FLOODING: SPATIAL SOCIAL VULNERABILITY AND INSURANCE DEMAND

UNDERSTANDING THE IMPACTS OF FLOODING ON SOCIAL VULNERABILITY AND ANALYZING THE EFFECT OF COVERAGE MAXIMUMS ON FLOOD INSURANCE DEMAND

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LAY ABSTRACT

In this research I analyze the population characteristics of the City of Calgary geographically in order to determine if more vulnerable populations are exposed to the hazard of flooding. I also look at the before-and-after flood population characteristics of the flooded and non-flooded areas to see if flooding makes communities more or less vulnerable following an event. My aim is to provide context for the flooding hazard in Calgary and see if a flood changes the population vulnerability of the affected areas afterwards.

I also conduct a choice experiment where I provide participants with a devised flood insurance scenario. I keep some of the variables constant, such as flood probability and insurance price, but change the amount of coverage and dwelling value randomly to see if they influence the likelihood that people buy insurance. The goal of this is to understand how insurance maximums can influence consumer demand.

ABSTRACT

This research explores geospatial patterns in social vulnerability to flooding and experimentally examines the effect of coverage maximums on flood insurance demand. In the first chapter, I analyze census data for the City of Calgary from 1991-2016 to identify trends in social vulnerability based on flood hazard level. Using a quasi-experimental design, I estimate the short-term changes in social vulnerability attributable to the 2013 Calgary flood. The results show that the Calgary flood was associated with a 2.6% increase in postsecondary education, a 1.4% decrease in the immigrant population, a 1.7% decrease in the visible minority population, a $7,100 increase in median family income, 2.8% decrease in home ownership, 3.7% increase in housing construction and 2.2% increase in recent movers. Together, these findings suggest that the highest flood hazard areas in Calgary are generally comprised of lower vulnerability populations; absolute loss potential from floods is getting higher over time due to higher property wealth in high flood hazard areas; and flooding events are associated with a decline in social vulnerability over the short-term.

In the second chapter, I examine flood insurance coverage preferences through the use of a hypothetical choice experiment. The experiment was designed to examine the effect of dwelling value and coverage limit on the probability of flood insurance purchase, while holding the probability of flooding and insurance price constant. Controlling for income, the results indicate that amount of coverage is negatively related to flood insurance demand, however, for people in high-value dwellings the opposite is observed. This may suggest an approach to flood insurance as an investment into high-value properties as a financial asset, but the trade-off in higher yearly premiums may not seem worth the investment for lower-valued dwellings. This research shows an inconsistent demand for flood insurance, dependent on dwelling value and independent of income.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ALL ABBREVIATIONS AND SYMBOLS

ATT	Average Treatment Effect on the Treated	The average causal effect of a binary treatment on an outcome of interest, specific to the treated cases
EAND	Elevation Above Nearest Drainage	A terrain descriptor exactly as described; used in flood hazard estimation
EUT	Expected Utility Theory	The economic theory concerned with decision making under uncertainty, whereby the decision maker compares prospects by their expected utility (or perceived satisfaction); calculated by adding the utility values of prospects multiplied by their respective probabilities
CV	Contingent Valuation	A method for estimating the value that a person places on a good, such as asking someone their willingness-to-pay for a good or service
DFND	Distance From Nearest Drainage	A terrain descriptor exactly as described; used in flood hazard estimation
FH	Flood Hazard	The product of the categorical EAND and DFND; used to classify areas by the expected frequency of floods. FH 5 represents severe flood hazard, FH 1 represents very low flood hazard
FRM	Flood Risk Management	A term describing the integrated set of actions and options to manage the flooding risk
FVI	Flood Vulnerability Index	An index or measure of overall population vulnerability to flooding, usually a combination of multiple socioeconomic variables
NHS	National Household Survey	The 2011 census survey designed to provide demographic, social, economic and housing information about people in Canada
NFIP	National Flood Insurance Program	The U.S. program which is managed by the Federal Emergency Management Agency (FEMA) and is the main source of flood insurance coverage for residential properties in the United States
PLFP	Property Level Flood Protection	Flood protections that are implemented at the property, such as sump-pumps or soil grading away from the home
SMD	Standardized Mean Difference	A summary statistic which measures the average difference of a sample from the mean, but is standardized in order to enable a comparison to other samples
QQ	Quantile-Quantile	In reference to Quantile-Quantile plots, which is a method of comparing the quantile distributions of two samples to determine if both share a similar distribution
WTP	Willingness to Pay	The most that a person is willing to pay for a good or service
WTB	Willingness to Buy	The expressed willingness to purchase a good or service, often the binary application of WTP to a pre-defined scenario

DECLARATION OF ACADEMIC ACHIEVEMENT

I, Connor Darlington, declare this thesis to be my own work. I am the sole author of this document. No part of this work has been published or submitted for a higher degree at another institution.

To the best of my knowledge, the content of this document does not infringe on the copyright of anyone.

My supervisor, Dr. Niko Yiannakoulias, has provided my guidance and support at all stages of this project. I completed all of the research work and writing for this thesis.

CHAPTER 1: INTRODUCTION

Flooding is the most frequent and highest cost natural disaster in Canada. When floods occur, they can cause property damage, loss of life, destruction of infrastructure, social and economic disruption from evacuations, and degradation of the environment (Burn & Whitfield, 2016). Between 1900 and 2018, the Canadian Disaster Database reported 309 disaster-level flood events across the country (Public Safety Canada, 2018). For Canadian homeowners, dealing with flooding has involved replacing damaged belongings, fixing damaged property, and in some cases temporary or permanent relocation. To better plan for and understand the impacts of flooding, many researchers from a wide array of disciplines are investigating the social, physical and political aspects of flooding in Canada.

Flooding causes a considerable amount of property and infrastructure damage in Canada. The estimated economic losses from flooding are $1.2 billion annually (Honegger & Oehy, 2016). However, single flood events can reach or exceed this amount – the Toronto flooding in 2013 resulted in $940 million in damages (Insurance Bureau of Canada, 2017a) and the Alberta flood of 2013 caused over $6 billion in damages and recovery (Government of Canada, 2017). There are several factors which contribute to these very high flood costs in Canada. First, an underinvestment in public infrastructure, outdated building codes and poor land-use planning contribute to losses (Insurance Bureau of Canada, 2015). Any development on floodplain or flood-prone regions creates exposure to the flooding hazard and can lead to recurrently damaged infrastructure.

Second, there are more people living in exposed areas and at higher property values (Oulahen, 2016), which means there is a higher loss potential.

Flooding is a very expensive problem for a variety of different stakeholders, including government agencies, homeowners and insurers. For government agencies, costs can include disaster relief, relocation support for residents, public infrastructure repair and resources to aid in evacuation and reconstruction. For homeowners, these costs may relate to flooded basements, water-damaged belongings, evacuation costs and relocation fees, as well as loss of wages if removed from work. For homeowners, the average cost of a flooded basement is $43,000 (Evans & Feltmate, 2019) but can be considerably more than that in the event of evacuation or relocation. For insurers, flooding losses from different insurance portfolios such as car, life, or business insurance can lead to a high correlation of losses at the same time. However, overland flood insurance was not available in home insurance policies until 2015.

Social Vulnerability

For homeowners, the costs of flooding can be very high. Amongst homeowners, certain characteristics make some groups more vulnerable to the effects of a disaster than others. For example, when flooding occurred in New Orleans as a result of Hurricane Katrina in 2005, lower income groups were more vulnerable during the response and recovery from reduced affordability of repairs, reconstruction and relocation (Masozera, Bailey & Kerchner, 2007). This can act to delay recovery in some areas compared to others, based on the set of options or accessibility of options available to different social groups. Factors such as income, education, employment, age and health can create different vulnerability to the flooding hazard. This type of vulnerability is known as *social vulnerability*, and is defined as the susceptibility of social groups to potential losses from hazard events (Cutter, 1996). In the context of flooding, social vulnerability refers to a population's ability to cope, afford and recover from a flood event.

The concept of vulnerability more generally serves an important role in the natural hazards research, being central to the development of hazard mitigation strategies at various levels of analysis in scale. Certain physical and engineering factors such as a lack of flood defences can increase an area's vulnerability to flooding, but so too can social factors. Different communities and areas may be equally impacted from a flood but suffer differently post-flood from access to an emergency fund, political power, resource accessibility and means of transportation. Often, social vulnerability research is focused on factors including socioeconomic, demographic and housing characteristics that influence vulnerability to hazards. Understanding social vulnerability is important because hazards often do more harm or take longer to recover from in areas where populations are more vulnerable. Understanding communities that are more vulnerable to the risks of natural hazards can be particularly helpful in crisis situations by distributing resources where they are most needed, and ensuring the most effective resources are provided.

Flood Insurance

When it comes to flood risk management, homeowners have few tools they can use to deal with the risks of flooding. Some mitigation options are available. Property level flood protection (PLFP), including sump-pumps, weeping tiles or adjusting soil grading can reduce the level of property damage when flooding occurs. However, the magnitude of flood events can in many cases overburden protective measures. A more temporary flood defence is the use of sandbags to create a wall around one's home. Unlike other home-related perils, flooding was not covered by insurers until 2015, meaning homeowners could invest in PLFP options such as sump-pumps, but if damages occurred, the only compensation that could be received would be through disaster relief.

Since 2015, flood insurance has been available in Canada. Insurance does not prevent floods from occurring, but changes the responsibility of financing disaster recovery. With insurance, the cost burden of disaster recovery is internalized—through the payment of premiums by the policyholder. Through paying premiums to an insurer, the policyholder is protected against one-time catastrophic expenses in the event of a flood. In theory, this reduces the burden of governments to pay for disaster recovery, internalizes risk to households, and may incentivize better decision making—such as voluntary relocation away from high risk areas, or investment in PLFP.

Insurance may be an important part of flood risk management; however there are challenges to effective flood insurance implementation in Canada. One challenge is the inability of insurers to insure high-risk residents. High-risk areas are often denied flood insurance coverage due to the high financial risks they pose to insurers. One solution to this has been to provide coverage with a low maximum payout, effectively reducing extremely high losses of entire home values for the insurers. Though we have an understanding of some characteristics associated with flood insurance demand from previous research, we are less aware of how these limits influence consumer purchases.

Purpose of The Study

This thesis will explore two components of flood management and flood impact research. First, I investigate social flood vulnerability in the City of Calgary, focussing on the geographic and temporal differences in vulnerability. I extend this analysis by estimating the short-term changes in social vulnerability that were attributable to the 2013 Calgary flood event. The objective of this chapter is to understand the relationship between people and the environment, while also introducing a new technique of disaster impact assessment.

