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The Economic Impact of the Oso Landslide: A Hedonic Approach

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THE ECONOMIC IMPACT OF THE OSO LANDSLIDE:

A HEDONIC APPROACH

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ABSTRACT

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Mass wasting, or landslides, commonly occurs in Washington State, posing risk to individuals residing in the area. The 2014 Oso landslide, the deadliest mass-wasting event in United States history, increased awareness for mass-wasting hazards in western Washington. Studying single-family homes from 2004-2017, this research uses a hedonic property model to measure consumer willingness to pay for a home in a mass-wasting hazard area after the Oso landslide and finds that home values in Snohomish County decreased by 11% after the Oso disaster.

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INTRODUCTION

1.1. Background

In the past thirty years, mass-wasting events caused more than $300 million of destruction and damage to homes, properties, and infrastructure in Washington State (Washington State Department of Natural Resources [WSDNR] 2015). Mass wasting, which includes events such as landslides and debris flows, poses serious risk to individuals residing in hazardous geographic areas, particularly in western Washington where these events frequently occur (WSDNR 2017b). The challenge comes in understanding how individuals perceive risk, specifically the risk associated with such natural phenomena.

To measure risk, economists commonly utilize revealed preference methods, tools used to analyze observable consumption choices made by individuals (Dorfman, Keeler, and Kriesel 1996; Tietenberg and Lewis 2016). Hedonic price models, a type of revealed preference method, uses proxy markets, such as real estate and labor markets, to measure preferences for environmental amenities and disamenities (Rosen 1974). An environmental disamenity is associated with adverse characteristics, such as natural hazards, because people do not prefer to reside in risky areas (Dorfman, Keeler, and Kriesel 1996).

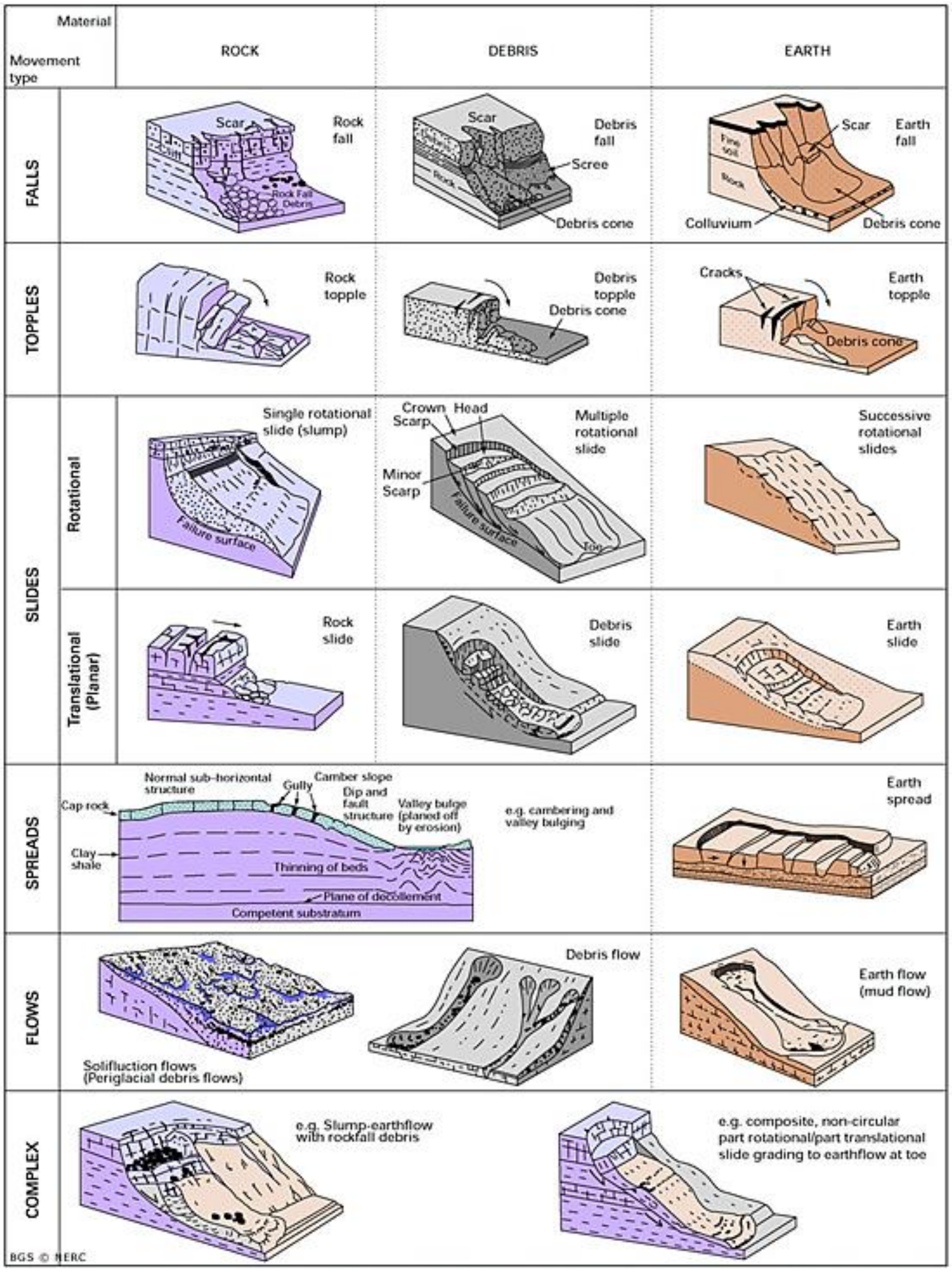
Economists use hedonic property models to estimate preferences for environmental hazards (Rosen 1974; Dorfman, Keeler, and Kriesel 1996; Kim et al. 2015). The housing market is an appropriate proxy to measure the risk related to mass wasting where risk is reflected in the marginal change in home price when all other factors that can affect the value of a home, such as physical home structure, characteristics of the surrounding area of the home, and environmental amenities, are held constant (Dorfman, Keeler, and Kriesel 1996; Kim et al. 2015). Government entities in Washington State have identified where mass-wasting hazards exist, but so far, no hedonic property models measure how individuals value the risk of living in mass wasting prone areas of western Washington (WSDNR 2015).

1.2. Mass Wasting

WSDNR (2017c) defines mass wasting as processes of soils and materials moving downslope, initiated when the force of gravity causes ground failure. Scientists classify mass wasting processes according to the type of movement and material involved (Varnes 1978). A rock movement primarily contains bedrock, a debris movement mainly contains coarse soils, and fine-grained soils make up earth movements (Highland and Johnson 2004). Shallow landslides fail at the soil level, and deep-seated landslides occur below the soil at the root of vegetation in the ground. Different types of sediment under a variety of settings and stress produce mass wasting (WSDNR 2017c). Slopes may experience shallow or rapid landslides, debris flows, and large or small deep-seated ground failures.

Shallow landslides include debris slides and rock avalanches, which often occur on steep slopes where soil lies on a higher concentration of solid material, such as bedrock. WSDNR (2017c) defines debris avalanches as materials breaking apart while rapidly moving downslope. Shallow landslides often affect streams and roads and more often occur on steep slopes because of lessened friction often with increased soil saturation, weakness of vegetation, and natural or unnatural vegetation removal. Land use activities by humans, such as forest practices and other extraction, accelerate mass wasting processes by changing the conditions of a slope. Vegetation removal causes ground sediments to become more saturated with increased precipitation (WSDNR 2017b). Vegetation, such as forest cover, soaks up groundwater, decreasing slope saturation during precipitation. In addition, it acts as a canopy, as less surface water becomes groundwater when more vegetation cover exists. Removing trees or vegetation can, therefore, lead to an increase in groundwater and increased slope saturation, causing more weight on slopes and making ground failure and mass wasting more probable.

Deep-seated landslides cover more area and cause more destruction than shallow landslides (Highland and Johnson 2004). Seismic shaking, weaknesses in geologic materials, and hydrological slope erosion triggers deep-seated landslides. Liquefaction occurs when seismic shaking saturates soil, causing slopes to lose sheer strength (Varnes 1978; Highland and Johnson 2004). Additionally, seismic shaking causes stress to earth material, decreasing the strength of slopes. Channel incision, or the undercutting of a slope due to hydrological flow, weakens the slope base and decreases slope stability, increasing the probability of mass wasting processes (Highland and Johnson 2004). Climate change, which includes glacial–interglacial transitions, intermediate climate change, and short-term climate change, accelerates deep-seated ground failure (WSDNR 2017c). Glacial–interglacial transitions involve major or long-term climate changes. Intermediate climate change includes fluctuations in climate patterns such as several wet or dry years, and short-term change involves extreme weather events, such as major storms or droughts. Figure 1 shows types of mass wasting processes (Novotny 2013).



Source: Novotny 2013.

Figure 1. Varnes classification of slope movement.

In the United States (U.S.), regions near the Appalachian Mountains, Rocky Mountains, and Pacific Coast region experience the most mass wasting. The Pacific Coast region contains more tectonic plate hazards subject to earthquake activity than other regions in the U.S. (WSDNR 2017b). Researchers estimated that 25 to 50 people die each year in the U.S. because of mass wasting. Additionally, WSDNR estimates that mass-wasting events cost the U.S. $2 billion per year. Washington State, where hundreds to thousands of mass-wasting events occur every year, is one of the most at-risk regions for mass wasting in the U.S. In fact, every year, the Washington State Department of Transportation budgets $15 million for cleaning up and repairing damage to transportation ways caused by mass wasting processes.

1.3. Mass Wasting in Western Washington

The frequency and magnitude of mass-wasting events in western Washington poses danger to residents in the area because of the proximity of homes, property, and infrastructure to mass-wasting hazards (WSDNR 2017b). The State experiences significant economic losses because of mass-wasting events. Table 1 shows the value of these losses from 1990 to 2014.

In western Washington in 1996, January snowfall was relatively high, and it was followed by heavy rain in February of the same year—191% greater than normal totals (WSDNR 2015). The heavy precipitation resulted in numerous mass-wasting events throughout the state, with the largest occurrence located in Lewis County. These landslides caused damage to and destroyed approximately 8,000 homes and several major highways, resulting in numerous temporarily closed roads. In February 1999, a mass wasting event destroyed or damaged forty-one homes and properties in Thurston County, costing a total of $10 to $15 million. In addition, the second costliest mass wasting disaster in the U.S. occurred in 1998 in Cowlitz County, impacting 138 homes, and costing more than $110 million. Heavy rainfall also triggered mass-wasting events throughout the state in 2003, 2007, and 2009, costing a total of almost $1 billion.

Table 1. Significant Deep-Seated Landslides in Western Washington

Year	County	Direct Costs ($ Millions)	Number of Damaged/Destroyed Homes
1990	Clallam	5	0
1990	Clallam	5	0
1990	Wahkiakum	5	0
1994	Lewis	10–15	0
1998	Cowlitz	110	138
1999	Mason	10–15	0
1999	Mason	5–10	0
1999	Mason	3	0
2003	Whatcom	10–15	0
2004	Jefferson	8	0
2005	Greys Harbor	5	0
2006	Greys Harbor	2	0
2008	King	5–10	0
2014	Snohomish	80	41

Source: (WADNR 2015)

Earthquake risk in western Washington increases the probability of mass wasting incidents. On February 28, 2001, the 6.8 magnitude Nisqually earthquake triggered mass-wasting events throughout western Washington (WSDNR 2015). The epicenter of the earthquake was in Thurston County, which caused considerable damage to the immediate and surrounding areas. Capitol Lake, located in Olympia, Washington, experienced the most notable mass wasting damage because of ground failure. The Nisqually earthquake cost the State approximately $34.3 million in damage.

Human land use practices accelerate mass wasting in western Washington (Shipman 2001; WSDNR 2015; 2017b). Land extraction and development activities stimulated mass-wasting events in 1997 in Snohomish and Clallam Counties, in 2005 in Grays Harbor County, and in 2006 in Snohomish County (WSDNR 2015). Timber companies clear cut near the area of the 2006 Snohomish County landslide since the early 1900s. This area was also the site of the 2014 Oso landslide, the deadliest mass-wasting event in U.S. history (Wartman 2016).

1.4. The Oso Landslide

On March 22, 2014, a deep-seated landslide occurred in Oso, Washington. The landslide significantly impacted a community called Steelhead Haven, resulting in forty-three fatalities (Wartman 2016). The Oso landslide destroyed forty-one homes and structures, and approximately one mile of the nearby highway, State Route 530 (Robertson 2015). State officials shut down the affected area of State Route 530, the main route between the cities of Arlington and Darrington, for approximately two months. The Oso disaster remains the most recent large-scale mass-wasting event to happen in western Washington.

The 2014 Oso landslide occurred in a known mass-wasting hazard area. Snohomish County officials documented the first mass-wasting event as early as 1900, when State officials wanted to remove debris from a wagon road between Arlington and Darrington due to a large mass-wasting event (Armstrong et al. 2015). The North Fork

Stillaguamish River often overflowed and shifted over the years due to mass-wasting, which flooded homes in the area. Steelhead Haven, a neighborhood established in 1960, was located below Hazel Slope, nicknamed Slide Hill because of the frequency of landslides on the slope. The North Fork Stillaguamish River, located just north of the neighborhood, undercut Slide Hill. The map in Figure 2, obtained from Armstrong et al. (2015), represents the proximity of Steelhead Haven to Slide Hill. The area was known for excellent outdoor recreation, including fishing, hunting, and camping. Even though several relatively minor landslides produced by Hazel Slope affected Steelhead Haven for several years, the community continued to expand.

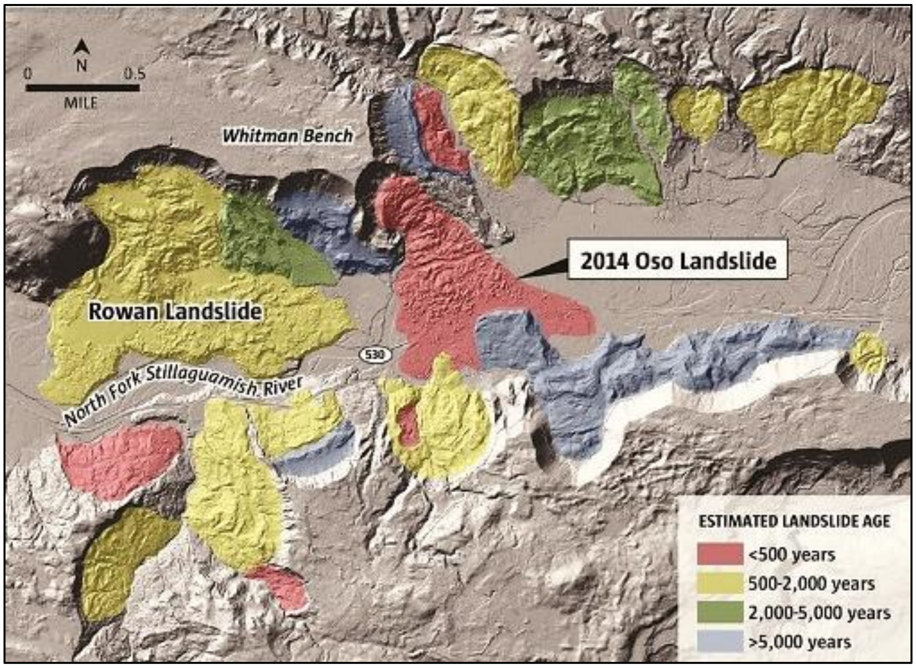
Source: Armstrong et al. 2015.

Figure 2. Slide Hill location in relation to the Steelhead Haven neighborhood.

In hindsight, several factors contributed to the Oso disaster. Western Washington experienced a particularly wet 2013 to 2014 winter; rainfall for the area of Oso was approximately 91% greater than average, saturating and destabilizing Hazel Slope

(Winters 2015). In addition, land use practices and heavy precipitation on the knowingly unstable Slide Hill contributed to the 2014 Oso disaster. Grandy Lake Forest Association most recently logged near Slide Hill, up until 2009 (Hughes 2014). The magnitude of the event surprised many individuals despite the warning signs.

