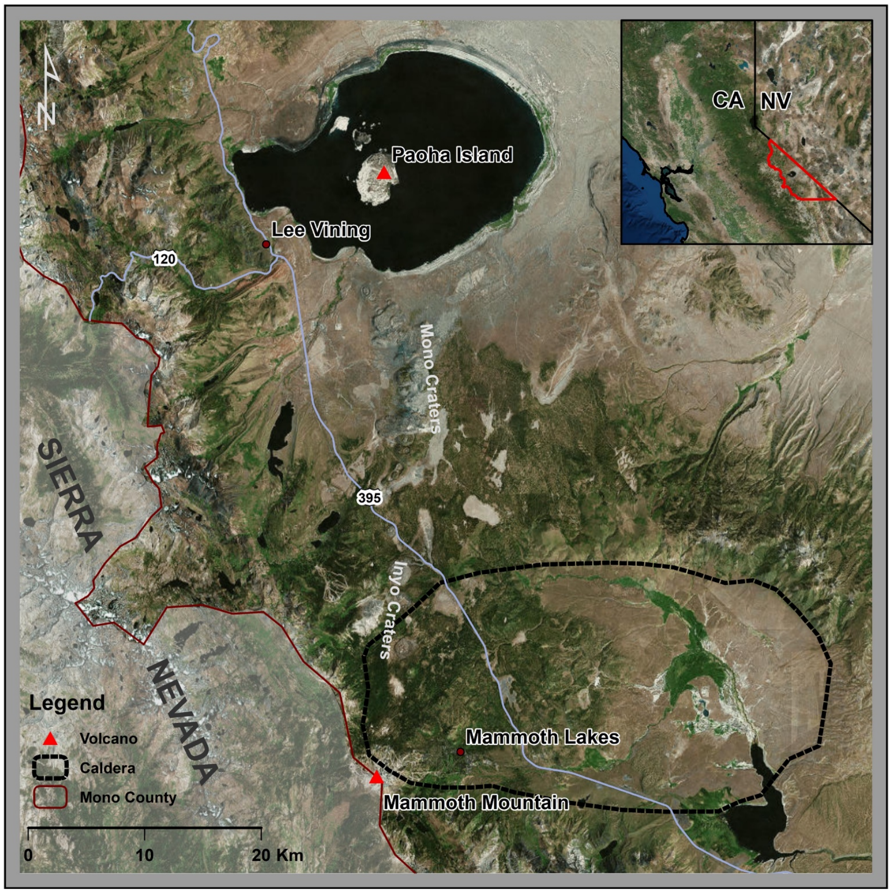


Fig 3.2: Map showing the geographic setting of the Long Valley Volcanic Region in Eastern California, USA.

One week after the May 18, 1980 eruption of MSH, four M~6 earthquakes at LVC's southern margin amplified concern of high levels of caldera unrest that began in 1978 (Hill et al., 2017). In May, 1982, following four years of shallow earthquake swarms along with uplift and ground deformation of the caldera floor, the USGS released a "Notice of Potential Hazard," about the volcanic potential at LVC (Mader, 1987). Mader (1987), Bernknoph, Brookshire and Thayer, (1990), and Hill et al. (2017) report that the public response to the statement was one of confusion and outrage. It was perceived that the hazard notice was linked to a decline in tourism and overall economy in the Long Valley region, sparking contention in the local community with volcano scientists and emergency managers (Hill et al., 2017). However, in contradiction to this perception, Mader (1987) reported that tourism numbers following 1982 were reported near record levels. Despite this report of an uptick in visitor numbers, we found no data concerning the performance of the overall economy.

Mammoth Lakes (see Fig. 3.2) is an alpine ski-resort town on the slopes of Mammoth Mountain—with populations fluctuating from ~8,000 to ~40,000 during peak tourism (Hill et al., 2017). On-going caldera unrest at LVC has involved both ground deformation and emissions of magmatic CO_2 gas through the flanks of Mammoth Mountain. Ground deformation has involved some 41cm of elevation and subsidence of the caldera floor and 85 cm of resurgent dome uplift (Savage & Clark, 1982; Hill et al., 2017). Magmatic CO_2 gas moving upward through the root zones killed trees (Hildreth, 2016) and pooling of the invisible and tasteless gas in low areas is responsible for four human fatalities, one in 1998 and three on April 6, 2006 (Brown et al. 2017).

2.3. Kīlauea Volcano, Hawai‘i Island

Hawai‘i Island (see Fig 3.3a.) was built by five overlapping basaltic shield volcanoes—three of which (Kīlauea, Mauna Loa and Hualālai) have been active in modern history (since ca. 1800). The majority of the island's land mass is covered by Mauna Loa, which last erupted in 1984, threatening the town of Hilo with lava flows (Trusdell, 2012). Kīlauea Volcano in the southeast of Hawai‘i Island is one of the most active volcanoes in the world, and until June 2018 erupted nearly continuously since 1983, primarily from Pu‘u ‘Ō‘ō on the East Rift Zone (ERZ). Kīlauea also had a lava lake between 2008 and 2018 (Neal et al., 2019). Unlike hazards associated with large magnitude, explosive volcanism characteristic of strato-volcanoes and caldera systems, the greatest losses from volcanism in Hawai‘i typically result from relatively slow-moving lava flows. Kīlauea lava flows have covered the entire subdivision of Royal Gardens and inundating most of the village of Kalapana (Fig. 3.3b). On May 3, 2018, the eruption at Puʻu ʻŌʻō moved further down the volcanoes Lower East Rift Zone (LERZ), when a series of fissures opened in Leilani Estates (a residential subdivision), destroying hundreds of homes (Neal et al., 2019).