Second, I conduct a choice experiment into flood insurance purchase behaviour in order to investigate the effect of policy coverage and dwelling values on consumer purchase behaviour. Through this analysis, I explore the factors which people consider prior to deciding whether or not to purchase a flood insurance policy for their home. This research is intended to understand how insurance policy characteristics may relate to consumer preferences.

Significance of The Study

This study is significant for several reasons. First, understanding the social vulnerability of populations in flood hazard areas informs the sustainability of future disaster management. In particular, by studying the geospatial patterns of social vulnerability, one may be better able to determine how to prepare for future flood events in terms of flood mitigation investment or other resource allocation. In addition, most social vulnerability research is focussed on determining *where is the most vulnerable*; however, in this study I extend that analysis to determine the attributable effect of a flood on social vulnerability. In other words, I provide a method for determining if flooding *increases* or *decreases* vulnerability following an event. If flooding is associated with a decrease in vulnerability, as in this research, it suggests the flooding disaster operates to increase resilience and decrease future vulnerability in hazard areas. Alternatively, if social vulnerability increases following a flood event, this may suggest an increasing costs and provision of resources for government agencies going forward.

Second, this research estimates how insurance coverage influences consumer demand for flood insurance, and how that varies by dwelling value and income. Currently, flood insurance demand literature is new in Canada due to the only recent introduction of flood insurance in Canada. This research provides a contribution to the evolving literature on flood insurance in Canada, and how consumer preference for flood insurance may vary based on dwelling, income, and policy coverage in an experimental setting. What we find is an inconsistent demand for flood insurance dependent on dwelling value and independent of income. This is an important consideration for homeowner flood protection, namely that higher-valued dwellings demand more coverage and may not be provided this coverage by insurers due to insurance risk in the Canadian market. This may result in other protection expenditure, such as self-protection instead and other PLFP measures.

CHAPTER 2: CHANGES IN SOCIAL VULNERABILITY TO FLOODING: A QUASI-EXPERIMENTAL ANALYSIS

Abstract

In this study I examine patterns of social vulnerability to flooding in Calgary, Canada and estimate the effect of the 2013 Calgary flood on social vulnerability. I analyzed data from the 1991, 1996, 2001, 2006 and 2016 Canadian Censuses (and the 2011 National Household Survey) to identify trends in social vulnerability based on flood hazard level. I then used a quasi-experimental study design to estimate short-term changes in social vulnerability attributable to the 2013 flood. The first part of this analysis suggests that high flood hazard levels are associated with the lowest levels of social vulnerability; specifically, higher levels of flood hazard are associated with higher average family income, higher average dwelling value, higher levels of post-secondary education, lower unemployment rates and lower proportions of visible minority and Indigenous populations. My results also illustrate that dwelling value has increased faster in high flood hazard areas than low flood hazard areas over the last 25 years. The second part of my analysis suggests that the 2013 Calgary flood is associated with a 2.6% increase in postsecondary education level, a 1.4% decrease in the immigrant population, a 1.7% decrease in the visible minority population and a $7,100 increase in median family income in flooded areas. The flood is also associated with a 2.8% decrease in homeownership, a 3.7% increase in housing construction and a 2.2% increase in recent movers. Together, these findings suggest that 1) the highest flood hazard areas in Calgary are generally comprised of lower vulnerability populations, 2) absolute loss potential from floods is getting higher over time due to higher property wealth and income in high flood hazard areas, and 3) flooding events are associated with a decline in social vulnerability over the short term.

Introduction

Vulnerability is an important concept in natural hazards research; however, its definition and application varies across a breadth of disciplines, including engineering, environmental science, and geography. Prior to the twenty-first century, the majority of research on the impact of natural disasters was focused on biophysical (or physical) vulnerability (Cutter, Boruff & Shirley, 2003; Zahran et al., 2008), which is the resilience of built surfaces and structures to hazard impacts, including the physical or structural features of the natural and built landscape (Zahran et al., 2008). Since then, more research has been conducted into the social and economic properties of populations which may lead to unequal impacts from disasters (Zahran et al., 2008; Lee & Van Zandt, 2019). The concept of social vulnerability is now used to describe the way that social structures and society-level characteristics can influence a population's ability to respond to a natural disaster independent of biophysical vulnerability (Cutter, 1996). Within the social sciences, social vulnerability includes factors such as economic, demographic and housing characteristics which influence susceptibility to harm and govern ability to respond (Cutter et al., 2003). Engineers consider social vulnerability as one of the components of a broader definition of vulnerability (Balica, Douben, & Wright, 2009) which also includes features of the built environment, such as the presence or lack of flood defenses or other protection (Elshorbagy et al., 2017). For the purposes of this research, we narrow the definition of vulnerability to social vulnerability as we focus on the population-level characteristics which may lead to unequal capacities to cope or adapt to the effects of flooding.

The primary purpose of this research is to understand long and short-term changes in social vulnerability to flooding in the City of Calgary, Canada. Part of this analysis is to describe trends in indicators of social vulnerability over the last three decades across different levels of flood hazard. In addition, I analyze short-term impacts of flooding resulting from the 2013 Calgary flood, which was the costliest natural disaster in Canadian history (Milrad, Gyakum, & Atallah, 2015; Gober & Wheater, 2015). This flooding event occurred between the 2011 Canadian National Household Survey and the

2016 Canadian Census. As these data sources contain similar information on population demographics and socioeconomic characteristics, the flood event presented an opportunity to compare pre and post-flood social vulnerability which could reveal short-term changes in social response to flooding. The concept of change in social vulnerability is of interest because if flood events are associated with increased social vulnerability, communities may become increasingly impacted by environmental disasters in the future. On the other hand, if flooded areas are associated with decreased vulnerability (through adaptation or selective migration, for example) floods may increase some forms of social resilience in high hazard areas. Understanding changes to social vulnerability in response to flood events may help communities allocate resources more effectively, as well as improve the development of policy instruments intended to reduce future flooding risks.

Background

Compared to biophysical vulnerability, social vulnerability describes the internal characteristics of social systems that make human societies differentially susceptible to damage, and result in different capacities to resist impacts (Allen, 2003). Social vulnerability is determined by factors such as poverty, marginalization, housing quality, and access to insurance, all of which result in different coping capabilities and resiliencies to adverse events including flooding (Brooks, 2003). Often social vulnerability is focused on identifying the most vulnerable members of society, which may include examining variations in population vulnerability between or within geographies (Brooks, 2003). In the context of flooding, social vulnerability can indicate areas within cities or regions that are prone to the negative consequences of a flood based on internal social characteristics, including the ability to afford, recover and cope with a flood event.

In order to analyze the many different social and demographic factors that can influence social vulnerability in a population, many researchers have created indices that combine socioeconomic variables (such as income, density of racialized communities, unemployment, housing tenure and other factors) into a single metric for measuring overall social vulnerability. Tapsell et al (2002) proposed a social flood vulnerability index in an attempt to measure the impact that floods could have on a particular community affected. The authors note that financial deprivation, including unemployment rate, household overcrowding, non-car ownership and non-home ownership make repairing and replacing items damaged by floods more difficult and take more time. Similarly, Cutter et al (2003) constructed an index of socioeconomic and demographic data in order to assess spatial patterns and identify counties vulnerable to environmental hazards throughout the United States (Cutter et al., 2003).

A number of flood vulnerability indices (FVIs) have been developed over the last two decades, many of which are based on climate change vulnerability indices. Flood vulnerability indices are often comprised of dozens of indicators reduced to a small number of indices using some dimensionality reducing procedure such as principal components analysis. The primary intent of these and similar FVIs is to communicate overall population vulnerability to a breadth of stakeholders, including the public, decision makers and the insurance industry (Balica & Wright, 2010). Importantly, FVIs can be used to link high social vulnerability to hazard, and isolate areas where there is a particular need for monitoring and intervention (Cutter, Mitchell & Scott, 2000; Burton & Cutter 2008). However, in spite of considerable effort to validate these indices, uncertainty in the choice of the most appropriate index components, and importantly, the relative weighting of components that comprise the indices makes the identification of robust and generally useful indices difficult (Tate, 2012). This means that vulnerability classification can vary depending on data sources, data availability and specific methodological choices within the same setting (Willis & Fitton, 2016).

Research into the relationship between social vulnerability and flood hazard has shown different patterns in different areas of the world. For example, Koks et al. (2015) found social vulnerability was higher amongst residents in high flood hazard areas in the Netherlands when measured by socioeconomic status, age, ethnicity, single-parent households and property construction year. In addition, Brouwer et al. (2007) found a positive relationship between environmental risk and poverty in Bangladesh, notably that poorer residents were more likely to live closer to flood prone areas. In contrast, Chakraborty et al. (2014) found that high flood hazard areas in Miami are associated with generally lower social vulnerability, notably through higher median family incomes and lower poverty rates. This conflicting evidence—that social vulnerability can be lower or higher in high flood hazard areas depending on context—is likely due to a mix of processes, including the perceived amenity value of living near water, the awareness of flood risk, flood mitigation measures, availability of flood insurance and other factors. The mix of these factors could suggest that a generalizable model of social vulnerability to flooding could be elusive, which in turn, stresses the importance of context-specific research (Rufat et al., 2015).

Together, these observations suggest that general purpose models of social vulnerability to natural hazards may not be appropriate, and that region-specific approaches, particularly in areas where hazard is high, are essential. In the analysis that follows, we examine indicators of social vulnerability to flooding in the City of Calgary, Alberta between 1991 and 2016. This research has two purposes. First, I describe the long term patterns of social vulnerability in Calgary by flood hazard level. Second, I estimate the change in social vulnerability attributable to the 2013 Calgary flood using multivariate matching to control for differences in population characteristics between areas and determining the effect unique to the flooded areas. The results of this research will be useful for understanding trends in social vulnerability by different levels of flood hazard in the City of Calgary. Moreover, it demonstrates a general methodological strategy for understanding changes in social vulnerability that is attributable to extreme weather events.

Methods

Study site

The City of Calgary has a history of significant flooding, but the 2013 flood represented the highest cost natural disaster in Canadian history. The city is located at the junction between the Bow and Elbow Rivers; the Bow River watershed descends from the mountains into Calgary at a steep slope, similarly to the Elbow River, which means high and rapid flow rates can enter the city without warning (City of Calgary, 2018a). The flood of 2013 was the product of numerous hydrologic events, including high mountain snowpack levels, a wet spring, atypical amounts of rainfall and the rapid melting of the mountainous snowpack to already saturated ground levels (Environment and Climate Change Canada, 2017). The 2013 flood led to a state of emergency, with over 100,000 people being evacuated and over 1,000 km of destroyed roadways, as well as numerous bridges and culverts being damaged (Environment and Climate Change Canada, 2017).