Researchers and scientists from the University of Washington estimate that the valley of the North Fork Stillaguamish River is struck by mass-wasting events of similar magnitude to the Oso landslide every 140 years on average (Droughton 2015; Wartman 2016). The scientists used Light Detection and Ranging (LiDAR) to determine where areas contain mass-wasting deposits and differentiated between each mass wasting deposit to identify separate mass-wasting events (LaHusen et al. 2015). LiDAR, a remote-sensing technique that utilizes laser light, produces very accurate predictions of measurements in a landscape, such as the height and length of features. The scientists used radiocarbon dating to determine the approximate age of mass-wasting deposits (Droughton 2015). Figure 3 shows LiDAR data along with age estimates of landslide deposits seen in the LiDAR imagery, the researchers produced (LaHusen et al. 2015). This analysis determined that the 2014 Oso disaster was no coincidence; based on history in the area, it was expected.



Source: LaHusen et al. 2016.

Figure 3. Mass-wasting deposits.

1.5. Current Policy

Policies and laws exist in Washington State to protect against mass-wasting hazards and manage the associated risks. The local governments, state government, and various agencies in Washington State work together to mitigate hazards due to mass-wasting with the goal of increasing public health and safety. Policies related to mass-wasting hazards in Washington State include watershed analysis, the State Environmental Policy Act (SEPA), Forest Practices Act, and the Growth Management Act.

Mass wasting impacts most forested basins in Western Washington, which can be aggravated by certain forest management behaviors (WSDNR 2011a). WSDNR determines possible mass wasting by providing management prescriptions for watersheds based on watershed analysis. To conduct watershed analyses, WSDNR identifies areas with mass-wasting potential and provides assessments of hazards based on the type and degree to which mass wasting occurs (WSDNR 2011b). Washington Administrative Code (WAC) 222-16-050(4) requires watershed analyses to be kept current by doing reanalysis of mass-wasting prescriptions when deemed necessary by WSDNR (Washington State Legislature [WSL] 1992a). Once WSDNR evaluates the potential area for mass wasting and assesses management strategies for a particular basin, the agency writes a prescription which SEPA reviews and finalizes (WSL 1992b).

In 1971, Washington State adopted SEPA, modeled after the National Environmental Policy Act (NEPA) of 1969 (Ecology 2016). Since 1971, the State made several amendments to SEPA. This policy advocates for environmentally efficient development propositions and mitigation techniques by offering information to agencies, applicants, and the public. For decisions made by agencies in the state that fall under the definition of an "action," SEPA must do an environmental review. SEPA reviews any action related to mass-wasting hazards with the goal of protecting Washington's environment, public health, and safety.

In 1974, the Washington State Legislature (WSL) enacted the FPA. WSDNR oversees the Forest Practices Board, which standardizes growing, harvesting, and processing activities associated with timber (Hughes 2014). These forest activities can fall under four different classes in the Forest Practices Act: class I, class II, class III, or class IV. According to WAC 222-16-050, which describes the classes of forest practices, timber harvest proposals in potential areas for mass wasting where current or past natural resource extraction exists become class IV activities (WSL 1988). Proposed harvests in designated logging areas subject to mass wasting become class III activities if applicants submit an official watershed analysis prescription with the application. WSDNR evaluates all forest practice applications and has thirty days to review and approve applications as stated in Revised Code of Washington (RCW) 76.09.050 (Hughes 2014). If WSDNR does not approve an application within the specified time frame, the State considers the application approved and the endeavor may take place, as long as SEPA does not need to review the proposal, the applicants meet all of the Forest Practices Rules, and the local government does not disagree with the planned activity.

In 2004, Grandy Lake Forest Association submitted a class III forest practice application for a harvest located on fifteen acres above the North Fork Stillaguamish River on and near Hazel Slope. However, WSDNR conducted a watershed analysis in the 1990s and designated Hazel Slope as a mass-wasting hazard because of the area's susceptibility to erosion, coupled with unstable soils on the slope. The Forest Practices Board did not approve the application in 2004 because Grandy Lake Forest Association did not produce the Hazel Slope watershed analysis with their application. Approximately one month later, Grandy Lake Forest Association re-submitted the application and excluded the area deemed sensitive by the Hazel Watershed Analysis from their proposed harvest. The Forest Practices Board approved Grandy Lake Forest Association's proposal in August 2004 for a 7.5 acre harvest even though the newly proposed harvest was near Hazel Slope. In 2006, Hazel Slope collapsed. The 2006 landslide did not harm people or homes, but the closest home was 500 feet away (Snohomish County Planning and Development Services [SCPDS] 2014).

In 2015, people affected by the 2014 Oso landslide filed a lawsuit against WSDNR and Grandy Lake Forest Association because of irresponsible timber harvests done prior to the 2014 landslide (Beasley 2015). Grandy Lake Forest Association extracted timber outside of their proposed harvest area granted in 2004, an area of mass wasting sensitivity. WSDNR settled for $50 million and Grandy Lake Forest Association settled for $10 million. In May 2014, two months after the Oso disaster, WSDNR stated that forest practice applications to be done on or near unstable slopes would require site reviews, regardless of whether a watershed analysis exists (Hughes 2014). Additionally, applications submitted for Class III practices now require a Slope Stability Informational Form if extraction takes place on unstable slopes.

After the 2014 Oso disaster, Snohomish County realized a need for increased safety. In September 2015, Snohomish County Planning and Development Services made amendments to Chapter 30.62B of the Snohomish County Code (SCC), which describes critical areas of geological hazards (SCPDS 2015). SCPDS redefined the *term landslide hazard area* to include an updated calculation for the hazardous range of a slope and changed the previous slope percentage consideration of a landslide hazard from 33% or greater to 30% or greater. Additionally, SCPDS made an amendment to prohibit development in these critical areas completely. In cases for development with no alternative locations, SCPDS provides methods for the development process. In August 2016, Snohomish County produced a critical area regulations update, which includes an updated map of landslide hazard areas in the county (SCPDS 2016). The map specifies areas with known landslide deposits, landslide hazards based on the definition in SCC

30.62B, and places susceptible to erosion. Snohomish County no longer allows development and other human land use activities in mass-wasting hazard areas, however, preexisting homes remain in places subject to mass-wasting risk.

1.6. Significance of Research

This research uses a hedonic property model to measure the impact of mass-wasting events on home values, thereby determining how people value the risk associated with mass-wasting hazards. Focusing on single-family homes in Snohomish County, where the 2014 Oso landslide disaster occurred, this study analyzes home prices for Snohomish County after the 2014 Oso landslide, holding all other factors constant (Dorfman, Keeler, and Kriesel 1996).

I use home sale data for 2004-2017 and mass-wasting hazard data in a geographic information system (GIS) to determine where home sales took place in areas of mass-wasting risk in Snohomish County. The research uses GIS methods to gather data about the proximity of homes to landslide hazards. The information feeds into analysis of the sale prices of homes in the area after the Oso landslide. This leads to more complete information regarding mass-wasting risk for public officials, real estate professionals, homeowners, potential home buyers, and resource managers.

This research produces a greater understanding of the preference for risk of mass-wasting hazards in Snohomish County (Dorfman, Keeler, and Kriesel 1996; Shipman 2001). In addition, this research assesses whether people are behaving rationally in regard to mass-wasting hazards. People may not be making rational decisions related to their willingness to pay for a home; they may be unaware of the risk and need to be informed about potential mass-wasting danger near their properties (Brookshire et al. 1985).

II
LITERATURE REVIEW

Environmental disasters pose risk to individuals in many parts of the world. Human decision-making processes must be understood by resource managers and policy makers to manage risk effectively (Tversky and Kahneman 1974; Slovic 1975; Smith 2013). This chapter examines how places in the world are economically affected by natural disasters, specifically mass wasting, and how researchers determine the value of those economic impacts. Additionally, the research related to human decision theory regarding risk helps clarify how people perceive the risk of natural disasters. I explore previous literature to explain how researchers measure the value of risk regarding floods, earthquakes, and mass wasting. This discussion includes possible methods for valuing risk of environmental hazards, which ultimately demonstrates the usefulness of a hedonic price model to evaluate the currently unknown risk of mass-wasting hazards in western Washington.

2.1. Economic Impacts of Natural Disasters

Natural disasters produce direct and indirect costs (Kern 2010). Additionally, natural disasters result in destruction leading to monetary costs, often increasing government expenditures (Smith 2013). Less prosperous areas experience more significant socioeconomic implications of natural disasters (Smith 2013). Places that are relatively poor often experience more deaths and damage to infrastructure and property when environmental disasters occur (Kern 2010; Rajapaksa et al. 2016).

Direct damage due to natural disasters includes physical and human capital losses, cleanup, and re-establishment of communities (Department for International

Development 2005). Indirect costs include production losses; physical distress; loss of salaries, wages, and profits; and, reduction of property values. Individuals affected by environmental disasters may experience losses and damages to assets and personal belongings. These losses for individuals influence their monetary positions because of necessary increases in consumption and potential decreases in opportunity costs and wages. Local, state, and federal governments also experience indirect costs through decreases of property taxes where infrastructure is damaged or destroyed and an increase in relief, assistance, aid, and cleanup costs (Sorkin 1982; Department for International Development 2005). Additionally, natural disasters impact the environment to varying degrees, depending on the disaster type (WSDNR 2017b). For example, mass wasting can cause water contamination, wildfires lead to air pollution, and wind storms can cause water pollution.

2.2. Economic Impacts of Mass Wasting

Mass wasting affects many areas around the world. In fact, Japan experiences direct and indirect costs from mass wasting of over $4 billion per year, while the United States, Italy, Canada, and India each spend approximately $1 to $2 billion per year on mass wasting causes (Schuster and Highland 2001; Sass 2005). Direct damage of mass wasting includes the loss of physical property such as highways, railways, utilities, and agriculture. In the event of a landslide, the government incurs the costs of repairing damaged roads, infrastructure, and property (WSDNR 2017b). In Italy, between the years 1945 and 1990, costs of damage due to landslides was over $15 billion (Smith 2013). Most deaths related to landslides occur in the Pacific Coast region, Central America, the

Caribbean, China, and areas of the Himalayan Mountains. These areas share common characteristics such as considerable amounts of precipitation, large mountain ranges, and significant amounts of people living in natural hazard regions. From 1990 to 2007, approximately 55,000 people died in landslide disasters in the world (Petley and Smith 2009; Smith 2013).

Vranken et al. (2013) assessed total direct and indirect damage caused by landslides using survey methods to value the socioeconomic impacts in an area west of Brussels, Belgium. The region has seen 291 landslides in the past of which 214, or 73.6% were deep seated. The authors estimated the decrease in real estate values of homes located in areas with landslide risk. This study used semi-structured surveys and focus interviews to gather information about the economic costs of landslides. The authors gave questionnaires to 10 private property owners of farms and homes to collect information about damages to private properties. In addition, Vranken et al. (2013) conducted 22 semi-structured interviews to gather information about damages done to public infrastructure. The authors conducted 5 focus interviews to receive information about economic costs associated with mitigating damage from landslides.

The authors quantified the monetary costs of direct damages due to the mass-wasting events, which totaled 688,148 euros per year. Indirect costs, including prevention of landslide damage to infrastructure and private property, totaled approximately 3,020,049 euros per year. The authors asked real estate agents and notaries to determine estimates of real estate before and after the landslides occurred, with the objective of assessing the significance in the decrease of home values. The results of the study show that roads, utility lines, and private properties experienced the most damage. For real estate, homes that experienced a small amount of damage due to landslides, for example, small cracks in walls, decreased in price by an average of 10%. Homes that experienced more severe damage due to landslides, such as large cracks in walls, decreased by an average of 32.5% of the total value. Overall, this research shows the significant direct and indirect costs of landslides, which greatly affected residents of the area.

Mass-wasting disasters not only affect economies, but the events produce costs for individuals as well. While researchers determined the economic costs for many mass-wasting events, a lesser amount of research exists related to the perceived risk of mass wasting for individuals. Resource managers and policy officials must understand people's preferences for living near environmental hazards to manage environmental risk fully (Smith 2013).

2.3. Risk

One assumption in the field of economics is that people behave rationally, but cognitive limitations often prevent them from making rational decisions due to a lack of awareness or complete information (Simon 1959; Slovic 1975). Individuals cannot be certain of the unknown future, so all decisions people make involve risk (Smith 2013). If individuals could predict or be certain of the outcomes of their decisions, then decisions would not involve any level of risk (Adams 1995). To improve policy, public officials should understand how humans make decisions and whether those decisions are rational (Smith 2013).

Decision theory evaluates how people make choices in situations of risk and uncertainty (Tversky and Kahneman 1973). This theory assumes that uncertainty of outcomes exists as a result of limited availability of information (Tversky and Kahneman 1973; Smith 2013). In general, people tend to avoid risk (Smith 2013). Evaluating the risk associated with a decision involves estimating the probability of an outcome through qualitative and quantitative measurements. However, rather than assessing risk probability, people tend to use more simplified models to make decisions (Simon 1959). Quantitative risk assessments for the public are important to increase availability of information for individuals to make rational decisions. Statistical risk valuations are quantitative estimates of risk conducted through scientific evaluations and based on factors such as economic impacts and the probability of the occurrence of events, but these assessments do not consider individual risk values.

Individuals make decisions based on their risk perception and reveal the value of personal risk through consumption choices (Smith 2013). Personal risk perception, a significant component in managing risk, often varies from statistical risk values. Human response to danger factors into how people perceive risk. Public officials must understand this response to improve public health and safety.

2.3.1. Perception of Risk

Perceptions of risk vary based on whether the risk is voluntary or involuntary (Smith 2013). Involuntary risks are situations out of a person's control, such as environmental hazards or disasters. These types of risk could include a volcanic eruption or an earthquake. The involuntary risk associated with an event may be considered unavoidable even if awareness of a hazard exists. Voluntary risks are those in which people readily partake, often on a daily basis, and are willingly accepted and considered controllable by individuals. For example, voluntary risks include common modern-day tasks such as driving and recreational activities. Avoiding these risks may involve a higher level of sacrifice from one risk activity to the next. As an example, individuals may sacrifice more to give up driving to work, rather than the opportunity to go skiing, because giving up work leads to a loss in wages. A person may be willing to sacrifice less depending on the voluntary risk activity. Although risks might be voluntary, many people do not have complete information related to the probability of risk occurrence.

Risk perception changes based on socioeconomic factors such as income and culture (Smith 2013). Family, friends, coworkers, public officials, culture, and religion influence people’s perceptions. Depending on the people with whom an individual surrounds himself or herself, perceptions of risk can be over or underestimated (Slovic 1975). Income levels also affect a person’s risk perception. While people generally opposed risky outcomes, risk aversion decreases when a person’s wealth increases (Smith 2013). In other words, when one’s income increases on average, the level of risk he or she is willing to accept increases. Therefore, with variations in income levels in society, risk aversion will differ among people.

Several biases effect human assessment of risk judgment. Prior experience affects how a person perceives future risk (Slovic 1975). In general, people tend to estimate the frequency of an event incorrectly, which leads to inaccurate risk assessments and irrational decision-making (Tversky and Kahneman 1973). The availability bias causes people to estimate the probability of the occurrence of an event by the number of times they can retrieve similar events from their memory. Rather than estimating probability of risk based on statistical measurements, people often judge this probability based on their own experiences. This phenomenon can be explained by the difficulty of imagining events that have a low probability of occurrence, as opposed to the ease of visualizing events that happen more frequently. Individuals have difficulty fathoming events that never personally affect them. Additionally, people tend to misjudge events as being likely to occur based on how recent a similar event has happened, known as the recency bias (Tversky et al. 1973). This bias effects how people determine temporal variations in risk perception. The human brain easily recognizes patterns, but sometimes incorrectly perceives patterns to be a determinant of the future, causing an introduction of cognitive bias when making decisions, known as the gambler's fallacy (Smith 2013).