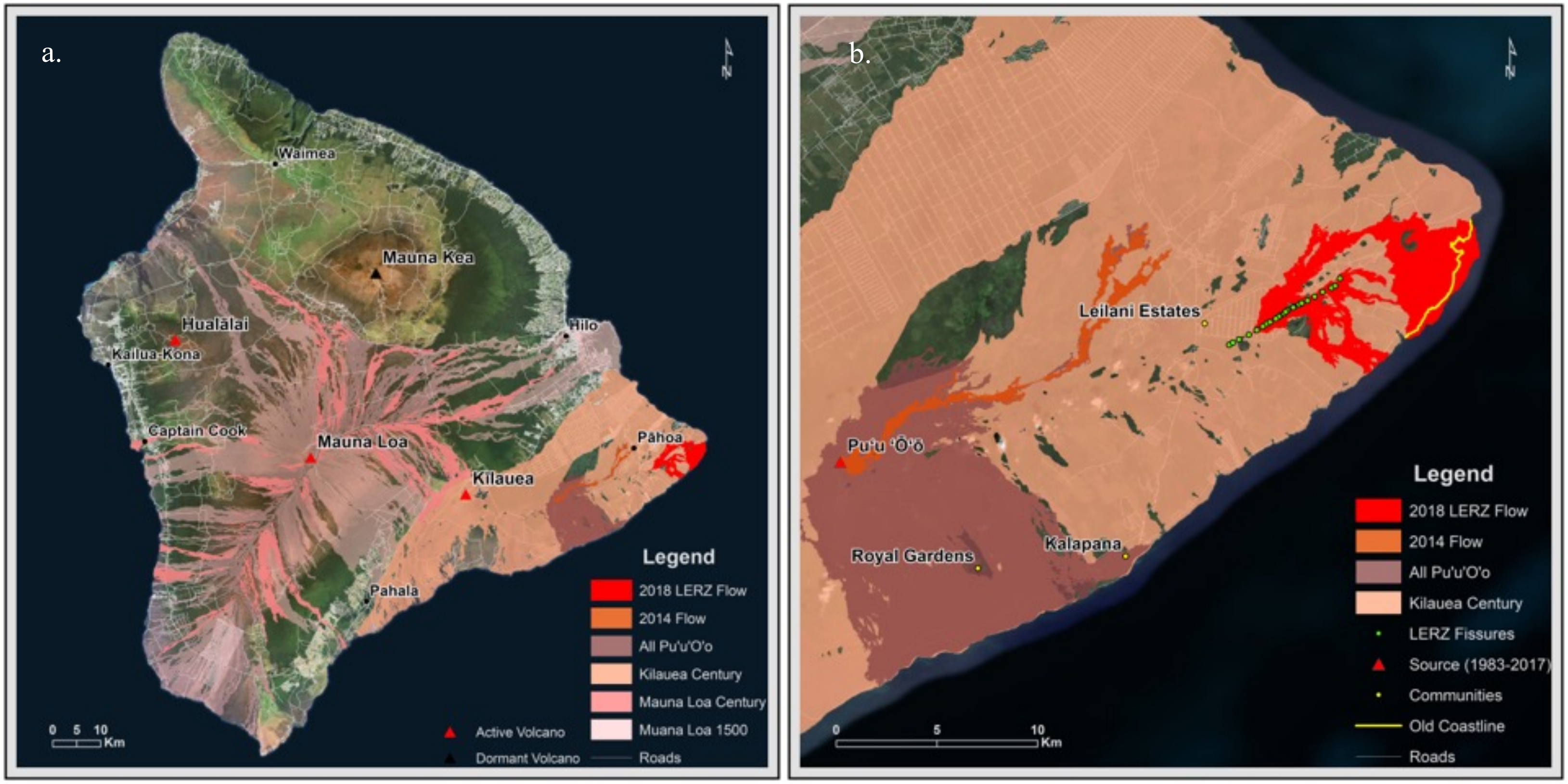


Fig 3.3: a) Map of Hawai‘i Island with historic and recent lava flows and b) zoomed in on the most recently active Kīlauea Volcano and Puna District.