Data

The primary source of data is the long-form Canadian Censuses (20% sample) of 1991, 1996, 2001, 2006, and 2016, and the National Household Survey of 2011. I used an ecological study design, analyzing variations in socioeconomic indicators in small geographic areas. All data are obtained for the smallest Census geography available; for 1991 and 1996 we used enumeration areas, and for the remaining years we used dissemination areas. For consistency, I will refer to these all as dissemination areas. We selected a composite of variables that are available in all years of study which reflect social vulnerability, are likely to vary geographically within urban areas, and which include commonly used indicators in previous flood vulnerability research (**Table 1**). All measures of income and housing values were adjusted for inflation to 2018 Canadian dollars using the Bank of Canada Inflation Calculator (Bank of Canada, 2019). The only indicator without an analogue in the existing literature (at least in the Canadian setting) is the Indigenous population; however, the authors considered this an important indicator of social vulnerability in the Canadian setting.

The map of the Calgary census metropolitan area was used for the study years at the level of dissemination area for the 1991, 1996 (Scholars GeoPortal, 2018), 2001, 2006, 2011 and 2016 Censuses and were clipped to the 2016 municipal boundary population centre layer (Statistics Canada, 2017a). Missing or omitted census data were removed from analysis. A digital geographic layer of flood hazard for Calgary was based on Elshorbagy et al (2017) topography-based flood hazard mapping, which used two

Table 1: Measures of Social Vulnerability

Indicator	Previous Research	Paraphrased Census Definition of Variable
Average family income	Fekete, 2009; Zahran et al., 2008; Kamel et al., 2012; Bjarnadottir, Li & Stewart, 2011	Average total income of economic families in reference year in dollars
Average dwelling value	Cutter et al., 2000; Andrey & Jones, 2008; Oulahen et al., 2015	Refers to the dollar amount expected by the owner if the asset were to be sold
Total population	Cutter et al., 2000; Chakraborty et al., 2005; Koks et al., 2015	Refers to the number of people residing in a given area
Total number of private dwellings	Cutter et al., 2000; Chakraborty et al., 2005; Koks et al., 2015	Refers to a separate set of living quarters with a private entrance either from outside the building or from a common hall, lobby or stairway
Unemployment rate	Fekete, 2009; Bjarnadottir et al., 2011; de Oliveira Mendes, 2009	Refers to rate of persons unemployed during the reference period (as opposed to employed or not in the labour force)
% Postsecondary education	Fekete, 2009; Myers, Slack & Singelmann, 2008; Andrey & Jones, 2008	Refers to the population 15 years and over that have achieved a postsecondary certificate, diploma or degree (as opposed to no certificate/diploma/degree or secondary school diploma or equivalency)
% Visible minority	Cutter et al., 2000; Flanagan et al., 2011; Van Zandt at al., 2012	Refers to whether a person belongs to a visible minority group (persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in colour)
% Immigrant population	Fekete, 2009; Flanagan et al., 2011; Koks et al., 2015	Refers to whether the person is or has ever been a landed immigrant or permanent resident and has been granted the right to live in Canada permanently by immigration authorities. This includes immigrants who obtained Canadian citizenship by naturalization.
% Indigenous population		Refers to whether the person identified with the Indigenous peoples of Canada, including First Nations, Métis and Inuit.
% Moved in the last 5 years	Fekete, 2009; Walker et al., 2014; King & MacGregor, 2000	Status of a person in relation to the place of residence on the reference day in relation to the place of residence on the same date five years prior
% Age 65+	Cutter et al., 2000; Fekete, 2009; Myers et al., 2008	Refers to the age of residents – the percentage of residents classified as seniors (65 years or older)
% Owned	Kamel et al., 2012; Bjarnadottir et al., 2011; Myers, Slack & Singelmann, 2008	Refers to the percentage of private households owned (as opposed to rented, or band housing)
% Housing constructed in last 5 years	Fekete, 2009; Koks et al., 2015	Refers to the period in time during which the building was originally constructed

parameters–elevation above nearest drainage (EAND) and distance from nearest drainage (DFND) to categorize flood hazard (Elshorbagy et al., 2017). EAND and DFND are categorized independently, and overall flood hazard level is calculated as the product of the two classes where Flood Hazard 5 (FH 5) represents severe flood hazard level (less distance and elevation from nearest drainage such as low-lying areas near riverine systems) whereas Flood Hazard 1 (FH 1) represents very low flood hazard level (larger distance and elevation from nearest drainage). This map was validated against a flood inundation map generated using hydraulic modelling by the City of Calgary, and showed considerable agreement with the 1-in-100 year flood inundation derived from hydraulic-modelling (Elshorbagy et al., 2017).

The flood hazard raster layer for Calgary was summarized into dissemination areas. For analytical purposes and modelling, the median flood hazard level was selected to classify each dissemination area for two reasons: 1) taking the average of categorical variables leads to non-integer outputs, creating a binning problem, and 2) the majority of Calgary is categorized at the lowest flood hazard (FR 1), leading to positively skewed averages and modes. In cases where the dissemination area median flood hazard level was split at 1.5, 2.5, 3.5 or 4.5, the hazard categorization was rounded up to the higher of two classes. The result is a map of Calgary at the dissemination area level with each dissemination area defined by its flood hazard level (**Figure 1**).

For the second part of the analysis, a flood file was used to distinguish flooded dissemination areas from non-flooded areas. The flood extent file was extracted from air photos taken on June 22, 2013, by the City of Calgary (City of Calgary, 2018b). Dissemination areas were categorized as 'flooded' if there was any overlap with the flood extent boundary file, otherwise they were classified as 'not flooded.' This means that results are likely to be conservative estimates of flood impact since some areas with comparatively little flood exposure will be classified as flooded. Both the flood hazard level for Calgary and the flooded dissemination area map of Calgary from the 2013 flood are displayed in Figure 1.

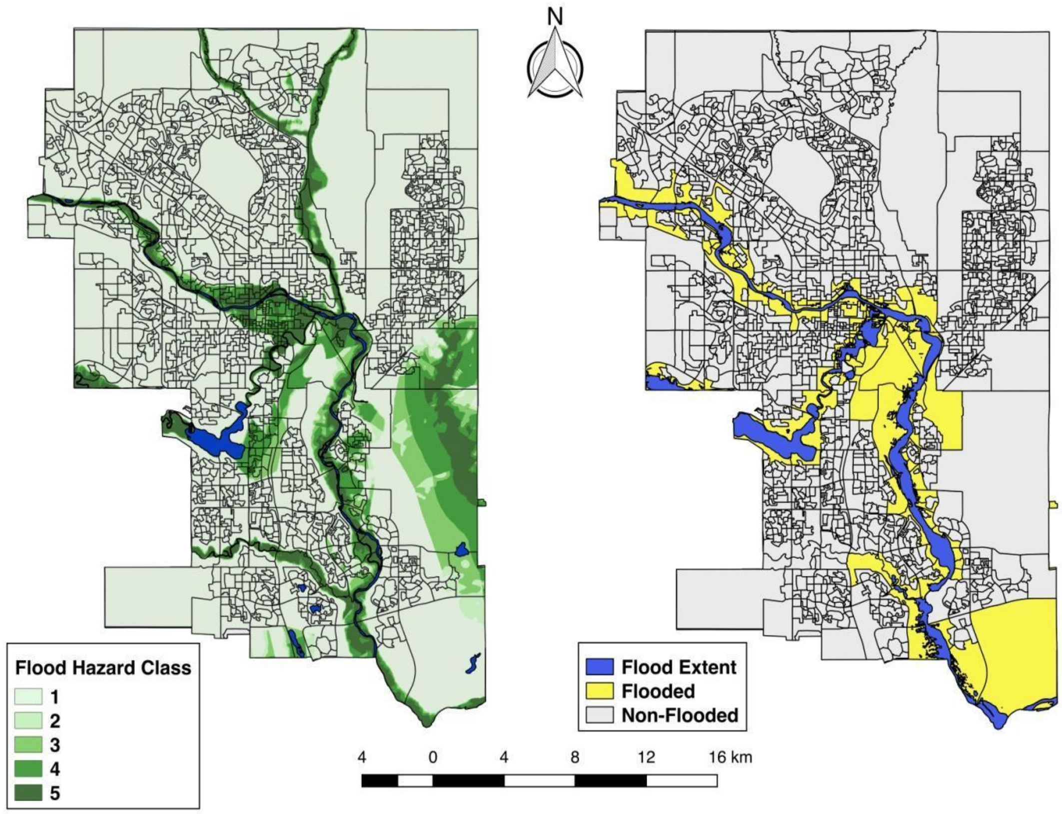

Figure 1: Map of Calgary by Flood Hazard Level and by Flood Extent at the Dissemination Area Level

Analysis

The first part of our analysis simply describes changes in measures of social vulnerability over time. This largely involves the interpretation of trends measures of social vulnerability over time and over flood hazard class.

In the second part of our analysis we use a statistical matching approach to separate the impact of a treatment effect (in this application, a flood event) from confounding factors through the use of matched controls. Matching has been used in other environmental studies, such as estimating the impacts of air quality regulation on economic activity (List et al., 2003), estimating the counterfactual impact of conservation programs on land cover outcomes (Jones & Lewis, 2015), and estimating the effect of flooding zone status on home valuation by matching on housing characteristics (Harrison, Smersh, & Schwartz 2001). After matching, differences over time are less likely to be due to differences in population characteristics between areas but rather to the treatment effect. In what follows, we offer a brief description of the methodology. More detailed discussion of the specific approach can be found in Diamond and Sekhon, 2013, and Sekhon 2011.

We use the average treatment effect on the treated (ATT) to determine the impact of flooding on social vulnerability. ATT is given by,

$$ATT = E[Y_1 - Y_0 \mid D = 1], \quad (1)$$

where D indicates the treatment status (flooded) and Y indicates the outcomes in treatment (Y_1) and non-treatment (Y_0) areas. Unlike experimental research where controls can be selected in a way that guarantees they have the same distribution of characteristics as the treated group, observational studies require restoring the comparability between groups in order to estimate treatment effects not confounded by other factors (Caliendo & Hujer, 2006). Therefore, in order to estimate ATT, we must first make an inference about the state of social vulnerability in flooded areas (treatment group) had they not been flooded (control group). One method of achieving this is through matching, where control areas are selected based on similarity in observed covariates to treated areas, which then allows a comparison of treated and matched control areas over two time periods (Pufahl & Weiss, 2009). Once matching is completed, an ATT conditioned on X is given by,

$$ATT = E[Y_1 \mid X, D = 1] - E[Y_0 \mid X, D = 1], \quad (2)$$

where X represents a vector of covariates used in matching. After matching, each flooded area has two potential outcomes, the actual 2016 response and the control-derived 2016 response, which allows a difference in means to be calculated.