Communication and presentation of information influences risk perceptions (Slovic 1975; Tversky and Kahneman 1974). Studies show that presenting the same information in different ways changes individual risk perceptions, which alters people's responses and reactions to information (Slovic 1975). Over exaggerated risk causes people to overreact.

In the modern world, media is one of the main sources of information. Biases in media information lead to misperceptions of risk. Media has difficulty eliminating biases in information due to constraints for journalists and reporters, such as availability of resources to evaluate problems and limited time to gather information. Media presentation affects how the public reacts to information. Overreaction from the public causes people to perceive a situation to be riskier, just as a lesser reaction causes people to underestimate a risky event. Media must communicate information regarding risk accurately and responsibly, so that viewer estimates of risk are less biased. Given the biases in media communication, the public must take responsibility for evaluating media information properly. Individuals should correctly judge and interpret information presented to them, rather than assuming information is unbiased. Media sources must limit the bias they introduce when presenting information so that individuals can make rational and informed decisions. Moreover, it is important for people to properly assess information to recognize biases on their own.

Even in the case of risky choices, people tend to be loss averse, causing them to dislike change (Slovic 1975; Thaler 1980). Thaler's (1980) theory of the endowment effect shows that people are less willing to give up assets that have sentimental or emotional value. The endowment effect is also consistent with places of sentimental value. When one resides in an area for an extended period of time, the person may not be willing to move away because of emotional attachment (Slovic 1975). However, irrational behavior can lead to more consequences because the future value of loss in some circumstances may be far more significant than current asset value.

Due to human cognitive limitations of making rational decisions and errors in determining probability of a risky event, public officials and resource managers must take steps to make human risk perception more accurate. Increasing awareness of risk eliminates error in human estimations of risk and leads to more rational decision-making (Slovic et al. 1974; Tversky et al. 1974). Additionally, policy makers can change incentives of individuals to prevent irrational decision-making regarding risk (Starr 1969; Tversky and Kahneman 1974; Slovic 1975).

2.3.2. Risk Perceptions of Natural Disasters

The negative relationship between the size of a disaster and the probability of its occurrence shows that destructive natural disasters happen less frequently but produce more significant impacts (Smith 2013). Environmental disasters with the least frequent occurrence include incidents such as earthquakes, tsunamis, volcanic eruptions, and mass wasting (Slovic 1975; Samarasinghe and Sharp 2010). Because of the low probability of these events, people often incorrectly assess the risk, even though these large-scale events are inevitable. People incorrectly evaluate risk of natural disasters because the outcomes of these hazards are involuntary, perceiving them to be out of one's control (Kates 1962; Smith 2013). However, individuals have control over their proximity to hazards. People can make decisions to self-insure through avoidance or mitigation, rather than suffer future consequences. Several biases cause people to misjudge risk they may face regarding environmental hazards (Slovic 1975).

Natural hazards often provide benefits to people including amenities, aesthetics, and recreational activities (Kates 1962). For example, natural hazards such as earthquakes and mass wasting occur in mountainous areas, where aesthetically pleasing attributes and amenities exist, such as views and availability of recreational activities. Individuals may value the benefits greater than the costs of associated hazards. The utility gained from views and recreational opportunities may outweigh the risk of environmental disaster if a person estimates the probability of dangerous outcomes as low. As an example, people generally pay more money for a home with a view of water or mountains for aesthetic benefits (Kates 1962; Kim et al. 2015). Although these cases of risk may be voluntary, bias exists related to the estimate of the probability of risk occurrence. However, in general, people willingly accept risk that also has benefits (Starr 1969).

Socioeconomics and demographics factor into risk perceptions of natural hazards. With an increase in income, people can more easily mitigate natural hazards and disasters, decreasing their amount of risk (Smith 2013). People with more disposable income can more easily move away from a natural hazard area relative to someone with less income. People with less income or who are poor may not have access to alternatives of living near an environmental hazard (Simon 1959). Additionally, poor people tend to be less able to take emergency measures such as mitigation, avoidance, and risk transference to lessen their impacts of environmental risk. In general, those with less income do not have ease of access to information related to natural hazards, especially information available in technological formats (Smith 2013). People with relatively lower incomes may misperceive risk and face situations of fewer alternatives.

Cultural and religious factors also influence risk perception of natural hazards. Many cultures view parts of the natural environment as sacred, such as mountains, which influences the perception of the risk associated with natural hazards (Smith 2013). If living near a natural hazard because of religious purposes, one would be likely to perceive a lower level of risk related to the hazard and be less willing to relocate because of the place’s sacred value. Cultural and religious values may cause individuals to misinterpret the probability of the risk they may face or not value the risk as highly because of the individual benefits they receive from the hazards (Slovic 1975).

Recency bias and availability theory influence risk perceptions (Tversky and Kahneman 1973). People who have experience with natural disaster events generally have a higher risk perception of environmental hazards (Chapman and Chapman 1969). After a natural disaster incident, individual value of risk generally increases immediately following the event likely because of an increased awareness of risk, and that increased value tends to dissipate as time goes on or as the event is no longer as recent. This recency bias causes people to misjudge the probability of a natural disaster occurrence. For example, researchers found that after an earthquake, the purchase of earthquake insurance increases, even though the probability of an earthquake occurrence did not necessarily increase. Availability theory says that people with experience of natural disasters more easily remember those events, which causes an increase in individual risk valuation. These biases may cause overestimations of risk (Tversky and Kahneman 1974).

Prolonged experience with a natural hazard that does not produce any consequences reduces how one perceives probability of risk (Slovic 1975; Tversky and Kahneman 1974). People with no past experiences with natural hazards tend to misjudge the impacts of these events because of an unawareness of the consequences of environmental disasters (Kates 1962). Given the fact that the most destructive disasters occur the least often, this unawareness is especially problematic (Brookshire et al. 1985). People assume their future will be consistent with their past experiences (Kates 1962;

Slovic 1975). It is, therefore, difficult, and nearly impossible, for an individual to fathom an event that they have not been affected by. For example, in a study conducted by Kates (1962), people were unable to comprehend impacts of floods when they had never experienced a flood in their lifetime. Individuals have difficulty recognizing what seem like random environmental disasters as probabilistic risk. In cases of natural hazards, people should not rely on experience because it will produce biased estimates of risk. Additionally, this bias prevents people from taking measures to prevent and mitigate risk, increasing danger to individuals even more (Slovic 1975).

The gambler's fallacy, the bias which causes people to use recognizable patterns as a probability of future events, affects assessment of natural hazards (Smith 2013). Experts of natural hazards and disasters produce estimates of average intervals in which environmental disasters occur. For example, mass wasting in the area of the 2014 Oso landslide occur every 140 years on average (Wartman 2016). The human brain recognizes this pattern and may present a bias for some individuals in determining their risk. Since the last significant deep-seated landslide occurred in the area in 2014, one may assume their risk of living in the area is low because of this estimated time interval (Smith 2013). However, this interval of occurrence is only an estimated average, and does not mean that the probability of a risky outcome is low. Using these patterns to estimate risk presents bias in probability outcome evaluations.

Given people's cognitive limitations of rational decision-making, it is important to provide individuals with necessary tools and information for them to make rational decisions regarding environmental risk (Slovic 1975). Decision-making behavior can be changed through policy, incentives, and cost controls. By providing individuals with a complete set of alternatives for managing natural hazards, documenting events of natural disasters and conveying information in an understandable way, people can be more informed about what risk they face and ultimately lead people to self-insure through avoidance and mitigation of environmental hazards (Slovic 1975; Brookshire et al. 1985). Decision-making about natural hazards should not be made based on experience or intuition; these decisions should rely on information and facts to avoid underestimating risk. Conveying this information to individuals allows them to make more informed and rational decisions regarding risk (Tversky et al. 1974; Slovic 1975; Brookshire et al. 1985).

Risk management and assessments lead to mitigation and awareness that decreases the overall impacts of environmental disasters (Smith 2013). To improve these processes, public officials and resource managers must understand how individuals value risk related to environmental disasters, since it differs from statistical risk obtained through scientific measures. These assessments can change risk preferences for the public, leading to an increase in health and public safety.

2.4. Measuring Risk

Several studies demonstrate the ability to quantify perceived risk (Brookshire et al. 1985; Dorfman, Keeler, and Kriesel 1996; McKenzie and Levendis 2008; Samarasinghe and Sharp 2010; d'Amato and Kauko 2012; Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Kim et al. 2015; Timar, Grimes, and Fabling 2014; Jia et al. 2016). These studies use revealed and stated preference methods to determine the value of risk of natural disasters. Decreases in consumption in relation to natural hazards reveal people's preferences for a disamenity. A change in home values after an environmental disaster event, holding all other factors constant, reveals a negative preference for risk. This change can be inferred as the value of risk related to natural disasters. Existing literature measures the level of perceived risk related to many natural hazards and disasters including, but not limited to, floods, earthquakes, and mass wasting.

2.4.1. Floods

Rajapaksa et al. (2016) utilized a hedonic property model to examine revealed preferences for housing based on the value of risk in an area of flood risk in the city of Brisbane in Queensland, Australia. The Brisbane floods that occurred in 2011 were one of the most economic costly natural disasters Australia has experienced. In 2009, the Brisbane City Council disclosed information of flood risk through the release of flood hazard maps to the public. The purpose of this study was to examine the effects of home values after the disclosed information of flood risk, and after the 2011 Brisbane floods. Housing transaction data was gathered from 2006 to 2013, which included the periods of the release of the flood risk maps and the 2011 Brisbane floods. All other factors being equal, risk is measured as the decreased difference in the marginal willingness to pay for a home after the flood event or disclosure of flood hazard information.

Homes located in the flood area had an average decrease of 18 to 19% of the total value after the 2011 Brisbane floods (Rajapaksa et al. 2016). Property values showed a smaller decrease of 1 to 4% after the hazard maps were released in 2009, a less significant impact than after the actual flood event. The temporal variation in property decreases were also estimated. Homes that were in high income areas rebounded at a faster rate than homes located in low income areas, showing that the flood events had a greater effect on low income places. The authors reveal the evidence for a need for mitigation in low-income areas and increased relief for low-income areas after disastrous events.

Samarasinghe and Sharp (2010) used a hedonic model to assess the effects of floods on home values in flood hazard areas in North Shore City, New Zealand. The study used 2,241 home sales that took place in 2006 in the study area. The authors also examined the impacts that increased information about flood hazards had on home values. Factors that can affect a value of a home, such as amenities, socioeconomics, and structural home characteristics are held constant in the model to eliminate bias in differences in home values. The authors estimated the risk associated with flood hazards in North Shore City. In the study, the researchers looked at the buyer's willingness to pay for a home in an area of a flood hazard, holding all other variables constant to estimate the value of risk associated with these hazards. Results of this study determined that home values were lower for homes located in areas of flood risk relative to homes sold in areas outside the potential flood zones. However, this value of risk increases when people are made more aware of the hazards through flood risk maps.

Dachary-Bernard, Rambonilaza, and Lemarie-Boutry (2014) used a hedonic price model to estimate the risk associated with flood hazards on the Gironde estuary in France. Development and irresponsible land use practices occurred in flood hazard areas due to increasing population in the coastal urban area. The hedonic price model is used to determine variations in property values, inferred as the value of risk associated with the flood hazards in the area. This study consisted of 11,258 observations of property transactions used to estimate the impacts of flood hazards on home values. Coastal amenities cause consumers to highly value the benefits of the area, increasing their willingness to pay. However, the results of the study indicate that flood hazard zoning is associated with a decrease in property values.

Hurricane Katrina, which made landfall in August 2005, caused significant devastation and loss to the city of New Orleans, Louisiana. This environmental disaster was related to flooding of 80% of the city, as well as damage or destruction to over 50% of the homes in the city (McKenzie and Levendis 2008). After the hurricane, the quality of housing and infrastructure saw a large decrease. The risk of the flood hazard due to flooding caused by Hurricane Katrina was estimated using a hedonic price model. The authors used 16,258 home transactions that took place between January 2004 and August 2006 to estimate the change in home values and the change in elevation of homes after the flooding happened. Elevation is a key factor of flood events, since homes at higher elevation are less likely to suffer consequences of flooding. The authors used structural data of homes sold between the specified dates along with neighborhood characteristic data obtained using GIS methods to estimate the value of a home in the area before and after the flooding took place. The estimates of changes in consumer willingness to pay reveal the perceived risk associated with flood hazards.

Higher elevation of a home decreases the amount of flood risk. Before Hurricane Katrina, each additional foot of an increase in elevation was associated with a 0.9% increase in home price. However, after Hurricane Katrina, homes increased by 4.5% with each additional foot of an increase in elevation. This increased risk value shows that people perceived flood risk to be more problematic after the floods due to the hurricane occurrence. The positive relationship between home price and elevation could be due to an existence of consumer awareness of flood risk before the flood event happened. However, this previous awareness could also be explained by other factors, such as enhanced views as elevation of a home increases. Even though consumers were possibly aware of the risk, the actual experience of this environmental disaster increased how people perceived the threat of danger.

2.4.2. Earthquakes

Brookshire et al. (1985) used a hedonic property model to measure preferences for earthquake risk in Los Angeles County and in the San Francisco Bay Area counties, including Alameda, Contra Costa, and San Mateo Counties in California. Several fault lines run through the state of California, making earthquake risk relatively high in the area. In 1974, the California state legislature passed a law regarding earthquake hazard areas, increasing public information related to earthquake risk. The United States Geological Survey (USGS) and California Division of Mines and Geology identified areas of earthquake faults that are subject to hazardous earthquake activity. These areas are referred to as Special Study Zones (SSZs). As of January 1979, California identified 251 SSZs. When a new SSZ is identified, people who reside within the hazard are notified. California state law requires real estate sellers to disclose information to buyers of property located in a SSZ. Brookshire et al. (1985) determined how this increase in earthquake hazard information affected consumer preferences for risk.

Studying single-family homes, Brookshire et al. (1985) measured the difference in home prices between homes located in SSZs and non-SSZs, holding all other factors that can affect the value of a home constant. Structural home characteristics and socioeconomics of an area change what consumers are willing to pay for a home, so these factors are controlled for in the model to examine only the effect of earthquake hazards on home price. The authors used home sale data for homes sold in 1978 and determined which of those homes were located within SSZs. In Los Angeles County, 291 homes were sold in 1978 in a SSZ, and in the San Francisco Bay Area counties, 745 homes were sold in SSZs. For each county, 5,000 homes were identified that were sold outside of a SSZ to use as a comparison for homes in hazards. The authors found that homes in Los Angeles County that are located within a SSZ sell for approximately $4,650 less than identical homes outside an SSZ. Homes in SSZs in the San Francisco Bay Area counties sell for an estimated $2,490 less than homes outside a SSZ. This information shows that consumers are willing to pay less for homes located in earthquake hazard areas, indicating that people are using risk information in a rational way, as homes subject to risk would ideally not be valued as highly as homes located in more safe areas.

Another study examined risk perception after the earthquakes that took place in the Canterbury Region of New Zealand from 2010 to 2011 using a hedonic model (Timar, Grimes, and Fabling 2014). Two large earthquakes occurred within a six-month time frame, the second resulting in 185 deaths. The earthquake activity caused damage to 20,000 homes and destroyed 6,000 homes in the Canterbury Region. Timar, Grimes, and Fabling (2014) estimated the risk related to earthquakes through changes in home prices after the earthquakes. Home prices before and after the earthquake events were compared using housing transaction data for Dunedin City and Hutt City. In Hutt City, where earthquakes and liquefaction are highly probable, the authors found a 2% decrease in home prices, showing an increase in risk preference. This increase in risk perception disappeared after three years. Dunedin City experienced no change despite the susceptibility of the area to liquefaction. The increase in the perception of risk was larger for the area with a higher probability of seismic activity. Since subjectivity to liquefaction risk is not perceived as highly as seismic risk, the authors recommend land use policy improvements for homes located in areas of liquefaction hazards.