The Hawaiʻi Property Insurance Association (HPIA) was created in 1991 to provide property insurance to homeowners who were not able to insure their homes in the private market because of the ongoing eruption at Kīlauea. During the 2014 lava flow, HPIA declared a moratorium on new insurance policies and a hold on increasing existing coverage for the Puna district (Donlon, 2014). Although there were minimal direct losses from contact of the 2014 lava flow with real property (one house and out building were destroyed, a portion of a loading/unloading zone at a solid waste transfer station and an electrical power pole were covered by lava), real estate prices suffered temporary losses and 10-15% of the Pahoa region moved from the region (Nakaso, 2015b, Poland et al., 2016). Most direct losses derived from mitigation activities by Hawaiʻi County, Hawaiʻi State and federal agencies in preparation for the lava flow, rather than from losses due to contact with lava. Mitigation activities included grading of three alternate roads, relocating several primary and secondary area schools and establishment of redundant critical facilities (e.g., police, fire, electric). In 2015, the State of Hawaiʻi enacted Senate Bill 589, which acknowledged that part of the impact from the lava flow crisis was, “due to the imposition of a moratorium on the sale of new insurance policies in certain areas in the Puna district.” The bill allowed homeowners that already had insurance to renew their insurance policies and provide coverage for new buyers of the property. However, moratoriums can still be emplaced by HPIA during lava flow disasters for new insurance policies, as they were during the 2018 eruption at the LERZ (Callis, 2018).

2.4. Steamboat Springs

Steamboat Springs is a ski resort town in Routt County, Colorado. Some 64% of the population of Routt lives within 10 km of the town of Steamboat Springs (U.S. Census Bureau, 2010). There is no volcanic potential in the region.

3. BACKGROUND

3.1. Alert Level Systems

In 1977, the USGS developed a non-hazard specific three-level warning system for all potential hazards within their responsibility under provisions of the Disaster Relief Act of 1974 (Mader, 1987). Major volcanic crises in the 1980's led to not only the establishment of new volcano observatories, (Cascades, Long Valley, and Alaska), but also to the development of Volcano Alert Level Systems (VALS) that were unique to volcano hazards particular to each observatory, with the exception of Hawaiʻi Volcano Observatory (HVO) (Fearnley et al., 2012).

As MSH erupted from May 1980 to 1986, the newly established Cascades Volcano Observatory (CVO) began to develop and implement the first VALS (Fearnley & Beaven, 2018). CVO used this warning system to issue alerts for 19 of 21 explosions during the 1980's (Brantley et al., 2000).

A prolonged period of heightened unrest of LVC beginning in 1978 prompted the issuance of a "Notice of Potential Volcanic Hazard" in 1982, the lowest alert at the time (Federal Register, 2007). In 1983, the national three-level system was dropped to one tier following contentions with the local community and scientific stakeholders surrounding LVC and the town of Mammoth Lakes. The Long Valley Monitoring Project—which evolved into the Long Valley Observatory (LVO) and then to the California Volcano Observatory (CalVO)—was established in December, 1982 with the responsibility for coordinating research, monitoring, and hazard communication to the public (Hill et al., 2017). As with MSH, the LVO was unable to utilize a single level warning system, and implemented two different VALS before the national USGS standardization of VALS in 2006 (Hill et al., 2017).

In contrast to more recent establishments of CVO and LVO/CalVO, the Hawai‘i Volcano Observatory (HVO) was established in 1912, but it never developed a VALS until the standardization in 2006. Until then, HVO scientists communicated directly with local agencies and stakeholders to develop sophisticated response procedures to volcanic hazards (Fearnley et al., 2012)

With such disparity between the VALs used by different observatories over the past four decades, it is difficult to assess the effectiveness of variable warning systems in the communication of volcano hazards. Winson et al. (2014) found that for events ending in an eruption, 19% (~30% for VEI > 3) of VALs issued between 1990 and 2013 accurately reflected the hazard before the eruption. Furthermore, the number of “accurate” VALs increases from 19% to 55% over time, and an increase in number of hazard alerts were issued where the alert level was increased, but there was ultimately no corresponding eruption. This research suggests that the success rate of volcanic alerts reflecting relative hazard level has improved over time.

3.2. Social and Economic Trends

Hazard proximity and impacts on housing prices have been examined for a variety of natural and technological hazards, often with inconsistent results. Generally, property located within or near flood hazard zones is lower than housing prices in less vulnerable areas (Bin et al. 2008; Zhang et al. 2009). Furthermore, housing prices were found to decline regionally following tornado and hurricane events (Ewing et al. 2006) and large earthquakes (Murdoch et al. 1993). Still, some studies have found no significant difference between property values inside and outside of flood zones (Babcock & Mitchell, 1980; Damianos & Shabman, 1979; Fried et al., 1999; Zhang et al., 2009). Donovan et al., (2007) found that housing prices for parcels that were at high risk to wildfire were positively correlated before wildfire risk ratings were posted on the

Colorado Springs Fire Department website. After the information was posted, there was no correlation.

Atreya and Ferreira (2015) found that housing prices were substantially lower in areas that had been inundated by floods, compared to properties within the same floodplain that had not been inundated. Additionally, Graham and Hall (2001, 2002) found that there were declines in housing prices after successive hurricanes. Collectively, these studies suggest that variability in the recency, frequency and severity of hazard events can influence risk perceptions, and ultimately the price that people are willing to pay for a home in a high-risk region (Lindell and Perry, 2004; Zhang et al. 2009). Furthermore, Zhang et al. (2009), suggest that property values are not always entirely dependent on hazard proximity, and that risk perceptions can be offset by the presence of amenities such as the world class alpine recreation at LVC and MSH, and proximity to coastlines and tropical forests in Hawai‘i.