Matching Methods

The estimation of ATT requires the appropriate selection of matched controls for each treatment group. For the purpose of comparison, we use three different matching techniques: 1) propensity score matching, 2) genetic matching, and 3) genetic matching using a propensity score as a covariate. Though a variety of matching techniques exist, these methods were selected as propensity score matching is a widely used, and genetic matching is a relatively newer matching technique (Diamond & Sekhon, 2013) and is, as far as we know, novel in the natural disaster impact literature.

We select the best fitting matching procedure based on three metrics that measure covariate balance. Covariate balance measures the degree to which matching restores the comparability between treated and control groups; the better the covariate balance, the better the match. These matching metrics include: 1) difference in sample means, 2) standardized mean difference (SMD), and 3) quantile-quantile (QQ) plot comparison. The overall difference in sample means between treatment and matched control groups provides an estimate of overall sample covariate balance but lacks information about individual matched estimates, which is why SMD and QQ plot comparisons are included as a test of fit. SMD reflects the mean difference between the treatment and controls divided by the standard deviation of the treatment group. A standardized measure such as the SMD was used due to the variety of variables and the respective differences in scale between them. QQ plot inspection was performed to visualize sample fit, check for outliers and to examine distributional compatibility between samples.

Propensity score matching (PSM) is based on the conditional probability of being assigned to a particular treatment given a vector of observed covariates (Rosenbaum & Rubin, 1983), and matches treated units to the most similar control unit based on a propensity score (Sekhon, 2011). In this application, the propensity score approach is based on a prediction of the probability areas are flooded. The predicted probability comes from a logistic regression model where the dependent variable is flooded/non-flooded status, and the independent variables are measures of social vulnerability. Each area obtains a model predicted probability, and the resultant probabilities are used to match non-flooded areas to flooded areas with the most similar predicted probability. For this research we use 1:1 matching with replacement, meaning each flooded area is paired with a single control area which can be replaced to match other flooded areas as well.

Genetic matching is a technique which uses a genetic search algorithm to optimize covariate balance. It does this by searching generations of covariate weights until the maximum observed difference between treatment and control covariate distributions is minimized (Diamond & Sekhon, 2013; Frey, 2014). Like other evolutionary algorithms, genetic matching optimizes by removing poorer-fitting solutions over time, iteratively 'evolving' towards a better covariate balance until some stopping criterion is met (e.g., the last *n* generations of solutions are identical). Since outcome data (in this application, whether or not a flood occurs in an area) are not used in the matching process, adjustments and improvements to model specification do not create sequential testing problems (Diamond & Sekhon, 2013) and only improve comparability between treatment and control groups, thus reducing bias.

The third matching method we use, genetic matching with propensity score, includes the propensity score as an additional covariate in the genetic matching process, which can improve overall covariate balance and is often recommended for optimization (Diamond & Sekhon, 2013).

Results

Patterns of social vulnerability in Calgary, 1991-2016

The highest flood hazard zone in Calgary is located along the Bow and Elbow rivers (**Figure 1**), while the majority of the rest of the city is at a very low flood hazard level. The areas experiencing inundation during the 2013 flood follow a similar pattern. I graph trends over time to illustrate patterns in the measures of social vulnerability by hazard level (**Figures 2-5**). On each figure, points are based on census data, and lines are a curvilinear best fit lines to help visualize the specific pattern of change over time.

A small proportion of the population has been living in areas with higher flood hazard levels since 1991, though populations have more than doubled in each hazard level since then (**Figure 2A**). High flood hazard areas have been comprised of higher average dwelling values consistently between 1996 and 2011, with an apparent slowing of this trend in 2016 (**Figure 2B**). The trend in the proportion of seniors is less consistent across flood hazard levels, but appears less variable over time, with the highest proportion of seniors living in FH 5 for most time points (**Figure 2C**).

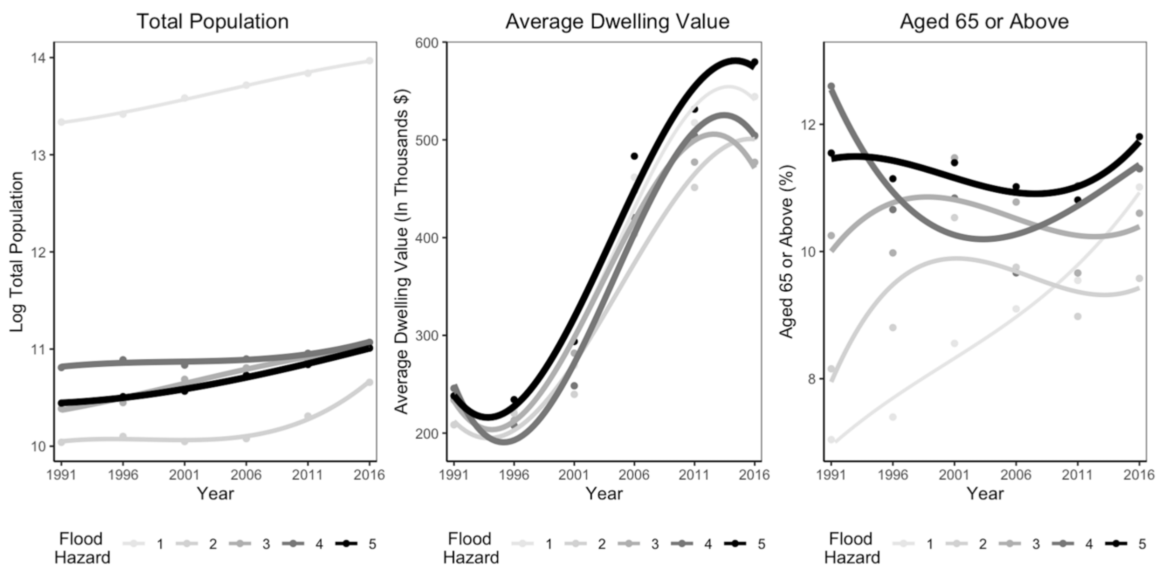

Figure 2 A-C: Changes in Total Population, Number of Private Dwellings and Average Dwelling Value Over Time by Flood Hazard Level

Measures of income (**Figure 3A**) and education (**Figure 3C**) have increased between 1991 and 2016 across all flood hazard levels. Average family income appears to have increased fastest in the highest flood hazard areas. Differences in levels of postsecondary education by flood hazard level appear to be increasing over time with education increasing faster in the highest hazard areas. Unemployment rates decreased from 1991 to 2006 across flood hazard level and increased sharply between 2011 and 2016 (**Figure 3B**). Unemployment rates are relatively consistent across flood hazard levels, with a slightly higher rate in FH 1.

Higher flood hazard areas have consistently had a lower proportion of home ownership than all lower flood hazard areas between 1991 and 2016, however up until 2011, home ownership appeared to be on the rise across the entire city (**Figure 4A**). Around 2011 to 2016, the increase in home ownership stopped across the city. The percentage of housing constructed within five years prior is relatively similar for all flood hazard levels in 2016, with considerable variation in the years previous (**Figure 4B**). Between 1991 and 2016, there was more residential mobility in high hazard areas of the

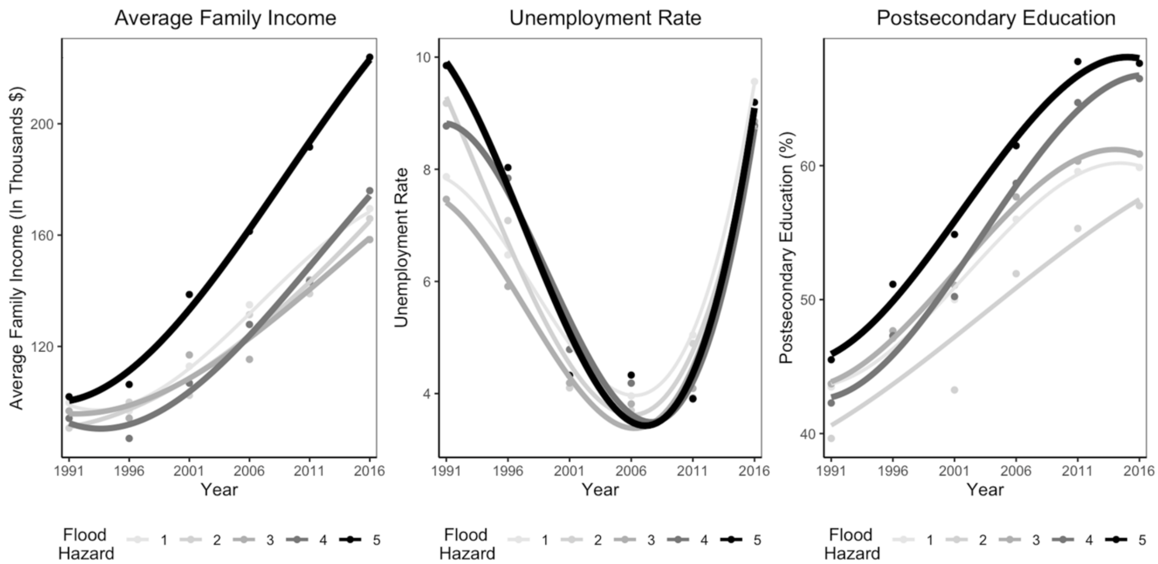

Figure 3 A-C: Changes in Income, Unemployment and Education Over Time by Flood Hazard Level

city than in low hazard areas, though the overall difference is relatively small (**Figure 4C**).

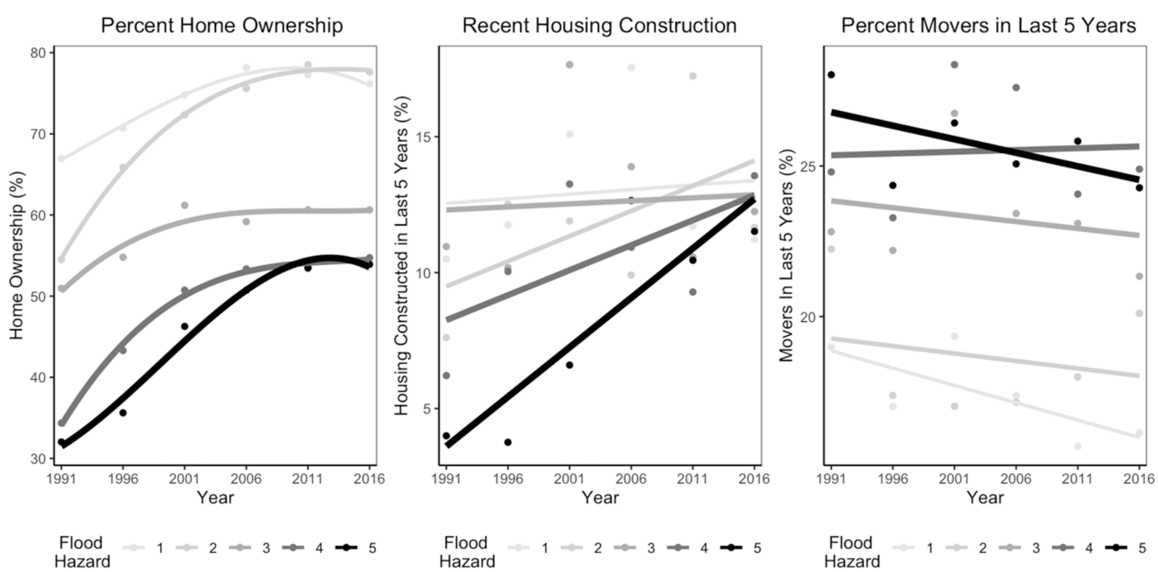

Figure 4 A-C: Changes in Home Ownership, Recent Housing and Recent Movers

Finally, over the study period the proportion of visible minorities increased for every flood hazard level, however FH 5 had the slowest growth rate and in 2016 had the lowest percentage of visible minorities compared to other hazard levels (**Figure 5A**). The proportion of immigrants was once highest in FH 5 but after 1996 higher flood hazard levels became associated with a lower percentage of immigrants (**Figure 5B**). The proportion of the population which is Indigenous is approximately the same across flood hazard levels from 1991 to 2016, showing an increasing trend with the exception of 2011 (**Figure 5C**).