2.4.3. Mass Wasting

Samaraweera et al. (2012) estimated the economic costs of landslides in Sri Lanka in Hali-Ela Divisional Secretariat Division where there is a significant risk of landslide danger. Between the years 1974 and 2008, 1,174 landslides occurred in Sri Lanka. Human factors such as construction and other land use activities affect this area which contains unstable soils, a place that is unsuitable for development. From 2003 to 2007, the Badulla district experienced the largest amount of displaced people, including the most significant property, infrastructure, and agricultural losses of any other district in Sri Lanka. To estimate the economic costs of landslides on property values, the researchers collected primary data by conducting surveys to gather information about households including sociodemographic information and previous experience with landslide incidents. Out of the sample of 160 homes, 83% had experienced landslide events in the previous five years to the survey. When considering the impact of home price due to landslides, poverty and employment plays an important role. Of the households, 22.3% of head of households were primary educated. Eighty-three percent of the sample was subject to landslide risk, 78% lived within ½ kilometer of landslide hazards, and 64% was in poverty.

A hedonic pricing approach was used to determine whether the landslides had an impact on property values in the sample. The model shows a relationship between land values and distance of a home to a landslide. Within the study area, each kilometer closer to the landslide decreased home values by 3,083 Indian Rupees (68 USD at the time of the study; Samaraweera et al. 2012). At the time of the study, average monthly per capita income in the study area was 9,369 Indian Rupees (Department of Census and Statistics 2015); the median monthly per capita income was 6,141 Indian Rupees.

In addition to a decrease in home values relative to landslides, these events also cause increased costs due to cleanup of landslides, delay in agricultural and construction activities, and damage due to properties, including farm land (Samaraweera et al. 2012). Because much of the area is in poverty, it has a lower ability to move away from the area of risk. Additionally, these households use their land for agricultural activities, which are difficult to relocate. The authors recommend a policy control to be put in place to lessen the amount of people who are living near landslide danger areas by resettling the households.

Kim et al. (2015) used a hedonic property model to measure the value of risk of an aesthetically pleasing nature park subject to mass-wasting hazards. The study area is Woomyeon Nature Park, a mountainous area, located in Seoul, Korea, where a significant mass-wasting disaster occurred in 2011. The authors studied the housing market in the area of interest between the years 2008 and 2014, before and after the 2011 landslide occurred. Only multifamily housing buildings were included in the study, which included 5,758 transactions in 212 apartment complexes. The authors included property and structure characteristics in their model. Kim et al. (2015) used landslide hazard maps published by the Korea Forest Service, which determine landslide risk by slope soils, steepness, size, and other factors. The Forest Service classifies landslide risk on a scale of 1–5, 1 being very high risk and 5 being no risk.

Before the landslide event, consumers were willing to pay 22% more for housing located within 100 meters of the nature park; however, after the landslide, this amount decreased to 7%. While the amenities of the nature park still contained aesthetic attributes, the value decreased after the landslide. Prices of properties located within 100 meters of the Woomyeon Nature Park decreased by 11.3% after the occurrence of the landslide in 2011. People were willing to pay less for homes located near the hazardous area because of the risk of danger. The authors believe this decrease in home value because of risk was due to an increase in awareness of the risk, which was unknown before the mass-wasting disaster.

2.5. Methods of Valuing Risk

Samaraweera et al. (2012) collected primary data through interviews and questionnaires, known as a stated preference method, to measure the risk associated with mass-wasting hazards in Sri Lanka. The hedonic model examined the effect on home price based on distance of a home to a landslide area. The authors used the difference in home values based on the hedonic model along with data from interviews and questionnaires to assess the overall cost of the landslide in Sri Lanka.

Stated preference methods have the potential to produce errors due to several biases, including strategic bias, information bias, response bias, and the willingness to pay versus willingness to accept bias (Tietenberg and Lewis 2016). Strategic bias is presented in stated preference methods when the respondent has the incentive to answer a question in a particular way. Information bias, which occurs when respondents have incomplete or false information, can also occur, for example, in cases of measuring economic impacts of mass wasting because one may not know the full extent of risks, hazards, and costs associated with mass wasting. These types of studies do not allow one to control for other variables that may affect the study, which is important to eliminate biased estimates of risk.

Kim et al. (2015) used a hedonic property model for multiple family homes with data that consisted of 5,758 home transactions. Kim et al. (2015) use an equation similar to the model used in this research but for a smaller scale area and for different types of homes. The effect of mass-wasting hazards on single-family homes was not examined.

2.6. Hedonic Methods

Revealed preference methods, such as hedonic models, limit bias in studies because consumer preferences can be observed and measured through consumption choices (Tietenberg and Lewis 2016). The actual value of risk associated with environmental hazards is revealed through the price that consumers are willing to pay for a home, holding all other factors constant (Dorfman, Keeler, and Kriesel 1996).

Hedonic property models are often used to address questions of the value of risk associated with natural disasters. Economists do this by examining changes in consumer preferences revealed through the housing market (Brookshire et al. 1985; McKenzie and Levendis 2008; Samarasinghe and Sharp 2010; Samaraweera et al. 2010; Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Timar, Grimes, and Fabling 2014; Kim et al. 2015; Rajapaksa et al. 2016). Natural disasters are factors that can affect the price of a home but are not physically traded on a market, so a hedonic property model is the best tool for measuring economic changes in the housing market due to these disasters (Lancaster 1966; Rosen 1974; Brookshire et al. 1985; Timar, Grimes, and Fabling 2014; Kim et al. 2015). The aforementioned studies from California, France, and Korea, among others, used a hedonic property model approach to measure the risk associated with natural phenomena (Brookshire et al. 1985; Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Kim et al. 2015).

Hedonic models, rather than stated preference methods, are the best technique to utilize in order to control for outside variables that may cause volatility in home values or bias (Lancaster 1966; Rosen 1974; Timar, Grimes, and Fabling 2015). Hedonic price models are well suited to understand how people perceive risk revealed through individual consumption choices (Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Timar, Grimes, and Fabling 2015; Kim et al. 2015).

2.7. Literature Gap

Researchers examined the impacts of mass wasting for places around the world, but the value of risk associated with mass wasting in the western Washington area, let alone the U.S., has not been studied. The costs inflicted by the 2014 Oso landslide are quantified, however the value of perceived risk associated with the Oso landslide has not been estimated. Evaluating this risk will lead to more precise estimates of people's preferences regarding mass-wasting hazards and a better understanding of how individuals make decisions concerning risk related to mass wasting (Brookshire et al. 1985; Smith 2013).

In the following research, I use a hedonic property model to examine mass-wasting risk. I use a much larger home sale database compared to mass-wasting studies done in Korea and Sri Lanka, which will result in an understanding of mass wasting risk preferences across a wider landscape. Finally, I focus on transactions for single-family homes rather than multiple family housing units. Studying single-family homes is more useful for this analysis because the study spans a region that contains more single-family homes than multiple family homes. In addition, in the United States, people more often rent multiple-family homes rather than buying them. Single-family homes provide a better measure of consumer willingness to pay to live in an area, since purchasing a home tends to be a longer-term decision than renting.

III
STUDY AREA, DATA, AND THE USE OF GEOGRAPHIC INFORMATION SYSTEMS

3.1. Study Area

The area being examined in this research is Snohomish County, located in western Washington. While the scope of this research is restricted to Snohomish County because of limited data availability, the region shares many similar physical characteristics with other areas in the Pacific Northwest. Western Washington is one of the places most susceptible to mass wasting in the United States, partially due to the exceptionally wet climate and high amount of forested land that is often harvested for timber (WSDNR 2017b). The area is very mountainous, contains many steep slopes, and lies on several fault zones. With rising population in the area, more people are susceptible to mass-wasting risk.

3.1.1. Geographical Background

Washington State is in the northwestern part of the United States, bordered to the north by British Columbia, Canada, to the east by Idaho State, to the south by Oregon State, and to the west by the Pacific Ocean. The highest point in Washington State is Mount Rainier at an elevation of 14,410 feet above sea level, and the lowest point is sea level, at the Pacific Ocean. The Cascade Mountain Range divides the state in half, creating eastern and western Washington. The western portion is made up of nineteen counties. This study focuses on Snohomish County.

Snohomish County is in the northern part of western Washington, bordered by Skagit County to the north, Chelan County to the east, King County to the South, and the

Puget Sound to the west. The highest point of elevation in Snohomish County is 10,541 feet, and the lowest point is at sea level, located at the Puget Sound. Figure 4 presents a map of the study area.

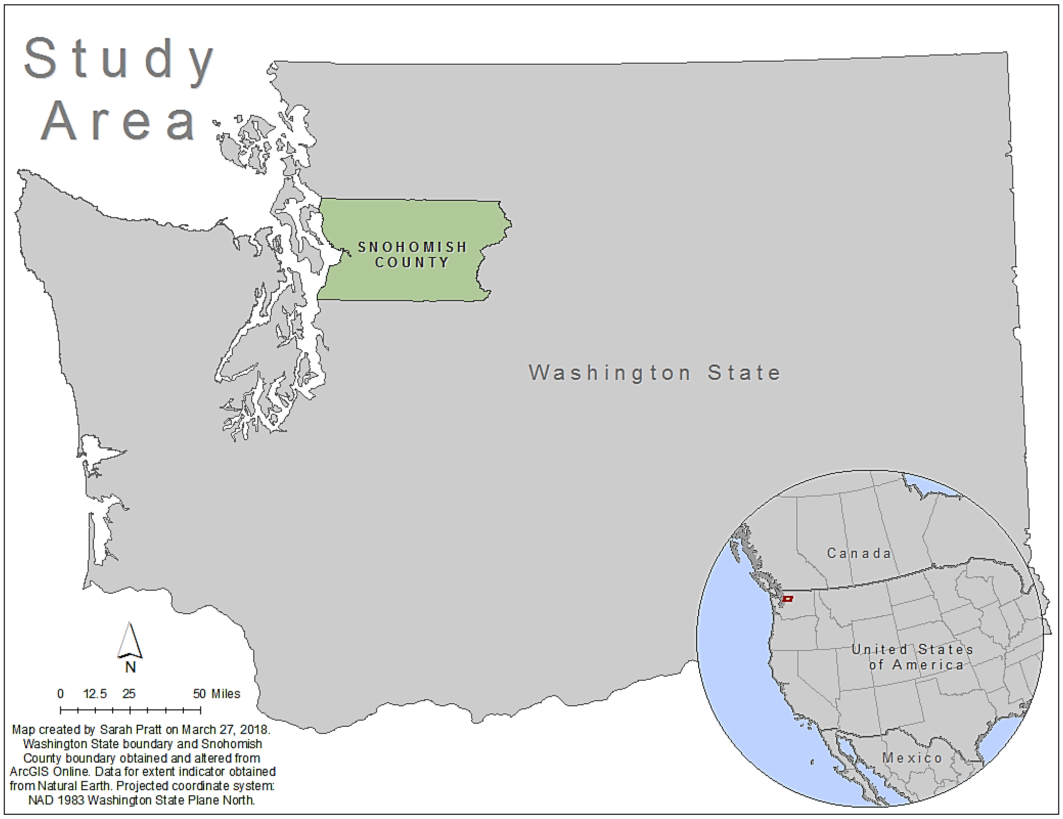
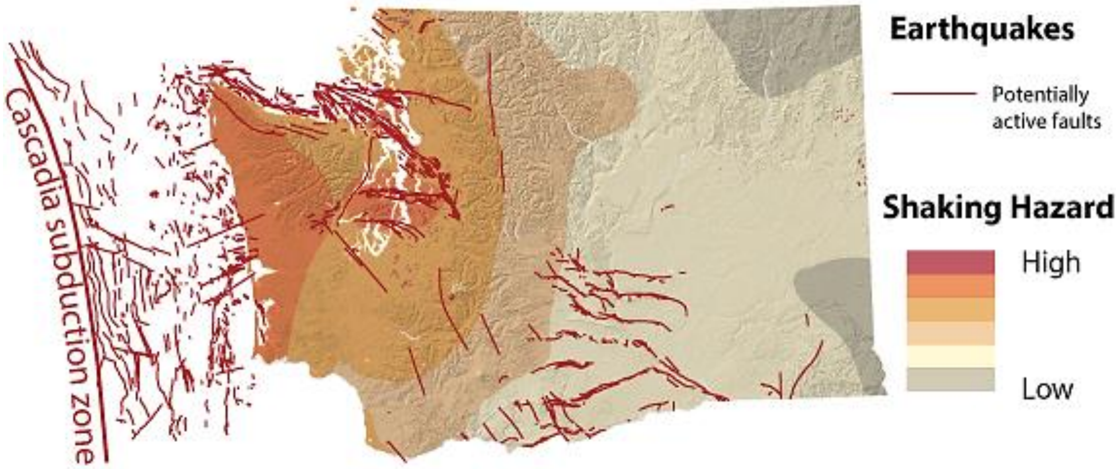


Figure 4. Study area.

3.1.2. Biophysical Characteristics

Western Washington is a mountainous region, where two large ranges, the Olympic and Cascade Mountains, are located. Western Washington has five stratovolcanoes that are part of the Cascade Mountain Range: Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams. Each one of the volcanoes is over 10,000 feet above sea level, except for Mount St. Helens, which before its eruption in 1980 also had an elevation above 10,000 feet. The Snohomish County boundary includes part of the northern Cascade Range. Glacier Peak, which has an elevation of 10,541 feet, is located within the boundary of Snohomish County in the eastern region of the study area. The mountainous region has considerable amounts of variation in elevation, which causes slopes to be especially steep, creating more mass-wasting hazards in the study area (WSDNR 2017b).

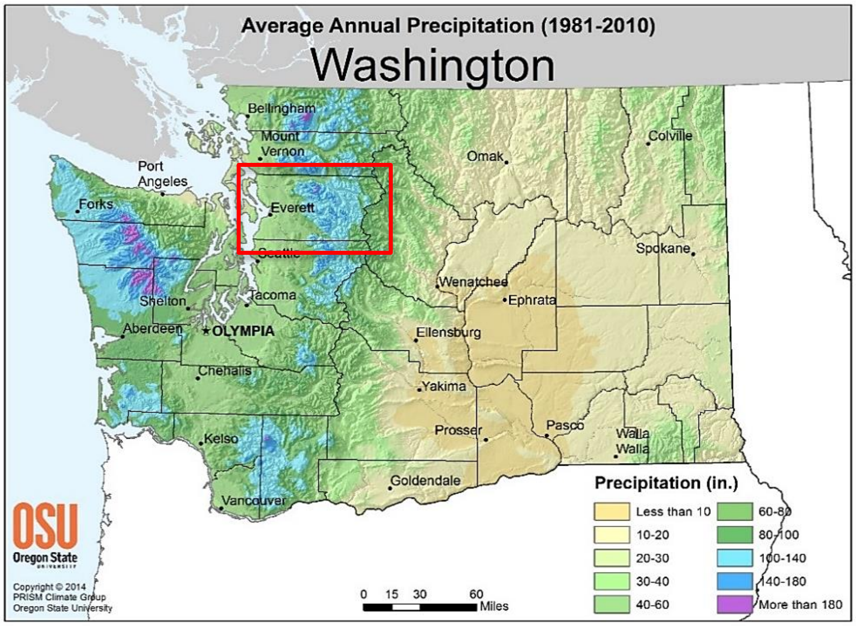
Western Washington contains several potentially active fault zones. As shown in Figure 5, western Washington is near the Cascadia subduction zone, which can produce sizeable earthquakes. Due to the earthquake hazards in western Washington, mass wasting is more likely to happen because shaking hazards can cause soils to be saturated with water (Highland and Johnson 2004). Earthquake shaking can result in the liquefaction of soil and cause slopes to move, each of which can trigger mass wasting (Hungr, Picarelli, and Leroueil 2014). Earthquakes cause stress and decrease the strength of slopes, which result in slope failure if the force of gravity exceeds the decreased strength of a slope (Varnes 1978). Therefore, western Washington's geologic setting relative to mountains and fault lines puts the area at a considerable risk for mass wasting.



Source: WSDNR 2018a.

Figure 5. Potentially active fault zones in Washington State.