Several studies have suggested that economic losses in the Long Valley region during the early 1980’s could be attributed to the presence of earthquake and volcano hazard notices (Mader, 1987, Bernknoph et al. 1990, Hill et al. 2017). Bernknoph et al. (1990) concluded that property values declined noticeably in the Long Valley region following increased perceived personal risk of property damage from earthquake or volcano hazards. Additionally, and in a multi-hazard survey of household preparedness in the LVVR, Peers (2019) found that the mean response ratings for earthquake risk perception were some 38% higher than volcanic risk, similar to a 30% difference between the hazard risk perceptions reported by Bernknoph et al. (1990).

There were several national recessions recognized by the National Bureau of Economic Research (NBER) for the time period of this study (1974-2016) (NBER, 2012). There was an oil crisis and stock market crash from November 1973 to March 1975. A short recession also occurred from Jan 1980 to July 1980 after interest rates were raised to counteract inflation in the 1970s. The Iranian revolution and increasing oil prices also drove the USA into a deep recession from July 1981 to November 1982 (NBER, 2012). High interest rates and oil prices drove another recession from July 1990 to March 1991. The dot-com bubble and the terrorist attacks on 9/11 (September 11, 2001) also lead to a recession from March 2001 to November 2001. Most prominently though, the Great Recession was caused by the subprime mortgage crisis from December 2007 to June 2009 (Grusky, Western, & Wimer, 2011).

3.4. Research Objective

The objective of this study is to compare housing prices and business patterns of the three volcanic regions in Hawaiʻi, California and Washington State and compare them with the control community in Colorado. The Long Valley region experienced volcanic alerts in response to high levels of unrest, while Kīlauea and Mount St Helens experienced direct losses from volcanic eruptions. Steamboat Springs was selected to observe economic trends in regions that are largely economically dependent on revenue from tourism, but are not threatened by active volcanoes. The analyses employ econometric methods to assess alert level and hazard level independently.

4. METHODS

4.1. Econometric Framework

This study assessed economic climates from 1974 to 2016 by utilizing economic indicator indices in two annual time series econometric regression models for each of seven counties at risk to exposure of the three volcanoes Kīlauea, LCV and MSH. County Business Patterns (CBP) are annual data provided by the U.S. Census Bureau since 1964. Establishment numbers, annual payroll, and mid-March employment are useful for studying economic changes spatially and temporally (Statistics of U.S. Businesses, 2018). The digital records for CBP in years prior to 1986 were provided by the National Historical Geographic Information System (NHGIS). Regression and correlation analyses were run on the entire dataset. Additionally, trending growth rates for housing prices and business patterns were explored in detail.

4.2. Dependent Variables

4.2.1. Establishment, Employment and Payroll

Establishment per 1000 km^2, Employees per 1000 inhabitants, and Payroll per employee (EEP), were aggregated to create a composite indicator of business health. The EEP index was created following guidelines for developing composite indicator variables by the Organization for Economic Co-operation and Development (OECD). The variables were normalized by subtracting the mean over time, and dividing by the mean absolute difference and adding 100 as in the following equation:

$$I_{ts} = \frac{x_t - \mu_{ts}}{|\mu_{abs}|} + 100$$

Where *I_{ts}=Indexed time series*

x_t= value at time t
μ_{ts}=mean over time
μ_{abs}=mean absolute value of difference from mean

4.2.2. Housing Price

This study utilized local Housing Price Indices (HPI) published by The Federal Housing Finance Agency (FHFA) (Bogin et al., 2016) to assess the behavior of the housing market over time. These data are annual, and referenced to a base year of 2000, from 1975 to 2017—complete for most counties in this study.

4.3. Independent Variables

4.3.1. Volcanic Alert and Hazard

Past bulletin reports from the GVP and from the USGS were analyzed to capture the relative historic volcanic alert level. MSH was the only volcano that had a consistent distribution of alert levels on a comparable four-point scale to USGS standardized VALS. Therefore, MSH received both an ordinal scale (no alert = 0, heightened unrest = 1, volcano advisory = 2 and volcano alert = 3) on the highest alert level based on the four level system used by CVO from 1980 to 2006 issued per year, and (non-eruptive = 0, potentially hazardous eruption = 1).

For LVC, only dichotomous variables were used to represent both published hazard statements and times of heightened unrest. Years in which reports indicate that an elevated alert level statement was issued for levels of unrest above background received a code of “1.” The years in which no alert was issued, or alerts were cancelled received a “0.” For example, the years of 1982 and 1983 received a code of “1” because of the release of the “Notice of Potential Volcanic Hazard” in 1982. In 1983, the notice was cancelled until 1991 when a five-level alphabetic alert system was emplaced. Therefore, the years 1983 to 1991 received a code of “0” despite high levels of caldera unrest. From 1991 to 1997, the alerts moved between lower levels of a 5-level alert system (Hill et al. 2017), all of which received a code of “1.” To account for years in which unrest levels could have warranted an alert above background levels that were not communicated due to the absence of a VALS at LVC, a binary (background levels = 0, elevated unrest = 1) scale was coded following archived USGS reports on volcanic activity.