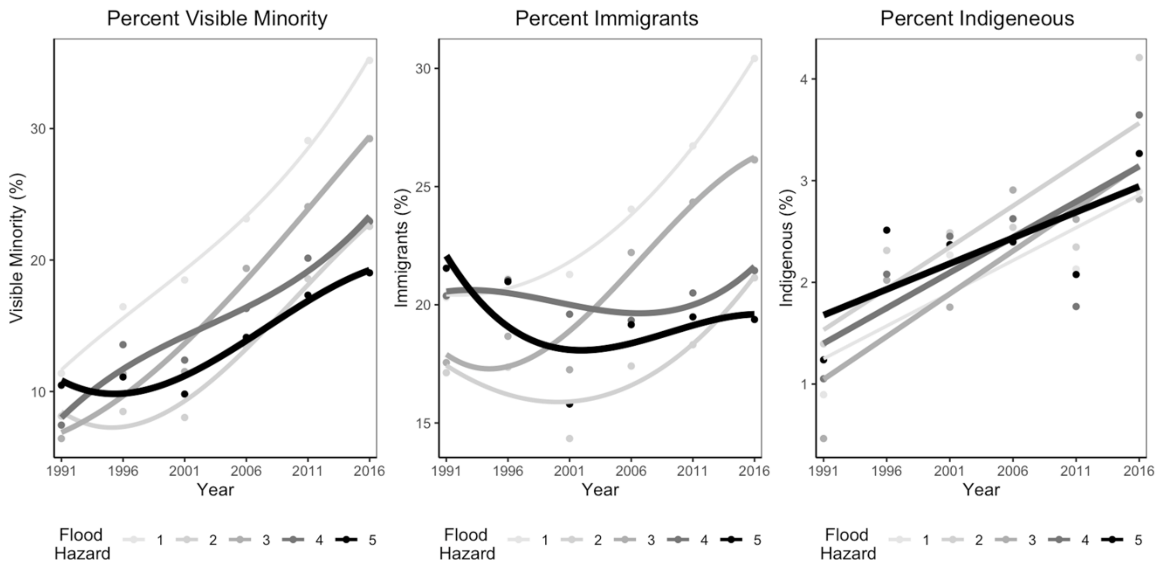

Figure 5 A-C: Changes in Visible Minorities, Immigrants and Indigenous population

Matching Evaluation

Table 2 presents the results of the multivariate matching across each technique. Pre-matching conditions show a pattern consistent with the summary statistics for the differences between flood hazard areas (**Table 2**). Baseline differences between the flooded (n=114) and non-flooded (n=1405) areas are considerable; on average, flooded areas had higher median family incomes, lower unemployment rates and higher proportions of the population with postsecondary education than non-flooded areas. Median dwelling values are roughly $115,000 higher than the non-flooded areas, with flooded areas representing roughly 10% lower home ownership, greater proportions of recent housing construction and a slightly higher proportion of recent movers. Compared to non-flooded areas, the proportion of visible minorities, immigrants and the Indigenous population is roughly 11.5%, 7% and 0.8% lower in flooded areas, and slightly higher in the proportion of seniors aged 65 or above.

Table 2: Evaluation of Matching Techniques for Baseline Social Vulnerability

	Before Matching			Propensity Score		Genetic Matching		Genetic Matching with Propensity	
	Flooded	**Non-Flooded**	**SMD†**	**Mean**	**SMD†**	**Mean**	**SMD†**	**Mean**	**SMD†**
Income, Unemployment, Education									
Median Family Income	141980	114785	34.14	140578	1.76	142816	-1.05	142467	-0.61
Unemployment Rate	4.01	4.9	-20.21	4.4	-8.72	4.46	-10.14	3.93	2
% Postsecondary	66.86	58.83	62.39	67.04	-1.36	65.75	8.66	66.85	0.09
Housing									
Median Dwelling Value	588549	473754	33.81	578569	2.94	580952	2.24	582355	1.82
% Owned	66.8	76.25	-32.27	65.97	2.86	68.13	-4.53	67.14	-1.16
% Housing Constructed in Last 5 Years	8.35	4.76	20.36	6.68	9.49	7.85	2.82	7.8	3.12
% Movers in Last 5 Years	16.02	14.55	11.48	15.54	3.77	15.95	0.53	15.94	0.63
Immigrants, Visible Minorities, Aboriginals									
% Visible Minority	15.78	27.24	-79.06	15.53	1.73	15.11	4.57	14.93	5.81
% Immigrants	18.91	26.04	-67.33	18.32	5.6	18.01	8.5	18.78	1.3
% Aboriginal	1.37	2.2	-29.22	1.45	-2.64	1.16	7.58	1.28	3.14
Seniors									
% Age 65+	12.04	10.74	15.2	11.2	9.78	11.68	4.14	11.97	0.78
Total Differences									
Total	●	●	405.47	●	50.65	●	54.76	●	20.46

† SMD = standardized mean difference

Individual covariate balance differed by matching method, but all techniques show an improvement in sample means and standardized mean difference (SMD) across covariates. The *total differences* section reflects the aggregate of each matching method's SMD, which has little interpretative ability on its own but guides the selection for which model optimizes matching best across all covariates. For this reason, the genetic matching method using a propensity score has overwhelmingly the best individual covariate and overall fit and will be used for the remainder of the analysis.

Impact of the flood on measures of social vulnerability

The mean effect of the flood on the flooded areas in Calgary is shown in **Table 3**. The values in the ATT column measure the overall difference between flooded and non-flooded controls over the 2011 and 2016 period for each indicator of social vulnerability. The last two columns indicate the changes in the flooded and non-flooded control areas that comprise the overall ATT. Change in most measures of social vulnerability was small. The percent of the population with a postsecondary education saw an increase of 2.61%, which was due to both an increase in education in flooded areas (1.04%) and a decrease in education levels on non-flooded control areas (-1.56%). The average treatment effect on recent housing construction was a 3.65% increase, which was comprised of a slight increase in housing construction in flooded areas (0.32%) and a decrease in non-flooded control areas (-2.78%). The ATT for the proportion of recent movers, was 2.18%, which was due to an increase in movers in flood areas of 1.28%, and a decrease in movers on non-flooded control areas (-0.82%). The ATT for home ownership was a 2.8% decline comprised of a 1.55% decrease in ownership in flooded areas and a 0.91% increase in ownership in non-flooded control areas. The ATT on median dwelling value was a very small increase (just over $600), but note that the standard error is also quite large, suggesting a high degree of imprecision in this estimate. Flooding had a small negative effect on the proportion of visible minorities and immigrants, with the average effect of the flood being a decrease of 1.65% and 1.35% for these two categories, respectively. In both cases the effect is the result of a greater increase in the proportions of these populations in non-flooded control areas. The flood had a negligible impact on the percentage of Indigenous residents and persons aged 65 or above.

Table 3: Change in Social Vulnerability Indicators and Average Treatment Effect on the Treated (flooded) Areas

	ATT	Std Error	*p*-value	Change in flooded areas, 2011-2016	Change in control areas, 2011-2016
Income, Unemployment, Education					
Median Family Income	7129.22	6056.69	0.239	14322.44	6706.9
Unemployment Rate	-0.05	0.53	0.919	5.01	5.15
% Postsecondary	2.61	0.94	0.005	1.04	-1.56
Housing					
Median Dwelling Value	603.88	27541.38	0.983	28625.3	34215.14
% Owned	-2.8	1.58	0.076	-1.55	0.91
% Constructed in Last 5 Years	3.65	1.55	0.018	0.32	-2.78
% Movers in Last 5 Years	2.18	0.84	0.009	1.28	-0.82
Immigrants, Visible Minorities, Aboriginals					
% Visible Minority	-1.65	1.12	0.143	2.98	5.47
% Immigrants	-1.35	0.94	0.15	1.17	2.66
% Indigenous	0.11	0.4	0.778	1.78	1.75
Age					
% Age 65+	0.26	0.42	0.544	1.82	0.26

Discussion

In this study we explored specific measures of socioeconomic vulnerability in Calgary, focusing on how these measures change over time across different flood hazard levels and in areas inundated by the 2013 flood. This research is important as to date comparatively little work has considered geographic variation in social vulnerability to flooding in Canada. While not a specific objective of the research, we also demonstrate a novel approach for determining the impacts of flood events on indicators of social vulnerability, which could contribute to how social vulnerability is interpreted in other settings. We now discuss these results in more detail, and in the context of findings from other research.

Impacts on dwelling value and indicators of income

The majority of flood hazard areas occur along the Bow and Elbow rivers, areas with the highest dwelling values and family incomes in the city, suggesting that the housing market places a higher amenity value on waterfront or near-water properties than the negative risk attached to flooding potential. Our analysis does not suggest any short-term change in this pattern; family income appeared to go up slightly in the areas affected by the 2013 flood, and dwelling value remained roughly unchanged. Furthermore, physical mitigation, such as the proposed Springbank off-stream reservoir on the Elbow river, could further reduce concerns about future floods, and make future downward adjustments in property values unlikely.

From an economic perspective, controlling for location and amenities, higher flood hazard should negatively impact dwelling value as this represents added risk. Bin and Landry (2013) found that flood zone property sale price decreased following major flooding in North Carolina, however this effect diminishes over time in the absence of further flooding from lowered risk perception. If the Calgary housing market incorporates flooding hazard into dwelling price, it is concealed through a dampening effect on already high dwelling values—especially considering insurers do not typically cover the highest risk dwellings (McClure, 2015). Assuming that the relatively new entry of flood insurance into the housing market in 2015 had no effect on dwelling value, the lack of change in dwelling value following the 2013 flood suggests a lack of short-term accounting for the flood hazard in dwelling prices, and not necessarily a lack of awareness about flood risk.