Mass wasting poses the most serious risk in western Washington during winter months because of high precipitation (WSDNR 2017b). Heavy rainfall weakens slopes due to increases in weight from groundwater. Many landslides that have occurred in western Washington, including the Oso landslide, have been triggered by increased rainfall (WSDNR 2015). According to the Western Regional Climate Center (2016), rainfall is measured 150 days on average in the inner valleys, and an average of 190 days near the coasts of western Washington. As shown in Figure 6, in western Washington between the years 1981–2010, average annual precipitation was 80 to 100 inches in most places, with areas near the Puget Sound getting 40 to 60 inches of precipitation. Some areas of western Washington even saw an annual average of 100 to 140 inches of precipitation (Prism Climate Group 2016).



Note: Prism Climate Group 2016; study extent added by author.

Figure 6. Average annual precipitation in Washington State, 1981–2010.

3.1.3 Sociocultural Characteristics

Logging, an important industry for Washington, the fifth largest state in the U.S. for employment in the timber industry, decreases slope stability (U.S. Bureau of Labor Statistics 2017; Javier 2017). Extracting timber can result in an increase in ground water, ultimately increasing the occurrences of mass-wasting processes (WSDNR 2017b). Since 2010, timber harvests have decreased by 31%. For western Washington, there has been a small decrease in timber harvests of about 4% and an even smaller decrease of 1% in timber production for the entire state. While timber production in the study area has been on a decreasing trend in the last few years, the amount of forest extraction that takes place remains significant (WSDNR 2018b). In Washington State, 32 of the 39 counties are involved in the timber industry, Snohomish County being one of them. In 2017, Washington State produced nearly 2.7 million board feet of timber, as shown in Table 2.

Of the 2.7 million board feet produced, the western Washington area produced 2.3 million, showing that most logging for Washington State occurs in the western portion. Snohomish County is the tenth largest producer of timber in western Washington, making up approximately 4% of the timber production for 2017.

Table 2. Total Volume of Harvested Trees Produced, Thousand Board Feet

County	2010	2011	2012	2013	2014	2015
Clallam	163,439	187,808	182,120	214,665	228,215	159,596
Clark	97,006	58,612	68,534	67,285	109,963	66,254
Cowlitz	209,846	245,515	231,802	259,812	224,733	247,355
Grays Harbor	332,514	342,866	320,209	305,373	279,555	252,732
Island	1,098	2,315	5,335	6,912	5,974	8,701
Jefferson	105,356	124,329	96,867	127,411	129,162	78,846
King	89,809	114,371	113,378	109,653	102,836	62,556
Kitsap	23,671	20,612	26,110	34,862	24,189	21,452
Lewis	360,722	411,052	365,467	395,809	385,312	377,297
Mason	104,168	110,244	108,098	105,641	112,144	96,109
Pacific	201,987	236,100	212,372	314,897	340,533	286,488
Pierce	147,549	141,934	120,053	120,593	137,893	111,626
San Juan	370	308	677	1,007	1,606	1,258
Skagit	118,487	111,522	105,463	116,674	120,305	100,421
Skamania	58,841	62,201	76,193	82,366	76,075	87,390
Snohomish	125,405	138,815	90,876	134,192	122,331	101,118
Thurston	112,311	92,134	71,664	171,302	75,495	87,628
Wahkiakum	65,331	78,057	80,332	72,268	70,636	68,816
Whatcom	69,201	83,506	70,142	72,098	62,966	58,741
Western WA	2,387,111	2,562,301	2,345,692	2,712,820	2,609,923	2,274,384
Total State	2,739,185	2,984,953	2,739,672	3,179,846	3,056,569	2,815,345

Source: WSDNR 2018b.

Population in western Washington increased in the last several years. From 2010 to 2016, population increased by about 8% in Snohomish County (WSOFM 2017). Table

3 shows population estimates for each county of western Washington from 2010 to 2016. In areas of greater population, mass wasting threatens more infrastructure, housing, and people, producing more fatalities and destruction.

Table 3. Western Washington Population Estimates

County	2010 Census	2011	2012	2013	2014	2015	2016
Clallam	71,404	71,600	72,000	72,350	72,500	72,650	73,410
Clark	425,363	428,000	431,250	435,500	442,800	451,820	461,010
Cowlitz	102,410	102,700	103,050	103,300	103,700	104,280	104,850
Grays Harbor	72,797	72,900	73,150	73,200	73,300	73,110	72,820
Island	78,506	78,800	79,350	79,700	80,000	80,600	82,910
Jefferson	29,872	30,050	30,175	30,275	30,700	30,880	31,090
King	1,931,249	1,942,600	1,957,000	1,981,900	2,017,250	2,052,800	2,105,100
Kitsap	251,133	253,900	254,500	254,000	255,900	258,200	262,590
Lewis	75,455	76,000	76,300	76,200	76,300	76,660	76,890
Mason	60,699	61,100	61,450	61,800	62,000	62,200	62,320
Pacific	20,920	20,900	20,970	21,000	21,100	21,210	21,180
Pierce	795,225	802,150	808,200	814,500	821,300	830,120	844,490
San Juan	15,769	15,900	15,925	16,000	16,100	16,180	16,320
Skagit	116,901	117,400	117,950	118,600	119,500	120,620	122,270
Skamania	11,066	11,150	11,275	11,300	11,370	11,430	11,500
Snohomish	713,335	717,000	722,900	730,500	741,000	757,600	772,860
Thurston	252,264	254,100	256,800	260,100	264,000	267,410	272,690
Wahkiakum	3,978	4,000	4,025	4,020	4,010	3,980	4,000
Whatcom	201,140	202,100	203,500	205,800	207,600	209,790	212,540
Western WA	5,229,486	5,262,350	5,299,770	5,350,045	5,420,430	5,501,540	5,610,840

Source: OFM 2017.

Increasing population comes with increasing development of homes and infrastructure. From 2010 to 2017, production of single-family housing units has increased by 7% in Snohomish County and 5% in western Washington. Table 4 shows increases in single-family housing units in the study area and western Washington for comparison (WAOFM 2017).

Snohomish County had a projected median income for 2017 of $80,579. Since 2010, Snohomish County has the second highest median household income for not only western Washington, but also the entire state. Where there is destruction from mass wasting in developed areas, especially those areas of higher income, the overall costs of mass wasting increases.

3.2. Geographic Information Systems

The field of environmental economics benefits from the use of geographic information systems (Parmeter and Pope 2012). With GIS, economists study how natural resources and environmental amenities and disamenities affect people's preferences for where they chose to reside. For example, using GIS tools in hedonic models, economists measured the effect on housing prices of air, noise, and water pollution (Metz and Clark 1997; Leggett and Bockstael 1998; Din, Hoesli, and Bender 2001), school quality (Black 1999; Figlio and Lucas 2004), hazardous waste sites (Gayer, Hamilton, and Viscusi 2000; Bui and Mayer 2003), cancer risk (Davis 2004), and recreation amenities (Lovett, Brainard, and Bateman 1997; Bateman, Lovett, and Brainard 1999; Jones 2010).

Hedonic methods are known to be subject to omitted variable bias, which occurs when one or more explanatory variables are left out of a model (Parmeter et al. 2012). The use of GIS in hedonic models relieves some of the omitted variable bias because of the ability to include variables other than structural home characteristics that affect home value, such as sociodemographic information and regional price variances.

Environmental economists use hedonic property models to evaluate the change in home price due to proximity to environmental amenities and disamenities (Tietenberg and Lewis 2016). While different types of home data exist, housing transaction data is often used and publicly available through local governments (Parmeter and Pope 2012). Ideally for hedonic methods, researchers would have information for every home within a study area, not only home transactions, but gathering this data would be timely, costly, and require survey methods to be used, which are subject to strategic bias. Housing transaction data provides a sample of the population of home prices in an area. Parmeter and Pope (2012) outline detailed steps to take for using hedonic models in economic research.

3.3. Data Descriptions

I used two datasets to complete this analysis. First, I obtained home transaction data from the Snohomish County Assessor. The second dataset contains mass-wasting hazard information for Snohomish County.

3.3.1. Housing Data

Every housing transaction has a spatial and temporal context (Parameter and Pope 2012). GIS makes the spatial component of housing transactions more accessible to economists. For a hedonic study, the housing transaction data must contain the sale price and date of each home, an address, and structural home characteristics such as number of bedrooms and square feet.

Snohomish County assessor's public records provided home sale data for Snohomish County. The database contains information for approximately 130,000 single-family homes sold between 2004 and 2017 and includes variables such as addresses, sale date, sale price, and structural characteristics including age, square feet, number of bedrooms, and number of bathrooms. About 5,000 observations contained unknown addresses where the input for the address variable was stated as “unknown” which I removed from the data set. The average home in the data set has 3 bedrooms, 2 bathrooms, and is 60 years old. The median sale price of a home in the data is $263,384.

3.3.2. Mass-Wasting Hazard Data

Snohomish County Planning and Development Services updated the County landslide hazard area map, made publicly available on August 10, 2016, detailing approximate locations of landslide hazard areas in the county (SCPDS 2016). I obtained the data from the updated map from the Snohomish County Assessor public records, which included shapefiles of known landslides and landslide hazard areas. Landslide hazards are defined by the Snohomish County government as areas potentially at-risk for mass wasting based on geologic, topographic, and hydrological factors, with a vertical height of 10 feet or more. Landslide hazards includes places of historical mass-wasting occurrences seen through deposits, places susceptible to basal undercutting by water bodies, slopes greater than 30%, and areas subject to debris flows or flooding in a canyon or valley (SCPDS 2015).

The updated landslide hazard area map produced by SCPDS uses mass-wasting hazard data from the WSDNR. The WSDNR (2017a) provides publicly available mass-wasting hazard maps compatible with GIS software. Since variation exists in what causes mass wasting, experts determine triggers for mass-wasting events. Scientists use different methods to assess slope stability by using a combination of aerial photographs, maps and historical landslide information (WSDNR 2011a). I obtained a geographic database provided publicly by WSDNR Division of Geology and Earth Resources GIS that contains polygon shapes of mass-wasting hazard areas that SCPDS also used in their updated map (WSDNR 2017a). The data includes mapped landslides at a 1:24,000 and 1:100,000 scale, mapped landslides from conducting watershed analyses, and areas subject to hydrological erosion.

I combined WSDNR data with the Snohomish County data so that the mass-wasting hazard data used in this analysis is identical to the landslide hazard area map published by Snohomish County in 2016. The map data from Snohomish County and WSDNR is based on the best available information as of August 2016 but does not represent survey accuracy. I merged the shapefiles containing the mass-wasting hazard data obtained from Snohomish County and WSDNR. I hereafter refer to this data as *mass-wasting hazard data*.

3.4. Geographic Information Systems Methods

I determined the spatial relationship between home points, mass-wasting hazards, and demographic information using GIS (Parmeter and Pope 2012). To control for spatial dependencies and neighborhood characteristics, I joined census block group data onto the home points. Census block group data is very precise demographic data, available through the U.S. Census Bureau in a GIS compatible format. In addition to these steps, I gathered other information and variables that that are useful in the hedonic model to lessen omitted variable bias.

3.4.1. Geocoding

I used Esri ArcMap to geocode the data, which can process many addresses in "batch" if given a complete street segment network with address ranges (Esri, 2017). For this analysis, ArcMap interpolated the addresses based on Snohomish County assessor GIS street segment data. I manually reviewed all addresses failing to achieve a score of 80 out of 100 from the ArcMap geocoding mechanism to see if a match could be determined, and then excluded unmatched addresses from further analysis. Of the addresses in the Snohomish County home sale data, 97% could be matched. Each individually matched address becomes a single point on the map. Figure 7 shows all matched homes in Snohomish County, where each point represents one home.

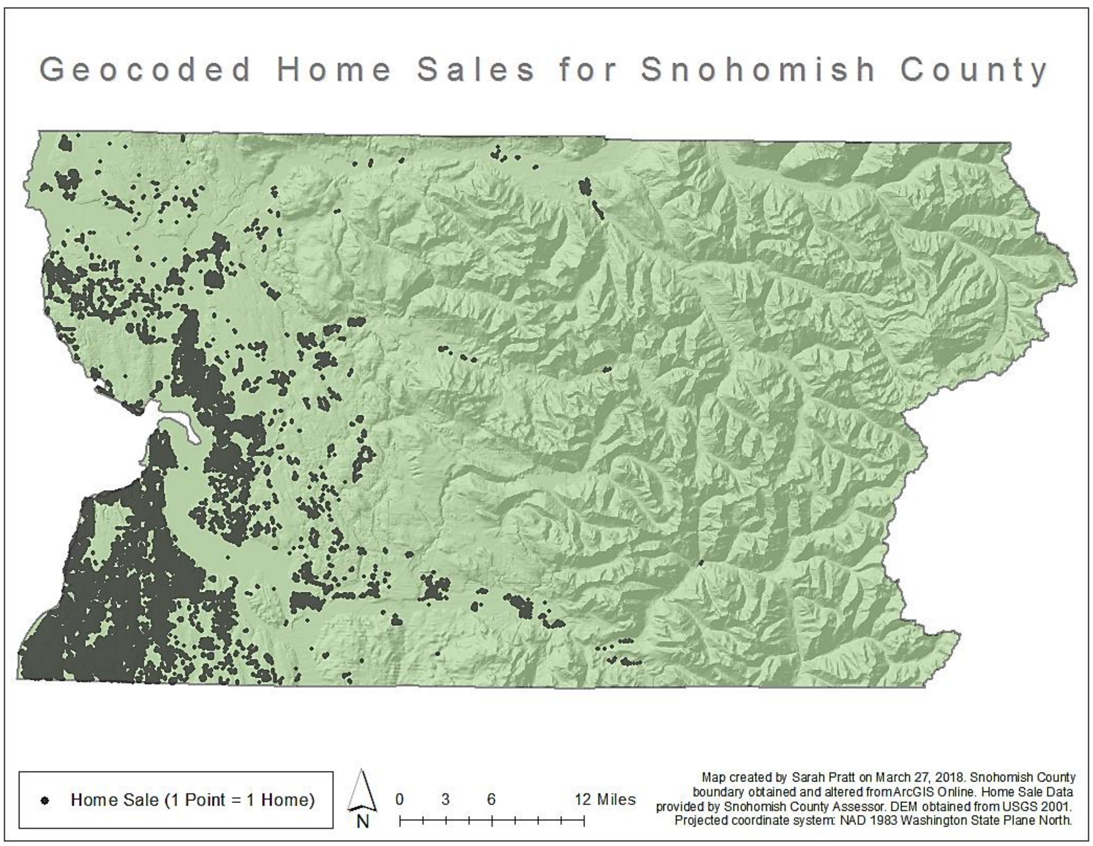


Figure 7. Geocoded home sales.

3.4.2. Spatial Joins

I used the Spatial Join tool in ArcMap to determine which homes were sold in mass-wasting hazards. This tool joins attributes from one shapefile to another, essentially merging data that shares a spatial relationship. I joined the home sale data to the mass-wasting hazard layer. I exported each attribute table as a text file, then imported the text files into Excel. There are 1,226 geocoded homes located in a mass-wasting hazard area. Figure 8 shows geocoded home points in relation to mass-wasting hazards.