Since no VALS was in place for Kīlauea until 2006, and it has been erupting since 1983, codes were assigned by following FEMA Major Disaster Declarations (MDD) that were issued for Kīlauea volcano. For each year that received an MDD, a code was assigned for the number of months of the incident period in that year.

4.3.2. Recession

This analysis included a variable to examine whether study regions experienced economic trends that followed national recessions. Years that the National Bureau of Economic Research (NBER) recognized a national recession received a code of “1,” while all other years received a code of “0.” Additionally, a separate dichotomous variable was created for the subprime mortgage price from 2007-2009.

5. RESULTS

5.1. Economic Trends

The linear economic trends are summarized in Fig. 4a-d. From 1974 to 1981 both Mono and Inyo County’s EEP increased exponentially, and Inyo HPI increased some 65% from 1977 to 1981. From 1981 to 1982 Inyo HPI decreased by some 21%, but rose 30% by 1983. During 1982 and 1983, the average rate of change for EEP declined by some 84% for Mono County, but continued to increase for Inyo County. From 1984 to 1990, Mono County EEP increased relative to 1982-1983, while Inyo remained relatively the same, and Inyo HPI rose some 45%. Inyo HPI remained relatively constant from 1984 to 1987 and then increased some 45% until 1993 when Mono and Inyo HPI fell 6% and 3% respectively from 1993 to 1994. Mono EEP dropped sharply in 1991 and fluctuated for the remainder of the 1990’s. Mono HPI dropped about 8% from 1993 to 1996. While EEP also declined from 1992 to 1993 for Inyo County, it quickly surpassed Mono by 1999. After EEP declined sharply from 1999-2000 for Inyo and Mono, both counties experienced positive overall growth in EEP and exponential increases in housing prices until 2007.

With the exception of Skamania EEP during the 1990's, MSH regional HPI and EEP growth were quite consistent between counties. On average, EEP rate of change was over 100% lower from 1978 than from 1975-1978 for Skamania, Cowlitz, and Lewis. Skamania EEP began to increase from 1980-1982, while growth in Cowlitz and Skamania returned in 1982. HPI increased slightly for Cowlitz and Lewis from 1979-1980, and declined 25% from 1980-1981 in Lewis. Cowlitz HPI continued to increase until 1981 at which time it decreased some 17% until 1983. Lewis HPI rose by 37% from 1981 to 1982. Regional HPI remained relatively stagnant for the remainder of the 1980's. Regional EEP fluctuated until 1986, at which point both Lewis and Cowlitz increased steadily until 1999 with the exception of minor fluctuations in the 1990's. However, Skamania EEP declined to 1980 levels from 1988-1992. EEP declined from 1999 through the early 2000's for all three counties before reaching a maximum in 2007.

The average rate of change for Hawai'i County EEP declined some 68% from 1983 to 1985 relative to growth from 1974 to 1982. HPI fell about 2% from 1983 to 1987. Increases in Hawai'i EEP and HPI during the late 1980s leveled off around 1990 until dropping off sharply until 1995. From 1991 to 1997, Hawai'i HPI declined some 12% until rapidly increasing from the early 2000's to 2007.

Routt County (Steamboat Springs), the control in this study, saw steady increases in EEP from 1974 through 2007 with minor fluctuations in the 1980's. Similarly, HPI increased steadily from 1986 to 2003 with an accelerated increase to 2007 until a dramatic decline as evidenced in every dataset.