Shrubsole et al (1997) used statistical matching to pair homes in floodplains within London, Ontario to those outside of the floodplain in order to examine the effects of floodplain designation on real estate value, and found both the perception of impact and actual land values were unaffected by floodplain regulation. In this research, median dwelling value also showed no strong effect attributable to the flood or flood hazard area in Calgary, however median family income increased at almost twice the rate of control areas. The roughly $7,100 average flooding effect on family incomes in the flooded areas represents a 5 percent additional growth compared to non-flooded control areas. If family incomes are growing faster in flood-affected regions while dwelling values are growing more slowly (or not at all), this may signal a change in the ratio of wealth away from the dwelling as an asset towards accumulated non-property wealth. Further research may seek to examine if long term change in dwelling value compared to income may reflect rising or realized costs designated to flood protection measures or insurance. For example, Harrison et al. (2001) note that in Florida the discount in market value for flood-prone housing is less than the cost of accumulated future flood insurance premiums, a finding which would suggest a disconnect between the estimated costs of flooding amongst consumers.

The proportion of the population with postsecondary education rises with increasing flood hazard level and increased further as a result of the flood in flooded areas. It is very likely that education and income are correlated, and the same amenity factors attracting a wealthier population to an area are likely attracting a more educated population as well. The 2.6 percent difference in flooded areas compared to non-flooded control areas could be an extension of the desirability for near-water properties regardless of flooding risk, where flooded area homes are being occupied by wealthier, more educated residents. It is important to note that many of the flooded areas are situated in the business core of the city, which hosts a wealth of job opportunities for the educated working class and population demographics may reflect this increased level of education. It is also worth noting that numerous academic institutions such as the CDI College Calgary Centre, Bow Valley College, and the West Island College are all near or within flooded areas, which may result in higher levels of postsecondary education in this region if students reside in this area post-graduation. Education has been shown to have a positive association with flood mitigation and flood insurance purchases (Atreya, Ferreira & Michel-Kerjan, 2015; Botzen, Aerts & van den Bergh, 2009; Ren & Wang, 2016) and is associated with higher lifetime earnings, which may enable higher educated (and financially capable) residents to purchase the higher valued dwellings in the flood regions (Cutter et al., 2003). It is therefore possible that the change we observe could be accompanied by an increase in mitigation measures (like overland flood insurance) in the highest hazard areas (Yiannakoulias et al., 2018).

Family income, unemployment rate and percent of the adult population with postsecondary education are all key measures of wealth and socioeconomic mobility. Moderate to higher flood hazard areas generally have higher family incomes than lower hazard areas in Calgary. Wealthier families are better able to protect from flooding and may choose to live in higher hazard areas because they provide other environmental or aesthetic benefits (Felsenstein & Lichter, 2014). This finding is in line with other research that has found that higher income households are most likely to be located in high flood risk regions, partly a product of access to water-related benefits and amenities (Chakraborty et al., 2014). Analyses of vulnerability to flooding following Hurricane Katrina has suggested that the physical impact of flooding was not differentiated by income (Masozera et al., 2007), however in this case, the ability to recover and the level of damage were related to financial resources (Masozera et al., 2007; Donner, & Rodríguez, 2008).

In the United States, there is some evidence of long-term decline in wealth and/or income resulting from the presence of environmental hazards (Shumway, Otterstrom & Glavac, 2014), particularly in densely populated areas (Fussell et al., 2017). However, there is also evidence of post-disaster increase in population and wealth (Schultz & Elliot, 2013). Our results are difficult to directly compare to previous research in the U.S., partly because of the difference in scale—our analysis is of a particular setting, rather than cross-county comparisons—but also because the Canadian context differs in a number of ways. For one, the effects of hurricanes tends to be less frequent and less severe, because of both the environment, and the distribution of the population. Of greater concern is seasonal inland flooding caused by snow melt, severe rainfall and ice jams, for which private overland flood insurance only recently became available. Furthermore, there is no federal equivalent to the U.S. National Flood Insurance Program in Canada, and while recent floods in Canada have caused significant impacts on highly populated areas (like Calgary, Toronto and Ottawa) flood concern in Canada is relatively low in the general population (Thistlethwaite et al., 2018).

Impacts on housing tenure, construction and mobility

In Calgary there is a higher percentage of homeowners in the low flood hazard zones than high flood hazard zones; the difference in proportion of owners between the lowest and highest hazard areas was over 20 percent in 2016. However, compared to control areas, flooded areas incurred a 2.8 percent reduction in home ownership attributable to the flood, while overall rates of ownership increased in control areas. Ownership rates are lower in flooded areas compared to the non-flooded areas overall, but the higher proportion of renters in this region paired with a further increase following the 2013 flood suggests flooding may deter permanent residence and favour rental or apartment units. It is worth considering that areas prone to flooding may also have intrinsic properties associated with renting, such as the previously mentioned academic institutions in these areas which may attract student renters. These lower levels of homeownership have logistical considerations for factors such as flood insurance, which is compartmentalized amongst landlord/tenant relationships between structural and contents protection.

Housing development in Calgary is similar across flood hazard levels in 2016. From analyzing the overall changes between flooded and control areas, it appears the majority of this positive effect on housing construction in flooded areas occurs from a decrease in recent construction in non-flooded control areas. This is in line with the flood hazard trends from **Figure 4B** which indicated an overall increase in recent housing construction for the higher flood hazard regions while the lower hazard levels saw a decline. This suggests that the presence of a flood did not reduce housing development in flooded areas.

The proportion of recent movers increased in flooded areas and decreased in the non-flooded control areas following the 2013 flood. The change attributed to the 2013 flood was just over a 2 percent increase in the number of recent movers. Given the overall increase in population in Calgary across each flood hazard zone, this may suggest a small but systematic change in residence resulting from the flood—where flooded areas saw a faster growth in population when compared to non-flooded control areas. Combined with the apparent increase in income in flooded areas, one could speculate that there was a net outflow of lower income residents, and the arrival of higher income residents, though this result cannot be confirmed with the results shown here. Regardless, the increase in movers suggests that after the 2013 flood, the flooded areas remained an attractive destination for some residents in spite of the salient evidence of flood risk.

Impacts on vulnerable communities

Finally, we observed that immigrant and visible minority populations were less likely to be located in the higher flood hazard areas in Calgary following the flood when compared to non-flooded control areas. This pattern, particularly with respect to racialized and otherwise marginalized communities, has been observed in other research. For example, research in Miami found that racial and ethnic minority populations were more likely to reside in inland low flood-risk areas, reflecting both unequal access to water amenities but also lower flood risk (Chakraborty et al., 2014). Following Hurricane Katrina, return migration of the black population was delayed due to the higher burden of impacts from the hurricane experienced at the time (Fussell, Sastry & VanLandingham, 2010). We do not have data to indicate whether these communities suffered more serious effects from the 2013 flood. Immigrants and visible minority populations have been increasingly less likely to reside in high flood hazard areas in Calgary over time. This may be in part a product of income, as some studies have shown immigrants have reduced employment success in Canada and face additional costs associated with settlement (Reitz & Banerjee, 2007). Though changes in flooded and control area means suggested increases in visible minority and immigrant proportion overall, flooded areas had reduced growth which could suggest outmigration from flooded areas or simply that the movers into flooded areas are less likely to be immigrants or visible minorities.

Persons 65 years of age and over appear to more often live in high flood hazard zones in Calgary. In Calgary, the proportion of the highest flood hazard residents who are seniors is 11.8 percent, higher than the senior proportion in all other flood hazard levels. This in part may be attributed to greater financial ability and wealth accumulated over one's lifetime as higher flood hazard homes have higher average dwelling values. Overall, the flood did not appear to significantly affect the proportion of the senior population over the short term.

Limitations

This research used the 2011 National Household Survey (NHS) versus the 2016 Canadian census. Prior to 2011, Canada had a mandatory long-form census but the government in power replaced this with the voluntary NHS. Differences in variable availability led to the exclusion of some study variables from 1991-2016, however the included variables in this research were continuously available throughout the census and NHS. However, due to the voluntary nature of the NHS, completion rates differed from 2011 (68.6 percent) to 2016 (98.4 percent) (Statistics Canada, 2015; Statistics Canada, 2017b). Since the survey was voluntary, this may select for some respondents over others and could be apparent in the responses captured by the population. The 2016 census would therefore capture more of the variability in responses than the 2011 NHS.

Another key limitation of this research is that we did not consider the breadth of measures in vulnerability. The range of social vulnerability research has included a wide variety of measures for different purposes and in different contexts. Other research has considered the role of health indicators, such as the population burdened by chronic disease (Aldrich & Benson, 2008), as well as the physiological vulnerability to environmental hazards. Both of these may be important direct indicators of flood vulnerability and are worth examining in further research. Our analysis did not take into account the mitigating role of multi-story buildings on household vulnerability. Some high flood hazard areas in Calgary have a larger number of multi-story dwellings, which could decrease some of the major financial risks of flooding to residents—since household items are likely to be above the flood level for most residents. However, it is worth noting that structural damages to multi-story buildings may still place a financial burden on residents, through increased condo maintenance fees, or through increases in rent as a result of maintenance costs.

Our analysis of flood risk is focused primarily on overland flooding associated with surface water, and therefore, does not cover the breadth of potential flooding risk. Flooding associated with catastrophic and localized rainfall (pluvial flooding) or malfunctioning of sewer systems may exhibit different patterns and correspond with higher or lower levels of social vulnerability in distinct pockets of the city. Pluvial flooding largely depends on the volume of rainfall, drainage and city-specific topography as well as water-diverting infrastructures, making 'high-risk' areas partly a product of engineering and vary by city. This is partly why our research is centered around the more scalable fluvial flooding risk.

Conclusion

The observations above present a fairly consistent message: social vulnerability to floods in Calgary appears generally lowest in the highest flood hazard areas. This is most clearly true for dwelling value, average family income and measures of racialization and immigration. However, the proportion of persons 65 and over was highest in the high flood hazard zones. Recent movers—who may also be more vulnerable to the hazards of flooding than long-time residents—also are in higher proportions in higher flood hazard areas in Calgary. The findings are in contrast to flood vulnerabilities and inequalities in other contexts such as the Netherlands, where a high proportion of vulnerable people reside in high hazard flood areas (Koks et al., 2015). The results also suggest that flooding may have a small impact on some indicators of social vulnerability over the short term. Income, education, new housing construction and recent movers are more likely in flooded areas, all else being equal, than non-flooded areas when controlling for other observable characteristics. In contrast, flooding had a negative effect on proportions of home ownership, visible minority populations and immigrant populations, further magnifying a legacy of lower social vulnerability in the high hazard and flooded areas of the city.