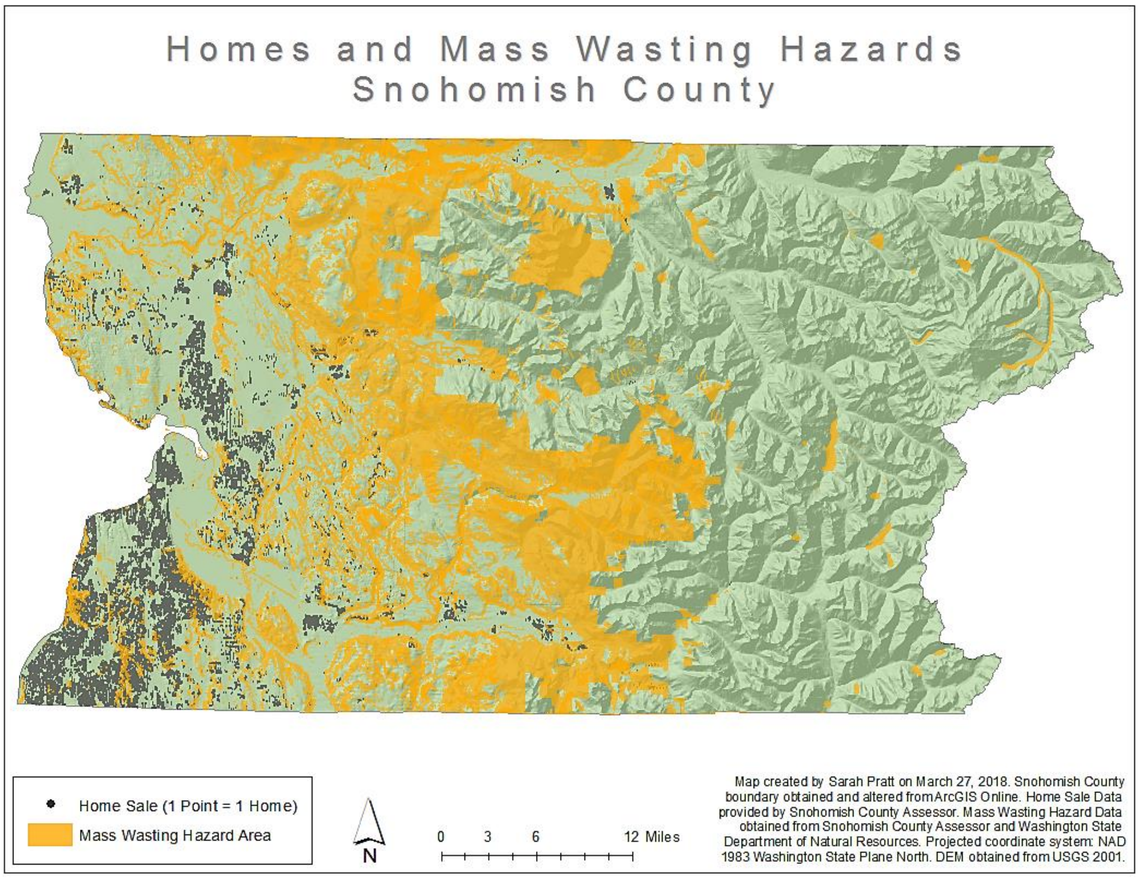


Figure 8. Homes in relation to mass-wasting hazards.

3.4.3. County Block Groups

Because socio demographic information and regional price variations affect home values in addition to structural home characteristics, I include these variables in the hedonic model (Parmeter and Pope 2012). Socio demographic factors include neighborhood characteristics such as proximity to amenities and schools, income, race, gender, and age groups. I used census block groups from the U.S. Census Bureau GIS data and imported the data into ArcMap. To gather block group information for each individual home sale, the Spatial Join tool joins the attributes from the home sale data to the census block group data, and as a result, in the attribute table, creates a new variable that contains a census block group ID number for each home transaction. I exported the attribute table as a text file and imported it Microsoft Excel.

3.4.4. Urban Boundaries

Snohomish County is a rapidly growing area. The county has many relatively large-scale cities, such as Everett, Snohomish, and Marysville. However, these areas of urban growth tend to be in areas where less mass-wasting hazards exist. Since prices of homes in urban areas may vary from home prices in rural areas, I include this variable in the hedonic model. I obtained shapefiles of urban growth boundaries from the Snohomish County GIS database, and overlaid the geocoded homes with the urban growth boundary shapefile. I again used the Spatial Join tool to determine the homes located within urban boundaries. The result of the spatial join is a new attribute table which merges the geocoded home data with the urban boundary data. About 87% of the homes sold are within urban boundaries. I exported this data from the attribute table as a text file and imported it into Microsoft Excel.

3.4.5. Elevation and Slope Analysis

I used Esri ArcMap to determine the elevation and slope for each home. Snohomish County defines a landslide hazard area as a slope greater than 30% (SCPDS 2015). The County used a 10-meter Digital Elevation Model (DEM), a raster grid where each cell represents an elevation value, in the mass-wasting hazard map to determine slopes greater than 30%. To match the mass-wasting hazard information to Snohomish County's, I evaluated the slope of each home point by mosaicking DEM rasters together to cover the entire area of Snohomish County. I obtained DEM files from USGS (2001). I used the DEM to create a slope raster by using the Slope Analysis tool in ArcMap. Slope Analysis determines the percentage or degree of slope based on the elevation and terrain in the DEM. I calculated the slope in terms of percent for my analysis. The highest slope in the data is 261%, which converts to approximately 67 degrees. This highest slope percent is located near Glacier Peak, in the eastern part of Snohomish County. To determine the slope of each geocoded home point, I used the Extract Values to Points tool in ArcMap. This results in an attribute table that contains percentage of slope for each home point. I exported the slope percentage table as a text file.

3.4.6. Variable Creation

I used the extracted GIS data to create binary variables for each home including binary rural and binary mass-wasting hazard variables. I assigned 0s and 1s to homes outside and inside of rural boundaries. To create a binary mass-wasting hazard variable, I assigned homes in mass-wasting hazards a 1 and other homes a 0. I created a binary variable for homes sold after the 2014 Oso landslide, where I assigned a 1 to homes sold afterward and a 0 to homes sold before. Finally, I created another binary variable for homes sold in a mass-wasting hazard area after the 2014 Oso landslide.

IV
JOURNAL ARTICLE

The Economic Impact of the Oso Landslide: A Hedonic Approach

Sarah Pratt *

Abstract

Mass wasting, or landslides, commonly occurs in Washington State, posing risk to individuals residing in the area. The 2014 Oso landslide, the deadliest mass-wasting event in United States history, increased awareness for mass-wasting hazards in western Washington. Studying single-family homes from 2004-2017, this research uses a hedonic property model to measure consumer willingness to pay for a home in a mass-wasting hazard area after the Oso landslide and finds that home values in Snohomish County decreased by 11% after the Oso disaster.

Keywords: hedonic, mass wasting, environmental economics, revealed preference, environmental impacts, landslides, risk, hazard

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4.1. Background

In the past thirty years, mass-wasting events caused more than $300 million worth of destruction and damage to homes, properties, and infrastructure in Washington State (Washington State Department of Natural Resources [WSDNR] 2015). Mass wasting, which includes events such as landslides and debris flows, poses serious risk to individuals residing in hazardous geographic areas, particularly in western Washington where these events frequently occur (WSDNR 2017b). The challenge comes in understanding how individuals perceive risk, specifically the risk associated with such natural phenomena.

To measure risk, economists commonly utilize revealed preference methods, tools used to analyze observable consumption choices made by individuals (Dorfman, Keeler, and Kriesel 1996; Tietenberg and Lewis 2016). Hedonic price models, a type of revealed preference method, uses proxy markets, such as real estate and labor markets, to measure preferences for environmental amenities and disamenities (Rosen 1974). An environmental disamenity is associated with adverse characteristics, such as natural hazards, because people do not prefer to reside in risky areas (Dorfman, Keeler, and Kriesel 1996).

Economists use hedonic property models to estimate preferences for environmental hazards (Rosen 1974; Dorfman, Keeler, and Kriesel 1996; Kim et al. 2015). The housing market is an appropriate proxy to measure the risk related to mass wasting where risk is reflected in the marginal change in home price when all other factors that can affect the value of a home, such as physical home structure, characteristics of the surrounding area of the home, and environmental amenities, are held constant (Dorfman, Keeler, and Kriesel 1996; Kim et al. 2015). Government entities in Washington State have identified where mass-wasting hazards exist, but so far, no hedonic property models measure how individuals value the risk of living in mass wasting prone areas of western Washington (WSDNR 2015).

4.1.1. The Oso Landslide

On March 22, 2014, a deep-seated landslide occurred in Oso, Washington. The landslide significantly impacted a community called Steelhead Haven, resulting in forty-three fatalities (Wartman 2016). The Oso landslide destroyed forty-one homes and structures, and approximately one mile of the nearby highway, State Route 530 (Robertson 2015). State officials shut down the affected area of State Route 530, the main route between the cities of Arlington and Darrington, for approximately two months. The Oso disaster remains the most recent large-scale mass-wasting event to happen in western Washington.

The 2014 Oso landslide occurred in a known mass-wasting hazard area. Snohomish County officials documented the first mass-wasting event as early as 1900, when State officials wanted to remove debris from a wagon road between Arlington and Darrington due to a large mass-wasting event (Armstrong et al. 2015). The North Fork Stillaguamish River often overflowed and shifted over the years due to mass-wasting, which flooded homes in the area. Steelhead Haven, a neighborhood established in 1960, was located below Hazel Slope, nicknamed Slide Hill because of the frequency of landslides on the slope. The North Fork Stillaguamish River, located just north of the neighborhood, undercut Slide Hill. The area was known for excellent outdoor recreation, including fishing, hunting, and camping. Even though several relatively minor landslides produced by Hazel Slope affected Steelhead Haven for several years, the community continued to expand.

In hindsight, several factors contributed to the Oso disaster. Western Washington experienced a particularly wet 2013 to 2014 winter; rainfall for the area of Oso was approximately 91% greater than average, saturating and destabilizing Hazel Slope (Winters 2015). In addition, land use practices and heavy precipitation on the knowingly unstable Slide Hill contributed to the 2014 Oso disaster. Grandy Lake Forest Association most recently logged near Slide Hill, up until 2009 (Hughes 2014). The magnitude of the event surprised many individuals despite the warning signs.

Researchers and scientists from the University of Washington estimate that the valley of the North Fork Stillaguamish River is struck by mass-wasting events of similar magnitude to the Oso landslide every 140 years on average (Droughton 2015; Wartman 2016). The scientists used Light Detection and Ranging (LiDAR) to determine where areas contain mass-wasting deposits and differentiated between each mass wasting deposit to identify separate mass-wasting events (LaHusen et al. 2015). LiDAR, a remote-sensing technique that utilizes laser light, produces very accurate predictions of measurements in a landscape, such as the height and length of features. The scientists used radiocarbon dating to determine the approximate age of mass-wasting deposits (Droughton 2015). This analysis determined that the 2014 Oso disaster was no coincidence; based on history in the area, it was expected.

4.1.2. Significance of Research

This research uses a hedonic property model to measure the impact of mass-wasting events on home values, thereby determining how people value the risk associated with mass-wasting hazards. Focusing on single-family homes in Snohomish County, where the 2014 Oso landslide disaster occurred, this study analyzes home prices for Snohomish County after the 2014 Oso landslide, holding all other factors constant (Dorfman, Keeler, and Kriesel 1996).

I use home sale data for 2004-2017 and mass-wasting hazard data in a geographic information system (GIS) to determine where home sales took place in areas of mass-wasting risk in Snohomish County. The research uses GIS methods to gather data about the proximity of homes to landslide hazards. The information feeds into analysis of the sale prices of homes in the area after the Oso landslide. This leads to more complete information regarding mass-wasting risk for public officials, real estate professionals, homeowners, potential home buyers, and resource managers.

This research produces a greater understanding of the preference for risk of mass-wasting hazards in Snohomish County (Dorfman, Keeler, and Kriesel 1996; Shipman 2001). In addition, this research assesses whether people are behaving rationally in regard to mass-wasting hazards. People may not be making rational decisions related to their willingness to pay for a home; they may be unaware of the risk and need to be informed about potential mass-wasting danger near their properties (Brookshire et al. 1985).

4.1.3. Literature Review

Several studies demonstrate the ability to quantify perceived risk (Brookshire et al. 1985; Dorfman, Keeler, and Kriesel 1996; McKenzie and Levendis 2008; Samarasinghe and Sharp 2010; d'Amato and Kauko 2012; Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Kim et al. 2015; Timar, Grimes, and Fabling 2014; Jia et al. 2016). These studies use revealed and stated preference methods to determine the value of risk of natural disasters. Decreases in consumption in relation to natural hazards reveal people's preferences for a disamenity. A change in home values after an environmental disaster event, holding all other factors constant, reveals a negative preference for risk. This change can be inferred as the value of risk related to natural disasters. Existing literature measures the level of perceived risk related to many natural hazards and disasters including, but not limited to, floods, earthquakes, and mass wasting.

Samaraweera et al. (2012) estimated the economic costs of landslides in Sri Lanka in Hali-Ela Divisional Secretariat Division where there is a significant risk of landslide danger. Between the years 1974 and 2008, 1,174 landslides occurred in Sri Lanka. Human factors such as construction and other land use activities affect this area which contains unstable soils, a place that is unsuitable for development. From 2003 to 2007, the Badulla district experienced the largest amount of displaced people, including the most significant property, infrastructure, and agricultural losses of any other district in Sri Lanka. To estimate the economic costs of landslides on property values, the researchers collected primary data by conducting surveys to gather information about households including sociodemographic information and previous experience with landslide incidents. Out of the sample of 160 homes, 83% had experienced landslide events in the previous five years to the survey. When considering the impact of home price due to landslides, poverty and employment plays an important role. Of the households, 22.3% of head of households were primary educated. Eighty-three percent of the sample was subject to landslide risk, 78% lived within ½ kilometer of landslide hazards, and 64% was in poverty.

A hedonic pricing approach was used to determine whether the landslides had an impact on property values in the sample. The model shows a relationship between land values and distance of a home to a landslide. Within the study area, each kilometer closer to the landslide decreased home values by 3,083 Indian Rupees (68 USD at the time of the study; Samaraweera et al. 2012). At the time of the study, average monthly per capita income in the study area was 9,369 Indian Rupees (Department of Census and Statistics 2015). The median monthly per capita income was 6,141 Indian Rupees.

In addition to a decrease in home values relative to landslides, these events also cause increased costs due to cleanup of landslides, delay in agricultural and construction activities, and damage due to properties, including farm land (Samaraweera et al. 2012). Because much of the area is in poverty, it has a lower ability to move away from the area of risk. Additionally, these households use their land for agricultural activities, which are difficult to relocate. The authors recommend a policy control to be put in place to lessen the amount of people who are living near landslide danger areas by resettling the households.

Kim et al. (2015) used a hedonic property model to measure the value of risk of an aesthetically pleasing nature park subject to mass-wasting hazards. The study area is Woomyeon Nature Park, a mountainous area, located in Seoul, Korea, where a significant mass-wasting disaster occurred in 2011. The authors studied the housing market in the area of interest between the years 2008 and 2014, before and after the 2011 landslide occurred. Only multifamily housing buildings were included in the study, which included 5,758 transactions in 212 apartment complexes. The authors included property and structure characteristics in their model. Kim et al. (2015) used landslide hazard maps published by the Korea Forest Service, which determine landslide risk by slope soils, steepness, size, and other factors. The Forest Service classifies landslide risk on a scale of 1–5, 1 being very high risk and 5 being no risk.

Before the landslide event, consumers were willing to pay 22% more for housing located within 100 meters of the nature park; however, after the landslide, this amount decreased to 7%. While the amenities of the nature park still contained aesthetic attributes, the value decreased after the landslide. Prices of properties located within 100 meters of the Woomyeon Nature Park decreased by 11.3% after the occurrence of the landslide in 2011. People were willing to pay less for homes located near the hazardous area because of the risk of danger. The authors believe this decrease in home value because of risk was due to an increase in awareness of the risk, which was unknown before the mass-wasting disaster.

Samaraweera et al. (2012) collected primary data through interviews and questionnaires, known as a stated preference method, to measure the risk associated with mass-wasting hazards in Sri Lanka. The hedonic model examined the effect on home price based on distance of a home to a landslide area. The authors used the difference in home values based on the hedonic model along with data from interviews and questionnaires to assess the overall cost of the landslide in Sri Lanka.