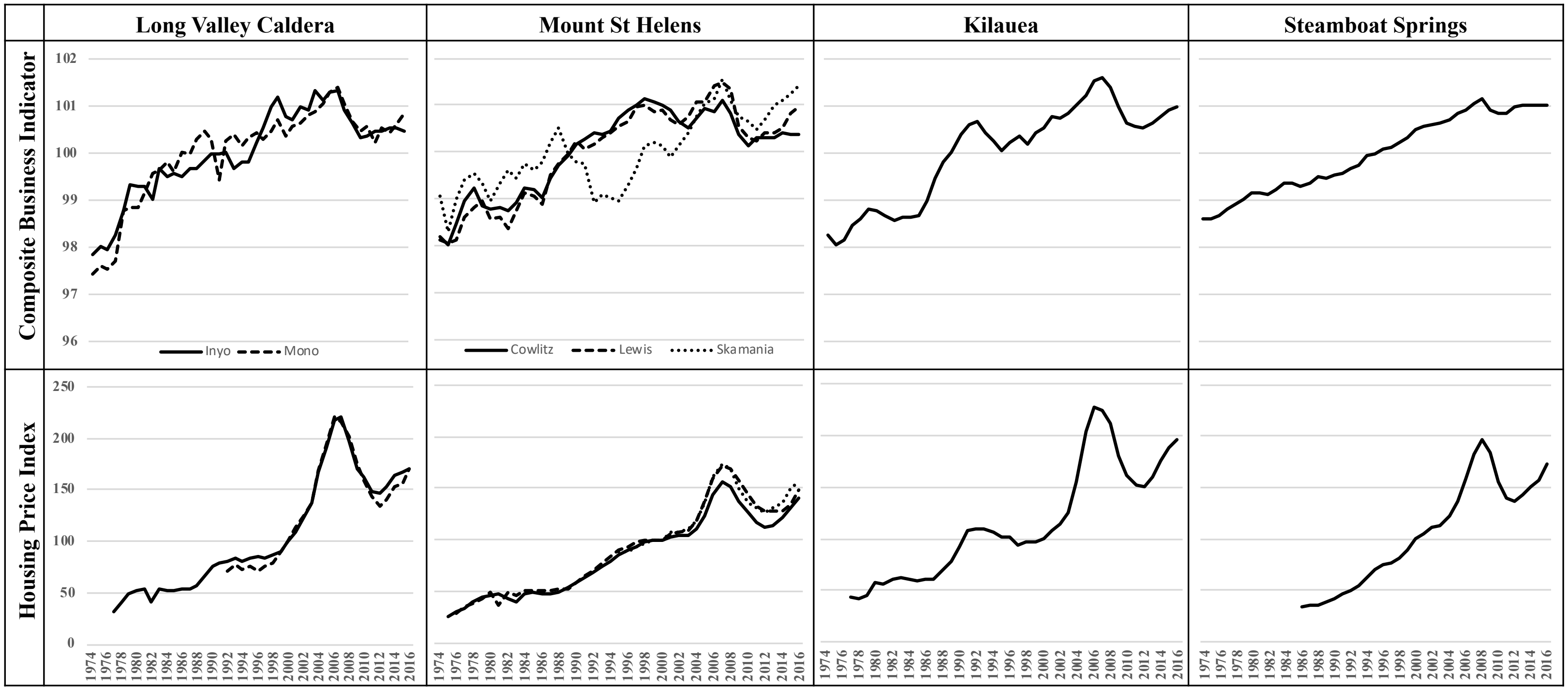


Fig. 3.4: Linear trends of housing prices and business patterns from 1974-2016.

5.2. Correlations

Not surprisingly, Hawaiʻi County HPI had a significant negative relationship with months in which there was a disaster declaration for Kīlauea Lava flow (r = -.39) (see Table 1). More importantly, HPI was also significantly negatively related to times in which a volcanic alert was issued for Mono (r = -.70) and Inyo Counties (r = -.31). Similarly, the dichotomous hazardous variable created for LVC was related to both Mono and Inyo HPI with r = -.54. Additionally, for LVC, alert level and hazard were only weakly interrelated (r = .36).

Alternatively, HPI was either not related to, or had a significant positive correlation with MSH alerts (r = .47) and hazard (r = .62) for Skamania county. Unlike the weak correlation between alert and hazard level at LVC, MSH alert level and hazard were strongly correlated (r =.80). Despite HPI and EEP being strongly intercorrelated for all counties, none were significantly correlated with any volcano alert or hazard variables.

Table 3.1: Means, standard deviations, and correlations. *95% confidence, **99% confidence

Case	Variable	Mean	Std.	N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	YEAR	1995	12.56	43																			
2	LVCVALS	.21	.41	43	-.15																		
3	LVCBI	.67	.47	43	-.17	.36*																	
4	HELENSBI	.42	.50	43	.00	-.09	.09																
5	HIVO	4.07	5.58	43	-.26	.49**	.49**	.08															
6	2007-09	.07	.26	43	.29	-.14	-.20	.32*	-.20														
7	INYOHPI	105.90	54.73	40	.90**	**-.31***	**-.54****	.14	-.48**	.48**													
8	MONOHPI	132.89	48.59	25	.74**	**-.70****	**-.54****	.75**	-.62**	.50*	.99**												
9	COWHPI	84.69	38.09	42	.95**	-.19	-.35*	.05	-.41**	.47**	.96**	.93**											
10	LEWISHPI	91.46	42.38	41	.94**	-.21	-.42**	.07	-.45**	.50**	.97**	.94**	.99**										
11	SKAHPI	125.85	26.61	22	.77**	-.55**	-.44*	**.62****	-.41	.58**	.95**	.93**	.99**	.98**									
12	HAWAIIHPI	115.21	54.58	40	.90**	-.20	-.49**	.13	**-.39***	.48**	.98**	.95**	.95**	.96**	.97**								
13	ROUTTHPI	104.81	51.13	31	.93**	-.46**	-.57**	.23	-.80**	.54**	.95**	.92**	.98**	.98**	.97**	.92**							
14	INYOEEP	100	.92	43	.84**	-.09	-.03	.14	-.16	.28	.81**	.60**	.86**	.83**	.29	.77**	.68**						
15	MONOEEP	100	1.00	43	.82**	.02	.08	.19	.07	.29	.78**	.83**	.81**	.79**	.69**	.78**	.72**	.93**					
16	HAWAIIEEP	100	1.05	43	.89**	-.01	-.15	.05	-.12	.35*	.86**	.92**	.90**	.88**	.86**	.88**	.80**	.90**	.88**				
17	COWEEP	100	.89	43	.79**	.11	-.02	-.09	-.05	.24	.66**	-.07	.81**	.76**	-.31	.68**	.41*	.90**	.86**	.92**			
18	LEWISEEP	100	1.02	43	.86**	.01	-.13	-.04	-.10	.31*	.79**	.55**	.88**	.85**	.37	.80**	.67**	.93**	.89**	.96**	.97**		
19	SKAEEP	100	.81	43	.82**	-.45**	-.25	.20	-.33*	.39**	.84**	.89**	.81**	.81**	.90**	.81**	.79**	.74**	.71**	.73**	.57**	.68**	
20	ROUTTEEP	100	.82	43	.99**	-.17	-.20	.04	-.31*	.36*	.93**	.88**	.98**	.97**	.90**	.91**	.96**	.89**	.85**	.91**	.83**	.89**	.823*