The general pattern we observe—high hazard, low vulnerability—may contribute to the further gentrification of the areas of the city where flood hazard is high. It is possible that some of the changes over this period were a systemic response to the financial costs associated with flooding such that residents with less capacity for covering unexpected costs from flooding move to other parts of the city. However, the general lack of awareness about flooding in Canada (Thistlewaite et al., 2018) suggests that awareness of these risks is very likely a minor influence on household decision making, particularly between flood events. It is perhaps more plausible that the pattern we observe is due to a mixture of local factors influencing development—other gentrifying mechanisms, land use changes, aging of the population and other factors.

CHAPTER 3: EXPERIMENTAL EVIDENCE FOR COVERAGE PREFERENCES IN THE FLOOD INSURANCE MARKET

Abstract

This study provides an examination of flood insurance coverage preferences through the use of a hypothetical choice experiment. The experiment was designed to examine the effect of dwelling value and coverage limit on the probability of flood insurance purchase, while holding the probability of flooding and insurance price constant. The results indicate that amount of coverage is negatively related to flood insurance demand, however, for people in high-value dwellings the opposite is observed. It appears that since more coverage is generally preferred to less, the higher probability of flood insurance purchase from people located in high-value dwellings indicates an approach to insurance as an investment into the home as a financial asset. For lower-valued dwellings, the trade-off of yearly premiums may not seem worth the investment. With the new availability of flood insurance in Canada, and the tendency for insurers to restrict coverage in high-risk areas, these findings suggest that a pool of property-wealthy homeowners may be prepared to pay for high flood insurance coverage, while at the same time, high prices for the highest-risk customers may be unfeasible to purchase. This research shows an inconsistent demand for flood insurance, dependent on dwelling value and independent of income.

Background

Flood insurance has been a way for homeowners to hedge against the risk of financial losses from flooding in many parts of the developed world for decades. In Canada, however, overland flood insurance has only been available since 2015, as the insurance industry previously opposed involvement due to concerns about its economic viability (Thistlethwaite, 2017). These concerns were in part due to a lack of adequate flood data for pricing the flooding risk, including high-quality flood mapping, civic information on flood defence infrastructure and household-level data on flood risk factors (Sandink et al., 2016). More generally, flooding has many properties that conflict with the economics of insurance, which works best when risks are random, uncertain and not correlated (Insurance Bureau of Canada, 2015). In contrast, flooding occurs in predictable areas at recurrent intervals and often has a high correlation of losses at the same time (Insurance Bureau of Canada, 2015). This is a phenomenon typical for climate risks generally, such as hurricanes or droughts, which can have considerable financial losses across many insurance portfolios at the same time, such as home, life, car and business insurance, leading to prices well beyond consumer willingness-to-pay (Charpentier, 2008).

A considerable portion of losses associated with flooding can be attributable to underinvestment in public infrastructure, out-dated building codes and ineffective land use planning (Insurance Bureau of Canada, 2015). Land use planning has a twofold impact on the risk and costs of flooding through both exposure of assets at risk and the effect of urbanization on river dynamics. Urban expansion can worsen or increase the prevalence of flooding by making surfaces more impervious, which can enhance river flows and reduce time to peak (Nirupama & Simonovic, 2007). For insurers, structures located in floodplains and other flood-prone regions reflect a predictable source of considerable loss, and homeowners outside of flood-prone regions often have little incentive to purchase flood insurance as the risk is mostly localized elsewhere. This predictability leads to adverse selection, where only high-risk households want flood insurance and insurers may limit coverage in these high-risk areas (Sandink et al., 2016).

Without a broad consumer-base of policies to share risk, prices for flood insurance can be extremely expensive and largely unaffordable for the property owners who want it.

Before flood insurance was available in Canada, only some water-related damages were covered, often through an additional home insurance endorsement of sewer backup coverage, which in Quebec also included seepage and water table rising (Insurance Bureau of Canada, 2015). In addition, water damages from indoor plumbing problems, appliance malfunctioning, or water entering the home through an opening caused by extreme wind could be covered by home insurance (Oulahen, 2015). Despite this limited offering, many homeowners believed they were insured for overland flood damages despite no inclusion on their home insurance policy (Sandink et al., 2010), and after the Calgary flood in 2013, many homeowners reacted by lashing out at insurance companies that rejected flood-related claims (National Post, 2013). This 'name-and-shame' approach to contesting denials of coverage, despite being contractually accurate, contributed in part to a fear of reputational risk for insurers, which led some insurers to pay for claims regardless (Insurance Bureau of Canada, 2015). In interviews with insurance industry representatives, it became evident that reputational risk and the risk of regulation were contributing factors to flood insurance coverage being eventually offered in Canada (Thistlethwaite, 2017).

Prior to flood insurance availability in Canada, financial support following a flood event was provided by government agencies (Thistlethwaite & Feltmate, 2013). Provincial and territorial governments would provide financial assistance through disaster relief programs, which became an important part of flood recovery and rebuilding throughout Canada (Sandink et al., 2016). The Government of Canada provides financial support to provincial and territorial governments through the Disaster Financial Assistance Arrangements (DFAA) in the event of a large-scale natural disaster with considerable cost (Public Safety Canada, 2019). However, the transition to flooding as an insurable peril represents a change for the *ex post* financial assistance away from the wider tax-paying population to the individual, with homeowners now expected to self-protect. This departure of financial liability away from the government to the homeowner incentivizes personal risk mitigation to reduce losses, and for insurance, risk reduction behaviour is incentivized through premium discounts (Botzen & van den Bergh, 2008). Different from disaster relief, flood insurance seeks to compensate policyholders to pre-disaster conditions, effectively increasing individual support, whereas government relief is intended to provide basic financial support (Insurance Bureau of Canada, 2015). Flood insurance additionally acts to reduce the financial burden on governments which provide support from taxation - instead insurer losses are (ideally) covered by the premiums of policyholders, maximizing the benefits of other government spending (Penning-Rowsell & Priest, 2015; Thistlethwaite & Henstra, 2017).

Despite its introduction in Canada, flood insurance still represents an area of development and faces challenges in its economic viability. The optional nature of flood insurance coverage lends itself to the adverse selection problem, as countries with optional coverage have historically observed demand occurring almost entirely in areas with a high occurrence of flooding (Sandink et al., 2010; Sandink et al., 2016; Jongejan & Barrieu, 2008). This results in low market penetration and leads to expensive (or unaffordable) rates for policyholders because diversification through risk pooling does not occur, leaving a small number of policyholders to share a large proportion of the costs (Insurance Bureau of Canada, 2015). Communities with low flood risk and already low demand for insurance may be charged higher premiums to offset some of the costs for high-risk communities, known as cross-subsidization, however this further reduces uptake in lower-risk communities (Jongejan & Barrieu, 2008). This can be largely overcome by charging actuarially fair premiums which represent individual homeowner risk and reduce dependency on cross-subsidization which further disincentivizes building in high-risk flood plains (Clark, 1998; Sandink et al., 2010). However, premiums reflecting individual homeowner risk are often unaffordable by the homeowners who demand it, which can lead insurers to choose not to insure flooding at all (Mehlhorn & Hausmann, 2012).

The economic viability of flood insurance also depends in part on the government relief structure for flooding, which now represents an insurable peril. For example, the departure from government relief to flood insurance is a transition towards homeowners making actionable decisions about protecting their property, which assumes homeowners are aware of the flooding risk. However, a study involving a survey of Canadians across provinces in 2016 indicated a disconnect between perceived flooding risk and actual risk, where property owners living in designated flood areas did not realize their risk and were generally not concerned about flooding (Henstra, Thistlethwaite, Brown, & Scott, 2018). This has important implications for flood protection as risk perception and intention to adopt flood mitigation measures are positively related (Zhai et al., 2006; Botzen & van den Bergh, 2009). To increase market uptake of flood insurance, both a widespread awareness of risk by all stakeholders as well as well as knowledge of limited government disaster relief is required in order to create the impetus for household level risk mitigation (Insurance Bureau of Canada, 2015). This is in part because government disaster support may discourage homeowners from purchasing flood insurance if both are viewed as substitutes, despite disaster assistance being largely insufficient to restore properties to pre-flood conditions (Kousky & Shabman, 2012).

Flooding can be an extremely costly natural disaster. Single flood events can cause billions of dollars in damages, and to homeowners, the average cost of a flooded basement in Canada is $43,000 (Evans & Feltmate, 2019). Water entering the home typically enters the basement and can cause losses through both structural damages and contents losses through damaged belongings. To protect from this flooding, flood insurance takes on the same format as other forms of insurance, where consumers pay an annual premium and a deductible paid by the insured prior to receiving a claim. Due to the magnitude and geographic clustering of losses for most types of flooding, there are numerous strategies insurers can employ to mitigate insurance risk. For example, raising premiums and deductibles for high risk insureds is common (Sandink, 2016). For high-risk consumers, insurers may also limit the availability of flood insurance to certain property owners or apply sub-limits to policy coverage, which caps the payout a customer would receive in the event of a claim (Sandink, 2016). For example, a high-risk customer may not be eligible for a flood insurance policy due to the excessive risk associated with their property location or may be charged higher premiums (Government of Canada, 2018). If such a policy is provided to high-risk homeowners, it may be subject to a limit in payout.

Flood insurance costs vary for many reasons, including geographic location, size of deductible, housing characteristics and flood mitigation measures in place. Though detailed insurance costs are not publicly available, anecdotal evidence[1] suggests that annual premiums can range from under a hundred dollars to tens of thousands of dollars. Like most insurance policies, the size of the deductible is inversely related to the annual premium, and further complicates average cost estimation. In the United States, which utilizes the National Flood Insurance Program (NFIP), the median yearly premium in 2016 across all single-family policies was \$512 and the average \$871 (Kousky, 2018), however the premiums are considerably higher in flood hazard areas designated by 100-year floodplains. However, the United States flood insurance regime differs from the Canadian context due to the NFIP's history of subsidized rates and due to the specific geographies of flooding, particularly on the southern coast.

Flood insurance now forms one component of a broader network of flood risk management (FRM) strategies, including property-level flood protections (PLFP) such as sump-pumps or soil-grading away from the home (Henstra, Thistlethwaite, Brown & Scott, 2018). Like other forms of flood protection, the effectiveness of flood insurance largely depends on consumer uptake, which is in its early years in Canada. In theory, flood insurance should provide everything the former disaster assistance provided to homeowners while offering more coverage, being more comprehensive, efficient, and being financed through collected premiums. However, the intention to pay for property-level flood protections including flood insurance is limited amongst Canadians despite the shared belief that property-owners should be at least partly responsible for mitigation (Henstra et al., 2018). This has led to the beginning of literature investigating the factors associated with Canadian homeowner willingness-to-pay (WTP) for flood insurance, a

[1] During the summer of 2017 and 2018, the researcher contacted 5 major insurance companies in Canada and asked agents about minimum, maximum, and mean prices for flood insurance in various cities. The researcher also received confirmation of the price range from flood insurance researchers at the University of Waterloo.

field of research well-developed in other countries. Such research is described as contingent valuation (CV), which reflects a method for estimating the value a person places on a good or service. Often this research focuses on population-specific factors related to WTP including socioeconomic characteristics, or characteristics related to risk perception. For example, using a survey conducted in Vancouver and Surrey, British Columbia (Canada), Oulahen (2015) found that WTP for flood insurance was associated with a higher perception of flood risk, sea level rise, climate change and increased prevalence of severe rainfall events.