Stated preference methods have the potential to produce errors due to several biases, including strategic bias, information bias, response bias, and the willingness to pay versus willingness to accept bias (Tietenberg and Lewis 2016). Strategic bias is presented in stated preference methods when the respondent has the incentive to answer a question in a particular way. Information bias, which occurs when respondents have incomplete or false information, can also occur, for example, in cases of measuring economic impacts of mass wasting because one may not know the full extent of risks, hazards, and costs associated with mass wasting. These types of studies do not allow one to control for other variables that may affect the study, which is important to eliminate biased estimates of risk.

Kim et al. (2015) used a hedonic property model for multiple family homes with data that consisted of 5,758 home transactions. Kim et al. (2015) use an equation similar to the model used in this research but for a smaller scale area and for different types of homes. The effect of mass-wasting hazards on single-family homes was not examined.

Hedonic property models are often used to address questions of the value of risk associated with natural disasters. Economists do this by examining changes in consumer preferences revealed through the housing market (Brookshire et al. 1985; McKenzie and Levendis 2008; Samarasinghe and Sharp 2010; Samaraweera et al. 2010; Dachary-

Bernard, Rambonilaza, and Lemarie-Boutry 2014; Timar, Grimes, and Fabling 2014; Kim et al. 2015; Rajapaksa et al. 2016). Natural disasters are factors that can affect the price of a home but are not physically traded on a market, so a hedonic property model is the best tool for measuring economic changes in the housing market due to these disasters (Lancaster 1966; Rosen 1974; Brookshire et al. 1985; Timar, Grimes, and Fabling 2014; Kim et al. 2015). The aforementioned studies from California, France, and Korea, among others, used a hedonic property model approach to measure the risk associated with natural phenomena (Brookshire et al. 1985; Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Kim et al. 2015).

Hedonic models, rather than stated preference methods, are the best technique to utilize in order to control for outside variables that may cause volatility in home values or bias (Lancaster 1966; Rosen 1974; Timar, Grimes, and Fabling 2015). Hedonic price models are well suited to understand how people perceive risk revealed through individual consumption choices (Dachary-Bernard, Rambonilaza, and Lemarie-Boutry 2014; Timar, Grimes, and Fabling 2015; Kim et al. 2015).

4.1.4. Literature Gap

Researchers examined the impacts of mass wasting for places around the world, but the value of risk associated with mass wasting in the western Washington area, let alone the U.S., has not been studied. The costs inflicted by the 2014 Oso landslide are quantified, however the value of perceived risk associated with the Oso landslide has not been estimated. Evaluating this risk will lead to more precise estimates of people’s preferences regarding mass-wasting hazards and a better understanding of how individuals make decisions concerning risk related to mass wasting (Brookshire et al. 1985; Smith 2013).

In the following research, we use a hedonic property model to examine mass-wasting risk. We use a much larger home sale database compared to mass-wasting studies done in Korea and Sri Lanka, which will result in an understanding of mass wasting risk preferences across a wider landscape. Finally, we focus on transactions for single-family homes rather than multiple family housing units. Studying single-family homes is more useful for this analysis because the study spans a region that contains more single-family homes than multiple family homes. In addition, in the United States, people more often rent multiple-family homes rather than buying them. Single-family homes provide a better measure of consumer willingness to pay to live in an area, since purchasing a home tends to be a longer-term decision than renting.

4.2. Study Area

Washington State is in the northwestern part of the United States, bordered to the north by British Columbia, Canada, to the east by Idaho State, to the south by Oregon State, and to the west by the Pacific Ocean. The highest point in Washington State is Mount Rainier at an elevation of 14,410 feet above sea level, and the lowest point is sea level, at the Pacific Ocean. The Cascade Mountain Range divides the state in half, creating eastern and western Washington. The western portion is made up of nineteen counties. This study focuses on Snohomish County.

Snohomish County is in the northern part of western Washington, bordered by Skagit County to the north, Chelan County to the east, King County to the South, and the

Puget Sound to the west. The highest point of elevation in Snohomish County is 10,541 feet, and the lowest point is at sea level, located at the Puget Sound.

Western Washington is a mountainous region, where two large ranges, the Olympic and Cascade Mountains, are located. Western Washington has five stratovolcanoes that are part of the Cascade Mountain Range: Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams. Each one of the volcanoes is over 10,000 feet above sea level, except for Mount St. Helens, which before its eruption in 1980 also had an elevation above 10,000 feet. The Snohomish County boundary includes part of the northern Cascade Range. Glacier Peak, which has an elevation of 10,541 feet, is located within the boundary of Snohomish County in the eastern region of the study area. The mountainous region has considerable amounts of variation in elevation, which causes slopes to be especially steep, creating more mass-wasting hazards in the study area (WSDNR 2017b).

Western Washington contains several potentially active fault zones. Western Washington is near the Cascadia subduction zone, which can produce sizeable earthquakes. Due to the earthquake hazards in western Washington, mass wasting is more likely to happen because shaking hazards can cause soils to be saturated with water (Highland and Johnson 2004). Earthquake shaking can result in the liquefaction of soil and cause slopes to move, each of which can trigger mass wasting (Hungr, Picarelli, and Leroueil 2014). Earthquakes cause stress and decrease the strength of slopes, which result in slope failure if the force of gravity exceeds the decreased strength of a slope (Varnes

1978). Therefore, western Washington's geologic setting relative to mountains and fault lines puts the area at a considerable risk for mass wasting.

Mass wasting poses the most serious risk in western Washington during winter months because of high precipitation (WSDNR 2017b). Heavy rainfall weakens slopes due to increases in weight from groundwater. Many landslides that have occurred in western Washington, including the Oso landslide, have been triggered by increased rainfall (WSDNR 2015). According to the Western Regional Climate Center (2016), rainfall is measured 150 days on average in the inner valleys, and an average of 190 days near the coasts of western Washington. In western Washington between the years 1981–2010, average annual precipitation was 80 to 100 inches in most places, with areas near the Puget Sound getting 40 to 60 inches of precipitation. Some areas of western Washington even saw an annual average of 100 to 140 inches of precipitation (Prism Climate Group 2016).

Logging, an important industry for Washington, the fifth largest state in the U.S. for employment in the timber industry, decreases slope stability (U.S. Bureau of Labor Statistics 2017; Javier 2017). Extracting timber can result in an increase in ground water, ultimately increasing the occurrences of mass-wasting processes (WSDNR 2017b). Since 2010, timber harvests have decreased by 31%. For western Washington, there has been a small decrease in timber harvests of about 4% and an even smaller decrease of 1% in timber production for the entire state. While timber production in the study area has been on a decreasing trend in the last few years, the amount of forest extraction that takes place remains significant (WSDNR 2018b). In Washington State, 32 of the 39 counties are involved in the timber industry, Snohomish County being one of them. In 2017, Washington State produced nearly 2.7 million board feet of timber. Of the 2.7 million board feet produced, the western Washington area produced 2.3 million, showing that most logging for Washington State occurs in the western portion. Snohomish County is the tenth largest producer of timber in western Washington, making up approximately 4% of the timber production for 2017.

Population in western Washington increased in the last several years, except for 2015. From 2010 to 2015, population increased by almost 11% in Snohomish County (WSOFM 2017). In areas of greater population, mass wasting threatens more infrastructure, housing, and people, producing more fatalities and destruction. Increasing population comes with increasing development of homes and infrastructure. From 2010 to 2017, production of single-family housing units has increased by 7% in Snohomish County and 5% in western Washington.

Snohomish County had a projected median income for 2017 of $80,579. Since 2010, Snohomish County has the second highest median household income for not only western Washington, but also the entire state. Where there is destruction from mass wasting in developed areas, especially those areas of higher income, the overall costs of mass wasting increases.

4.3. The Use of Geographic Information Systems

The field of environmental economics benefits from the use of geographic information systems (Parmeter and Pope 2012). With GIS, economists study how natural resources and environmental amenities and disamenities affect people's preferences for where they chose to reside. For example, using GIS tools in hedonic models, economists measured the effect on housing prices of air, noise, and water pollution (Metz and Clark 1997; Leggett and Bockstael 1998; Din, Hoesli, and Bender 2001), school quality (Black 1999; Figlio and Lucas 2004), hazardous waste sites (Gayer, Hamilton, and Viscusi 2000; Bui and Mayer 2003), cancer risk (Davis 2004), and recreation amenities (Lovett, Brainard, and Bateman 1997; Bateman, Lovett, and Brainard 1999; Jones 2010).

Hedonic methods are known to be subject to omitted variable bias, which occurs when one or more explanatory variables are left out of a model (Parmeter et al. 2012). The use of GIS in hedonic models relieves some of the omitted variable bias because of the ability to include variables other than structural home characteristics that affect home value, such as sociodemographic information and regional price variances.

Environmental economists use hedonic property models to evaluate the change in home price due to proximity to environmental amenities and disamenities (Tietenberg and Lewis 2016). While different types of home data exist, housing transaction data is often used and publicly available through local governments (Parmeter and Pope 2012). Ideally for hedonic methods, researchers would have information for every home within a study area, not only home transactions, but gathering this data would be timely, costly, and require survey methods to be used, which are subject to strategic bias. Housing transaction data provides a sample of the population of home prices in an area. Parmeter and Pope (2012) outline detailed steps to take for using hedonic models in economic research.

4.4. Data Descriptions

We used two datasets to complete this analysis. First, we obtained home transaction data from the Snohomish County Assessor. The second dataset contains mass-wasting hazard information for Snohomish County.

4.4.1. Housing Data

Every housing transaction has a spatial and temporal context (Parameter and Pope 2012). GIS makes the spatial component of housing transactions more accessible to economists. For a hedonic study, the housing transaction data must contain the sale price and date of each home, an address, and structural home characteristics such as number of bedrooms and square feet.

Snohomish County assessor's public records provided home sale data for Snohomish County. The database contains information for approximately 130,000 single-family homes sold between 2004 and 2017 and includes variables such as addresses, sale date, sale price, and structural characteristics including age, square feet, number of bedrooms, and number of bathrooms. About 5,000 observations contained unknown addresses where the input for the address variable was stated as "unknown" which we removed from the data set. The average home in the data set has 3 bedrooms, 2 bathrooms, and is 60 years old. The median sale price of a home in the data is $263,384.

4.4.2. Mass-Wasting Hazard Data

Snohomish County Planning and Development Services updated the County landslide hazard area map, made publicly available on August 10, 2016, detailing locations of landslide hazard areas in the county (SCPDS 2016). We obtained the data from the updated map from the Snohomish County Assessor public records, which included shapefiles of known landslides and landslide hazard areas. Landslide hazards are defined by the Snohomish County government as areas potentially at-risk for mass wasting based on geologic, topographic, and hydrological factors, with a vertical height of 10 feet or more. Landslide hazards includes places of historical mass-wasting occurrences seen through deposits, places susceptible to basal undercutting by water bodies, slopes greater than 30%, and areas subject to debris flows or flooding in a canyon or valley (SCPDS 2015).

The updated landslide hazard area map produced by SCPDS uses mass-wasting hazard data from the WSDNR. The WSDNR (2017a) provides publicly available mass-wasting hazard maps compatible with GIS software. Since variation exists in what causes mass wasting, experts determine triggers for mass-wasting events. Scientists use different methods to assess slope stability by using a combination of aerial photographs, maps and historical landslide information (WSDNR 2011a). We obtained a geographic database provided publicly by WSDNR Division of Geology and Earth Resources GIS that contains polygon shapes of mass-wasting hazard areas that SCPDS also used in their updated map (WSDNR 2017a). Finally, we combined WSDNR data with the Snohomish County data so that the mass-wasting hazard data used in this analysis is identical to the landslide hazard area map published by Snohomish County in 2016. For simplicity, we merged the shapefiles containing the mass-wasting hazard data obtained from Snohomish County and WSDNR. We hereafter refer to this data as *mass-wasting hazard data*.

4.5. Geographic Information Systems Methods

We determined the spatial relationship between home points, mass-wasting hazards, and demographic information using GIS (Parmeter and Pope 2012). To control for spatial dependencies and neighborhood characteristics, we joined census block group data onto the home points. Census block group data is very precise demographic data, available through the U.S. Census Bureau in a GIS compatible format. In addition to these steps, we gathered other information and variables that that are useful in the hedonic model to lessen omitted variable bias.

4.5.1. Geocoding

We used Esri ArcMap to geocode the data, which can process many addresses in "batch" if given a complete street segment network with address ranges (Esri, 2017). For this analysis, ArcMap interpolated the addresses based on Snohomish County assessor GIS street segment data. We manually reviewed all addresses failing to achieve a score of 80 out of 100 from the ArcMap geocoding mechanism to see if a match could be determined, and then excluded unmatched addresses from further analysis. Of the addresses in the Snohomish County home sale data, 97% could be matched. Each individually matched address becomes a single point on the map.

4.5.2. Spatial Joins

We used the Spatial Join tool in ArcMap to determine which homes were sold in mass-wasting hazards. This tool joins attributes from one shapefile to another, essentially merging data that shares a spatial relationship. We joined the home sale data to the mass-wasting hazard layer. We exported each attribute table as a text file, then imported the text files into Excel. There are 1,226 geocoded homes located in a mass-wasting hazard area.

4.5.3. County Block Groups

Because socio demographic information and regional price variations affect home values in addition to structural home characteristics, we include these variables in the hedonic model (Parmeter and Pope 2012). Socio demographic factors include neighborhood characteristics such as proximity to amenities and schools, income, race, gender, and age groups. We used census block groups from the U.S. Census Bureau GIS data and imported the data into ArcMap. To gather block group information for each individual home sale, the Spatial Join tool joins the attributes from the home sale data to the census block group data, and as a result, in the attribute table, creates a new variable that contains a census block group ID number for each home transaction. We exported the attribute table as a text file and imported it Microsoft Excel.

4.5.4. Urban Boundaries

Snohomish County is a rapidly growing area. The county has many relatively large-scale cities, such as Everett, Snohomish, and Marysville. However, these areas of urban growth tend to be in areas where less mass-wasting hazards exist. Since prices of homes in urban areas may vary from home prices in rural areas, we include this variable in the hedonic model. We obtained shapefiles of urban growth boundaries from the Snohomish County GIS database, and overlaid the geocoded homes with the urban growth boundary shapefile. We again used the Spatial Join tool to determine the homes located within urban boundaries. The result of the spatial join is a new attribute table which merges the geocoded home data with the urban boundary data. About 87% of the homes sold are within urban boundaries. We exported this data from the attribute table as a text file and imported it into Microsoft Excel.

4.5.5. Elevation and Slope Analysis

We used Esri ArcMap to determine the elevation and slope for each home. Snohomish County defines a landslide hazard area as a slope greater than 30% (SCPDS 2015). The County used a 10-meter Digital Elevation Model (DEM), a raster grid where each cell represents an elevation value, in the mass-wasting hazard map to determine slopes greater than 30%. To match the mass-wasting hazard information to Snohomish County's, we evaluated the slope of each home point by mosaicking DEM rasters together to cover the entire area of Snohomish County. We obtained DEM files from USGS (2001). We used the DEM to create a slope raster by using the Slope Analysis tool in ArcMap. Slope Analysis determines the percentage or degree of slope based on the elevation and terrain in the DEM. We calculated the slope in terms of percent for my analysis. The highest slope in the data is 261%, which converts to approximately 67 degrees. This highest slope percent is located near Glacier Peak, in the eastern part of Snohomish County. To determine the slope of each geocoded home point, We used the Extract Values to Points tool in ArcMap. This results in an attribute table that contains percentage of slope for each home point. We exported the slope percentage table as a text file.

4.5.6. Variable Creation

We used the extracted GIS data to create binary variables for each home including binary rural and binary mass-wasting hazard variables. We assigned 0s and 1s to homes outside and inside of rural boundaries. To create a binary mass-wasting hazard variable, we assigned homes in mass-wasting hazards a 1 and other homes a 0. We created a binary variable for homes sold after the 2014 Oso landslide, where we assigned a 1 to homes sold afterward and a 0 to homes sold before. Finally, we created another binary variable for homes sold in a mass-wasting hazard area after the 2014 Oso landslide.