5.3. Regression

The alert and hazard variables for the LVC region were not significant predictors in the regression models. The only significant volcano variable of the 14 regression models was for Skamania County for MSH. The 2007 to 2009 Great Recession variable and annual trend variables were significant predictors in nearly every model. Table 3.2 summarizes these results.

Table 3.2: Regression results by volcanic region and county.

			Model 1 (HPI)						Model 2 (EEP)					
Volcano	County	Variable	B	Std. Error	Beta	t	Sig.	Adj R2	B	Std. Error	Beta	t	Sig.	Adj R2
LVC	Mono	LVCVals	-32.38	19.55	-0.29	-1.66	0.11	0.70	0.38	0.22	0.16	1.73	0.09	0.67
		Year	2.97	1.16	0.45	2.57	0.02		0.07	0.01	0.82	8.85	0.00	
		Crash	51.39	17.64	0.35	2.91	0.01		0.28	0.36	0.07	0.79	0.44	
	Inyo	LVCVals	-11.04	8.20	-0.09	-1.35	0.19	0.85	0.09	0.20	0.04	0.48	0.63	0.69
		Year	3.79	0.31	0.81	12.41	0.00		0.06	0.01	0.83	9.19	0.00	
		Crash	47.95	13.17	0.23	3.64	0.00		0.19	0.32	0.05	0.57	0.57	
Kilauea	Hawaii	HI MDD	-0.07	0.67	-0.01	-0.10	0.92	0.85	0.03	0.01	0.14	1.97	0.06	0.81
		Year	3.84	0.33	0.82	11.60	0.00		0.08	0.01	0.89	12.47	0.00	
		Crash	49.62	13.65	0.24	3.64	0.00		0.51	0.29	0.12	1.76	0.09	
MSH	Cowlitz	MSH Alert	0.80	3.21	0.01	0.25	0.80	0.94	-0.20	0.18	-0.11	-1.09	0.28	0.64
		Year	2.75	0.13	0.89	21.23	0.00		0.06	0.01	0.78	7.76	0.00	
		Crash	31.18	6.44	0.21	4.84	0.00		0.16	0.37	0.05	0.45	0.66	
	Lewis	MSH Alert	4.38	3.57	0.05	1.23	0.23	0.94	-0.15	0.17	-0.07	-0.87	0.39	0.728
		Year	3.09	0.15	0.88	20.89	0.00		0.07	0.01	0.83	9.87	0.00	
		Crash	37.92	7.08	0.24	5.36	0.00		0.36	0.35	0.09	1.02	0.31	
	Skamania	MSH Alert	15.86	5.56	0.29	2.85	0.01	0.84	0.26	0.14	0.16	1.78	0.08	0.71
		Year	2.64	0.36	0.65	7.27	0.00		0.05	0.01	0.79	8.99	0.00	
		Crash	24.85	7.67	0.33	3.24	0.01		0.35	0.29	0.11	1.22	0.23	
None	Routt	Year	4.78	0.22	0.85	22.22	0.00	0.96	0.06	0.00	0.96	36.09	0.00	0.97
		Crash	54.24	6.51	0.32	8.34	0.00		0.25	0.09	0.08	2.96	0.01	

6. DISCUSSION

The correlation results from this study show that there is a similar and significant negative relationship between housing prices and volcanic alert at LVC, and between major lava flow disasters and housing prices at Kīlauea. This finding suggests that indirect losses from the increased threat of a volcano hazard could have significant, short-term impacts on property values comparable to direct impacts in volcanic regions largely dependent on revenue from tourism-based activities. It is understandable that housing prices may be substantially lower in areas that have been inundated by lava flows in recent history. This was supported by Atreya and Ferreir (2015) which found that prices for properties that had been physically inundated by floods were lower than prices within the same floodplain which had not been inundated.

The threat of the June 27, 2014 Puʻu ʻŌʻō lava flow caused substantial indirect losses to the Pahoa region of Hawaiʻi, though the flow ceased before causing extensive direct physical losses (Poland et al. 2016). These losses were shared across county, state and federal governments along with taxpayers in general due to the various levels of government response. Although Poland et al. (2016) discuss a considerable impact to housing prices and residential migration from the Pahoa region in response to the lava flow, in this dataset, there is no noticeable trend in the island HPI or EEP during this period. Additionally, Hawaiʻi Senate Bill 589 acknowledges substantial impacts to businesses and property values, as the reason that insurance laws were "improved."

Claims in literature about the unrest of LVC (Mader, 1987; Bernknoph et al., 1990, Hill et al., 2017) leading to poor economic climate in the early 1980's perceived by public as a result of the "Notice of Potential Volcanic Hazard" issued in 1982, is an understandable reaction from time series data observations in this study. Inyo HPI fell substantially from 1981-1982 and both

Mono and Inyo HPI growth was limited while LVO was using their first 5-level VALS (1991-1997), which indicated low levels of unrest above background for most years (Hill et al., 2017). Additionally, although EEP was not significantly correlated with either volcano related variable for LVC, regional business growth rates declined during these times overall from previous rates.

Economic trends of the MSH region show an immediate decline after 1980, accelerated from a downward trend beginning in 1978 for all counties. With the exception of Skamania county EEP in the mid 1990's, overall trends resumed positive growth rates after 1982. A 2015 report by Headwaters Economics supports this finding by claiming that the region experienced strong growth overall after the establishment of Mount St. Helens Monument. These findings, paired with close proximity to the major metropolitan of Portland OR, a major hub in the technological industry, could directly or indirectly contribute to the overall resilience of the regional economy.

Additionally, periods of declining growth rates in these study regions often correspond linearly to national recessions recognized by NBER in the early 1980's and 1990's. However, statistically, pre-2007 recessions were not significantly correlated to economic indicators. Only the 2007-2009 Great Recession was a significant predictor variable in this study. In the control region of Steamboat Springs, the 2007 to 2009 recession was also a significant predictor of economic trends.

Ultimately, the results of this study suggest that volcanic alert levels at the LVC caused a decline in economic trends, but the decline was only temporary and recoverable. Similar trends were observed at MSH and Kīlauea, which have experienced persistent episodic eruptions since the early 1980's. These findings are consistent with findings from other natural hazards studies including Graham and Hall (2001, 2002) which noticed immediate, but temporary declines in housing prices following successive hurricane events.

7. CONCLUSIONS

This study provides evidence that indirect impacts of volcanic alerts and volcanic activity should be examined independently. Volcano alerts and eruptions can both have impacts on housing markets and businesses in the short term, but these events are not significant predictors of long-term economic trends as with the affects from global recessions as seen during the Great Recession from 2007 to 2009. Overall, the volcanic regions in this study have experienced more annual variability since 1974 during episodic activity and unrest than non-volcanically active destination tourism regions such as Steamboat Springs, CO. Furthermore, volcano tourism could have a positive effect on regional economy as seen overall in the post-1982 Mount St. Helens region.

Econometric analysis suggests that considerable direct losses from volcanic activity are not necessary to cause indirect losses that may result in a socio-economic crisis evidenced by the 2014 lava flow crisis at Kīlauea and elevated unrest of the LVC. We identified an important issue to be addressed in disaster resilience—as federal government assistance is provided during the disaster response and recovery phase for direct impacts of Presidentially designated major disasters, there is limited or no assistance for indirect impacts as they are much more immeasurable or observable.

The framework used in this study has implications to increase understanding surrounding social and economic activity in response to hazards and hazard alerts of all types. For volcano-specific hazards, this methodology could be applied systematically to all regions at risk to exposure from volcanic hazards. Additionally, as time series databases become more robust, this framework could be applied to smaller geographic regions within counties to further reduce uncertainty in quantifying impacts of volcanic activity.

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CHAPTER 4

CONCLUSIONS AND FUTURE RESEARCH

Ultimately, the two studies in this manuscript identify challenges in volcano risk communication, and disaster resilience in general. The results suggest that it may not necessary for a catastrophic volcanic event to occur for a social or economic crisis to occur. This notion has been implied specifically to the LVC case study by Mader (1987), Bernknoph et al. (1990), and Hill et al. (2017). The methods employed in this systematic examination provide insight into how persistent volcano crises challenge disaster resilience socially and economically.

Study one focused on risk perceptions and preparedness in the Long Valley region and identified a negative relationship between the variables. Furthermore, the differences between levels of earthquake and volcano risk perceptions were of similar disparity between study one, and findings in Bernknoph et al. (1990). This, paired with some 42% of respondents having over 30 years of tenure in the region, could suggest a cognitive bias influenced by the history with volcanic unrest in the region. Positive relationships between level of exposure and hazard adjustments for wildfire hazards, and also between level of exposure and risk perception of earthquake hazards are not unexpected, due to the relative imperceptible physical effects of prolonged volcanic unrest at LVC. These results could provide insight to further investigate issues in risk communication and perception of information channels, specifically during caldera unrest.

Study two provides evidence that indirect impacts of volcanic alerts and volcanic activity should be examined independently. The econometric analyses suggest that extensive direct losses from volcanic activity are not necessary for indirect losses that can result in short term economic crises evident in county level business patterns and housing prices. These findings identified an important issue to be addressed in disaster resilience. Federal government assistance is provided during the disaster response and recovery phase for direct impacts of presidentially designated major disasters, however, there is limited or no assistance for indirect impacts as they are much more immeasurable or observable.

The framework of study two could be applied on a national scale by following the outlined methodology. As databases on economic indicators become more robust, trends could be explored in smaller communities, perhaps reducing uncertainty in the analysis. Furthermore, the framework can be applied to hazards and hazard alerts of all types. Recognizing that crises are social phenomena, and disasters are physical events, the methods used to estimate the impacts of disasters should continue to be multidisciplinary in nature.

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