4.6. Methods and Empirical Issues

Equations 1 and 2 determine the upper and lower limits of data values. Tukey (1977) defined outliers as values in data that lie above the upper limit and below the lower limit. In the equations, IQR is the interquartile range, which is a measure of the middle 50% of the data. We use these equations to exclude outliers from the model.

$$Upper\ Limit = Q_3 + 1.5(IQR) \tag{1}$$

$$Lower\ Limit = Q_1 - 1.5(IQR) \tag{2}$$

Of the dataset, there are 87,514 available observations that do not contain empty values. We include real price variables between 30,014 and \$344,758, for which there are 84,148 observations. Slope percent values are included between zero and 52.5%, where there are 81,461 observations. Square feet (100s) includes values between 1.36 and 21.4, with 78,944 observations. Lastly, total baths include values between zero and four, with 85,881 observations.

We utilized 70,024 observations from Snohomish County. Of these, 140 homes were sold in hazard areas after the Oso landslide. Table 6 displays summary statistics for the observations in the model. The average home in the model is 1,160 square feet, has an approximate average of 2 bathrooms, is on an average of a 15.5% slope, and is about 43 years old.

Table 4. Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Real Price (2016 $)	70,024	164,091	61,129	30,014	344,620
Hazard Zone	70,024	0.002	0.045	0.000	1.000
Square Feet (100s)	70,024	11.6	3.3	1.4	21.4
Total Baths	70,024	1.9	0.7	0.5	3.5
Slope %	70,024	15.5	11.7	0.6	52.7
Age	70,024	43	25	0	144
Rural	70,024	0.1	0.3	0.0	1.0

This research empirically analyzes the impact of the Oso landslide on home values, holding all other factors constant that may affect the value of a home. Rosen (1974) first described hedonic methodology, where consumer products are characterized as bundles of goods, rather than just a single good. In the real estate market, each characteristic of a home makes up the bundle. This research uses the hedonic real estate pricing model created by Rosen (1974):

$$P(z) = P(z_1, \ldots, z_n) \tag{3}$$

In Rosen's (1974) model, P equals the price of a home, and z marks the differentiated characteristics of the estimated fixed value of the home, such as number of bathrooms and number of square feet. While preferences for homes vary among people, it is common knowledge that the price of a home is dependent on several factors, such as structural characteristics including number of bedrooms and bathrooms, neighborhood demographics, and proximity of the home to amenities and disamenities. However, evidence from previous literature suggests that the bundle of characteristics that make up a home's sale price includes mass-wasting hazards (Samaraweera et al. 2012; Kim et al. 2015). Equation 4 estimates the impact of mass-wasting hazards on home price.

Since the study spans a large area, we use spatial and temporal controls. To control for regional price variations within the data, best practice is to use geographic indices variables (Parmeter and Pope 2012). Each home is assigned the Census county block group to which it belongs. In addition to the regional control, we control for price fluctuations through time by including year and month variables.

Further, we use robust standard errors and cluster the standard errors by the block group that each home is located in. Gauss Markov assumptions, which render the best linear unbiased estimator, are violated by heteroscedasticity. Heteroscedasticity exists in the model if the variance of home prices are unequal across the characteristics of the home, or the independent variables in the model. Robust standard errors produce consistent estimates of standard errors across all values (Cameron and Miller 2015). Clustering by the census block group that each home is located in allows us to obtain efficient coefficient estimates under conditions of heteroscedasticity that exist within each block group.

$$lnRealPrice_{igt} = \beta_1 + \beta_2 HazardZone_{igt} + \Sigma\left(\beta_3 C_{igt}, \dots, \beta_8 C_{igt}\right) + Block_g + Year_t + Month_t + e_{igt} \quad (4)$$

Equation 4 measures the percent change in real home price given that the home is located in a mass-wasting hazard area and was sold on a date after the 2014 Oso landslide occurred, estimated by coefficient β_2. In equation 4, $lnRealPrice_{igt}$ represents the natural log of the real price of home sale i in census block group g at time period t, where we sum home characteristics, C_{ipt}, including square feet, number of bathrooms, percent slope, age, age^2, and binary rural variables. We include Age^2 in the model because the relationship between price of a home and the age of a home is non-linear. $Block_g$, $Year_t$, and $Month_t$ represent the fixed effect variables for census block, year, and month. e_{igt} estimates the individual error term.

4.7. Results

Table 5 displays the results for equation 4 for mass-wasting hazard risk in Snohomish County during the 2004 to 2017 time-period. The impact of mass-wasting hazards on home sale price is negative and significant. Changes in the natural log of price are interpreted as percentage change in price. Thus, the coefficients on independent variables approximately correspond to the percent change in home sale price. This is a reasonable approximation for coefficient values less than 0.1; the approximation becomes increasingly poor as the values of the coefficients increase beyond 0.1. Homes sold in mass-wasting hazard areas after the Oso landslide are impacted by approximately -8.5% in terms of price and is statistically significant at the 0.05 level, where there is a 5% chance that a type II error exists between mass-wasting hazards and home price. In terms of median home price, the decrease equates to a loss of approximately $15,000 for homes located in a hazard area after the Oso landslide, holding all other factors constant.

Table 5. Results for Equation 4

VARIABLES	(4) $lnRealPrice$
Hazard Zone	-0.0850**
	(0.0315)
Square Feet	0.0443***
	(0.00366)
Total Baths	0.193***
	(0.0140)
Slope %	0.00162***
	(0.000142)
Age	-0.00667***
	(0.000873)
Age^2	5.26e-05***
	(8.51e-06)
Rural	0.154***
	(0.0192)
Constant	11.12***
	(0.0657)
Observations	70,024
R-squared	0.371

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.8. Discussion and Conclusion

This research shows that, in general, people do not prefer to live in areas of mass wasting hazards in Snohomish County. The results of this research showing a negative preference for environmental risk are consistent with empirical results of other disaster risk studies, including Brookshire et al. (1985), Kim et al. (2011), Dachary-Bernard, Rambonilaza, and Lemarie-Boutry (2014), Samaraweera et al. (2012), and Timar, Grimes, and Fabling (2014).

The decrease in home values indicates that people behave rationally in regard to mass-wasting hazards in Snohomish County. A rational person would be willing to pay less for a home located in a mass-wasting hazard area that is otherwise identical to a home outside of a hazard area. Large scale mass-wasting events of similar magnitude to the Oso landslide are relatively low probability, high cost events (Slovic 1975). Whether the change in sale price for homes in hazard areas should be higher or lower than the 11% decrease found in this study is a question that should continue to be explored. Since large scale mass-wasting events have a low probability of happening, the 11% decrease may be reasonable.

The decrease in home price in areas of mass-wasting hazards for homes sold after the Oso landslide indicates that awareness of mass-wasting hazards exists in Snohomish County. The Oso landslide raised an awareness of mass-wasting hazards in western Washington, especially due to the highly publicized event. The 2014 Oso landslide was significant in the way that it caused local governments in Washington State to adjust their methods of producing mass-wasting risk information.

After the Oso landslide, availability of risk information related to mass wasting increased. Snohomish County updated their laws related to mass wasting and produced maps about two years after the event detailing landslide hazard areas. In addition, Washington Division of Geology and Earth Resources (2017) published a document after the Oso landslide titled “A Homeowners Guide to Landslide Hazards for Washington and Oregon.” Knowledge of irresponsible land use practices and neglecting to act on the hazard area in Oso resulted in a lawsuit against Washington State and Grandy Lake

Forest Association, which settled in December 2015, further increasing information about the disaster.

The results of this research do not indicate whether all individuals in Snohomish County have complete information about mass-wasting risk. Unless buyers do research to determine where there are areas of mass-wasting risk, this information may be unknown or incorrectly assessed at the time of a home purchase (Binder 1997). Snohomish County and WSDNR provide online mass-wasting hazard risk information. However, this information must be sought out by individuals, but there are constraints in terms of being able to access the data, such as having an electronic device and Internet access. To ensure that all individuals can access to the information, new policy may be needed (Binder 1997; Brookshire et al. 1985). The type of policy that should be put in place cannot be understood by the results of this study and should be further explored.

Based on RCW 64.06.020, the Washington State government does not require real estate agents to disclose information about mass-wasting hazards or deposits that exist on or near homes being sold (WSL 1996). The government only requires sellers to disclose information related to current damage of the home being sold due to mass wasting causes based on the seller’s best knowledge at the time of the real estate sale. Therefore, buyers may not be provided with complete information about the risk of mass wasting when purchasing a home because many homes in areas of risk have not yet been damaged due to mass wasting.

Requiring real estate agents to provide information about mass-wasting hazards to home buyers and owners would somewhat eliminate constraints for individuals to access mass-wasting hazard information (Binder 1996). Evaluating and disclosing this information would further increase awareness of risk to homeowners and buyers, ensuring they can make rational decisions given complete information.

Policy makers could look at California State law for an example of this type of policy. California State law requires real estate agents to disclose information to property buyers about homes located in SSZs, areas that are at-risk for earthquake hazards (Brookshire et al. 1985). Additionally, people who live in areas where new SSZs are identified are required to be informed. This policy raises awareness of earthquake risk and allows home buyers to make more rational decisions regarding the risk. Although this is not the only policy that could increase awareness, enacting a similar policy would eliminate constraints to individuals accessing information about mass-wasting risk.

Since the Growth Management Act requires local governments in Washington State to determine critical geologic areas, counties could produce publicly available maps that show individual home points in relation to mass-wasting hazards. Snohomish County already produced a map detailing mass-wasting hazards, but a finer resolution map identifying specific street segments and infrastructure could be useful to homeowners (SCPDS 2016). Producing more detailed information would allow homeowners to be able to easier identify whether they are at-risk for a hazard.

The results of this research do not indicate why individuals make decisions to pay less for a home in a mass-wasting hazard area. For example, people may buy homes in areas of mass-wasting hazards for many reasons, whether it is because they see the home price as a good deal, or because they would rather protect their family with shelter despite risk. In addition, individuals might value characteristics of homes and neighborhoods, such as leisure and environmental amenities, higher than they value the cost of a mass-wasting event. Qualitative research methods such as interviews and questionnaires could help indicate why individuals make decisions to buy homes in areas of mass-wasting risk.

Further work should focus on understanding the full impact of mass-wasting hazards on home values in western Washington. The study area of this research was limited to Snohomish County, so an impact of the Oso landslide was not estimated outside the county boundaries. Snohomish County's mass-wasting hazard model and current map is unique to Washington State. Counties in the state define mass-wasting hazards differently and quality of GIS data varies. In addition to western Washington, mass-wasting events occur in other parts of the state. Future research should examine other areas of western Washington and Washington State to determine the varying degrees of risk preference for mass-wasting hazards. With a more detailed set of mass-wasting hazard information on a county level, along with home transaction data for other counties within Washington State, estimates of mass-wasting risk can be improved.

In the absence of observations for homes sold in hazard areas, we estimated a model with binary variables to attempt to capture intertemporal effects. We used two binary variables, the first being a variable for homes sold within six months of the Oso landslide, and the second for homes sold between six and twelve months of the Oso landslide. There are very few observations: nineteen for homes sold within six months, and seventeen for homes sold between six and twelve months. All else equal, homes sold within six months of the landslide decreased by approximately 14.8% in terms of price (statistically significant at the 10% level), and homes sold between six and twelve months decreased by 8% in terms of price (not statistically significant). This model is suggestive of how home prices may have evolved over time, showing that home prices decreased by a lesser amount as time progressed after the Oso landslide.

Future research should focus on temporal studies, which would help explain how long the impact of a mass-wasting event lasts, or whether the risk preference is transitory or permanent. Understanding this impact would further contribute to the full understanding of perceived mass-wasting risk in other regions.

V
POLICY, PROBLEMS, AND FUTURE RESEARCH

5.1. Policy

This research shows that, in general, people do not prefer to live in areas of mass wasting hazards in Snohomish County. The results of this research showing a negative preference for environmental risk are consistent with empirical results of other disaster risk studies, including Brookshire et al. (1985), Kim et al. (2011), Dachary-Bernard, Rambonilaza, and Lemarie-Boutry (2014), Samaraweera et al. (2012), and Timar, Grimes, and Fabling (2014).

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5.2. Problems

This analysis uses secondary housing data from Snohomish County Public Assessor. While time and money limit the researcher in collecting primary data, secondary data is subject to error. Since I did not gather the original data myself, I do not know the amount of error that exists in the data. To geocode the homes, I cleaned the data, and approximately 5,000 homes were not be matched to the map document simply due to some addresses containing *unknown* or incorrect data. Humans input secondary data into databases, so some degree of error exists. Before geocoding, I carefully examined the addresses and found many mistyped zip codes. Since addresses were miss-inputted into the database, other inputs could be incorrect too, misrepresenting the value or characteristics of homes sold.

In this research I used home transaction data, so homes that were not sold between 2004 and 2017 in Snohomish County were not included. It is impossible to know the true value of every home in the study area, so the home transactions provide a sample of the homes located in the study area. For time and cost purposes, the home transaction data provides a general estimate of the preference for mass-wasting hazard areas.

The geocoding technique also contains error. I used street level data, so ArcMap places home points near driveway entrances on the street level, rather than the exact midpoint or rooftop of the home. Home locations are interpolated along the street block based on how the house number corresponds with the address ranges in the block. This creates some error in the placement of points on the map that represent homes. For example, homes with longer driveways may be subject to more error than homes with relatively shorter driveways. Additionally, homes in rural areas may be more spaced out than how they are represented on the map. Rooftop accuracy data would help eliminate some of this error. However, obtaining rooftop accuracy data is expensive and takes much more time than using available data from Snohomish County.

5.3. Future Work

The results of this research do not indicate why individuals make decisions to pay less for a home in a mass-wasting hazard area. For example, people may buy homes in areas of mass-wasting hazards for many reasons, whether it is because they see the home price as a good deal, or because they would rather protect their family with shelter despite risk. In addition, individuals might value characteristics of homes and neighborhoods, such as leisure and environmental amenities, higher than they value the cost of a mass-wasting event. Qualitative research methods such as interviews and questionnaires could help indicate why individuals make decisions to buy homes in areas of mass-wasting risk.

Further work should focus on understanding the full impact of mass-wasting hazards on home values in western Washington. The study area of this research was limited to Snohomish County, so an impact of the Oso landslide was not estimated outside the county boundaries. Snohomish County's mass-wasting hazard model and current map is unique to Washington State. Counties in the state define mass-wasting hazards differently and quality of GIS data varies. In addition to western Washington, mass-wasting events occur in other parts of the state. Future research should examine other areas of western Washington and Washington State to determine the varying degrees of risk preference for mass-wasting hazards. With a more detailed set of mass-wasting hazard information on a county level, along with home transaction data for other counties within Washington State, estimates of mass-wasting risk can be improved.

This is the first hedonic mass-wasting risk study done in the U.S., but the methods can be applied on a national level. Many areas in the U.S. are subject to mass-wasting hazards, such as the Rocky and Appalachian Mountain regions. The nation has a diverse landscape and demographic factors, so more research is needed on a national level to fully understand mass-wasting risk preference in other areas outside of Snohomish County. Risk preference for mass wasting may vary due to factors including frequency and scale of mass-wasting events, in addition to socio demographics. The results of this research are not fully generalizable outside the study area.

In the absence of observations for homes sold in hazard areas, I estimated a model with binary variables to attempt to capture intertemporal effects. I used two binary variables, the first being a variable for homes sold within six months of the Oso landslide, and the second for homes sold between six and twelve months of the Oso landslide. There are very few observations: nineteen for homes sold within six months, and seventeen for homes sold between six and twelve months. All else equal, homes sold within six months of the landslide decreased by approximately 14.8% in terms of price (statistically significant at the 10% level), and homes sold between six and twelve months decreased by 8% in terms of price (not statistically significant). This model is suggestive of how home prices may have evolved over time, showing that home prices decreased by a lesser amount as time progressed after the Oso landslide.

Future research should focus on temporal studies, which would help explain how long the impact of a mass-wasting event lasts, or whether the risk preference is transitory or permanent. Understanding this impact would further contribute to the full understanding of perceived mass-wasting risk in other regions.

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