From previous research, we can gain an understanding of factors related to WTP and willingness-to-buy (WTB) flood insurance. In many cases where flood insurance is optional (as in Canada), the success of flood insurance in protecting homeowners depends in part on how many people are willing to purchase flood insurance and the price they are willing to pay for it in relation to policy cost. A sample of past research into flood insurance contingent valuation can be broken down by outcome measured, such as willingness-to-buy (Hung, 2009; Petrolia, Landry & Coble, 2013; Ren & Wang, 2016; Väisänen, Lehtoranta, Parjanne, Rytkönen & Aaltonen, 2016), willingness-to-pay (Botzen & van den Bergh, 2012; Oulahen, 2015; Raschky, Schwarze, Schwindt & Zahn, 2013), or observational studies of flood insurance policies-in-force (Atreya et al.,, 2015; Brody, Highfield, Wilson, Lindell & Blessing, 2017; Brown & Hoyt, 2000; Kousky, 2010; Kriesel & Landry, 2004; Lo, 2013a; Lo, 2013b; Shao et al., 2017). Other contingent valuation research has considered WTP for flood mitigation protections (Botzen et al., 2009; Jones, Clark & Malesios, 2015; Lin, Shaw & Ho, 2008; Owusu, Wright & Arthur, 2015), WTP for flood risk reduction (Botzen, Aerts & van den Bergh, 2013; Clark et al., 2002; Clark, Griffin & Novoty, 2005; Thunberg & Shabman, 1991; Zhai, Sato, Fukuzono, Ikeda & Yoshida, 2006), and WTP to reduce the inconvenience of flooding (Zhai & Ikeda, 2006). Though each method differs by outcome of interest, the purpose behind such research is to provide an estimation of value for each method of flood protection.

Contingent valuation methods, such as willingness-to-buy, are often used when access to real market data is not accessible or when it is difficult to observe market transactions under the specified conditions. Some aspects of the flood insurance market in Canada can be estimated from publicly accessible documents, however insurance policies vary by company and location. In addition, insurer policy-level data is kept confidential and pricing models are proprietary, so observational studies typically require partnerships with insurers - perhaps a possible extension of this research going forward. The use of hypothetical choice raises questions about the transferability of findings into action and the generalizability of results, however such choice experiments are often the simplest method for investigating theoretical questions (Kahneman & Tversky, 1979). It is also noted that profit-seeking and loss-avoiding insurers may have less flexibility towards policy experimentation than the researcher.

Economic Models of Insurance

Many theoretical models of optimal insurance coverage and insurance demand are rooted in expected utility theory (EUT) (Smith, 1968; Ehrlick & Becker, 1972). EUT assumes that people are rational actors making consumption decisions by maximizing the expected utility (or satisfaction) from choosing between the options available. The demand for insurance has historically been justified under EUT as a demand for certainty; specifically, the preference for certain losses instead of actuarially equivalent uncertain losses (Nyman, 2001). In other words, the purpose of insurance is to change a potentially large, uncertain loss into a certain small loss (Newhouse, 1978, p. 19). This exchange is explained through risk aversion, a well-established behaviour of humans away from uncertainty. Risk aversion is explained in EUT through the diminishing marginal utility of wealth (further assuming the utility function is concave), suggesting money, when nearer to poverty, is more valuable than when one is rich (Rabin, 2013). **Figure 6** displays the hypothesized diminishing marginal utility of wealth curve. Under this utility function assumption, human preference against uncertainty in lifetime wealth is because the marginal value of money is higher when we are poor than when we are rich.

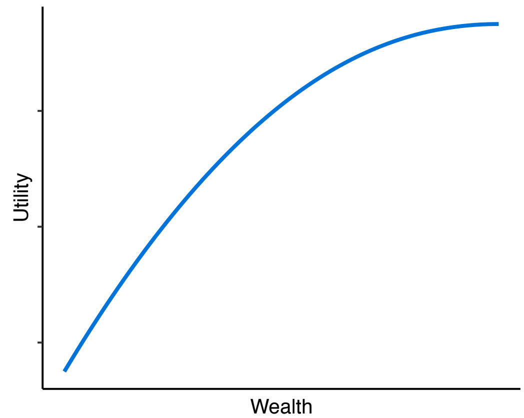

Figure 6: Diminishing Marginal Utility of Wealth

However, the core assumption of human behaviour towards certainty in losses is challenged by prospect theory, which finds risk aversion in situations involving gains but risk seeking in choices involving losses (Khaneman & Tversky, 1979; Tversky & Khaneman, 1981). This preference towards uncertainty with losses challenges the core assumption of insurance purchase as a preference towards a certain loss and is in conflict with the decisions to purchase insurance to reduce uncertainty. From prospect theory, one explanation behind insurance preference is due to the human bias of overweighting low-probability events (Khaneman & Tversky, 1979). This increases the desirability of protecting oneself due to higher-than-actual perception of the risk and a desire to avoid loss.

Another possible explanation for insurance demand from the field of health insurance economics is described in Nyman (2001), where insurance demand is derived from the greater marginal utility of income when one is 'ill', than otherwise. More generally, demand for insurance reflects a payoff or transfer of income to the adversely impacted (for example, flooded) state, where the utility of that income is greater, instead of conventional explanation of demand for certainty or risk avoidance. This emphasizes that demand for insurance occurs because the uncertain payoff is structured to occur along with the bad (or adversely impacted) state (Nyman, 2001). This theory, *state dependent utility*, attempts to reframe insurance demand back under expected utility theory, in contrast to the risk-seeking behaviours of people under loss scenarios towards a certainty of income in the state where income will be more valuable.

However, the traditional economics approach of viewing people as utility maximizing, rational agents has been challenged in many empirical studies. For example, there is evidence that low-probability and high-consequence events including flooding are approached differently from high-probability, low-consequence events in terms of insurance behaviour, with a preference for insuring the latter (Browne, Knoller & Richter, 2015). Slovic et al (1997) proposed that below a certain (low probability) threshold, an individual considers the probability of such an event to be zero. For flooding, this may be close to true – in areas of very low flood hazard, the probability of a flood occurring may be less than a fraction of a percent each year. Although there is empirical evidence of higher-than-expected risk aversion over modest stakes in the home insurance market (Sydnor, 2010), for flood insurance we can observe either the lower probability event being subjectively discounted (Slovic et al., 1997) or overweighed (Khaneman & Tversky, 1979). This in part can be explained by risk misperception amongst people, where even with standard risk preferences, inaccurate subjective beliefs about claim rates or losses can lead to considerably high risk aversion, leading to overpaying for modest risks (Sydnor, 2010). More likely in the context of flooding in Canada, the risk is realized by the homeowners being flooded regularly, and the risk is discounted elsewhere.

Without dwelling on which economic theory best optimizes insurance coverage in a normative way, it is best to consider the current understanding of flood insurance demand and decision-making from previous literature. To provide a basic template for flood insurance demand, borrowing from Smith (1968), demand for insurance is determined by wealth, the loss probability, the insurance price, the value of asset(s) at risk, and the individual's utility function. Therefore, a person considering the decision of whether or not to purchase insurance considers their financial position, how likely a flood would be (*and how likely a loss from that flood would be*), the cost of the insurance policy, and the value of the dwelling or its contents which are at risk. This is in line with research from the United States, where price, income, and risk perception are influential in the demand for flood insurance (Brown & Hoyt, 2000). When making a decision, the utility function of each individual is unique but reflects the trade-off of forgone use for the money that could be spent on the insurance premium. This determination varies from person to person but ultimately is assessed in the decision to purchase insurance.

From research, we have seen lower uptake in flood insurance than one may expect from traditional economic models and this can be explained twofold. First, there is low risk awareness of the flooding hazard in Canada (Henstra et al., 2018), even for people living in higher flood hazard areas. This disconnect represents an underweighting of the probability that a flood will occur for residents. This is aligned with a more general underestimation of the likelihood of low probability catastrophic natural events or suffering a loss from one (Kriesel & Landry, 2004). This underestimation of the flood probability and a subsequent lower uptake of flood insurance (even when subsidized, as in the United States) may be due to a lack of understanding of flooding risk, or a lack of information regarding the flooding hazard (Chivers & Flores, 2002).

Secondly, a history of government relief following flood events may create the expectation that damages will continue to be covered into the future (Kousky, Michel-Kerjan & Raschky, 2018), a consideration for the Canadian setting as it fully transitions to flood insurance. Consumers have historically depended on government relief following floods (when the peril was not insurable), and so the mental accounting of the flooding hazard through market insurance is a new feature of flood risk management in Canada.

In what follows, I summarize the methods and findings from an experiment which was administered by the author to persons residing in Canada. In this hypothetical choice experiment, participants are provided a scenario in which the probability of flooding and the per-dollar cost of insurance is held constant, while dwelling value and flood insurance coverage are assigned at random. With the assignment of participants' real-world income, the effect of dwelling value and total coverage on the probability of flood insurance purchase is tested. By implementing experimental choice, this enables the controlling of factors related to the flood insurance purchase decisions that would otherwise be difficult to measure in the real flood insurance market in Canada.

Theoretical Framework

Through discussions with insurance representatives and an analysis of recent research, it has become evident that in Canada, insurers are limiting flood insurance coverage in high flood-risk areas. Though specific policy availability depends on each insurance company, homeowners in high-probability flood areas, such as 1-in-50 and 1-in-100 year flood zones, may face either no insurance coverage, a cap or maximum payout in coverage, or incredibly expensive premiums (upwards of $10,000 per year). Though an extensive literature of research exists in population-level socioeconomic factors related to flood insurance demand, such as education or age, it is worth examining policy characteristics, such as how different caps on coverage may impact flood insurance demand, holding the price per dollar of insurance constant. More specifically, the purpose of this research is to answer to the following two questions:

1. *Controlling for price, how does amount of coverage influence probability of purchase?*
   and
2. *Controlling for income, how might this differ by dwelling value?*

We are currently unaware of how a limit on payout may affect flood insurance demand. For example, the limiting of insurance payout may make alternatives to insurance, such as self-insurance – a reduction in the magnitude of potential losses, and self-protection – lowering the probability that a loss occurs, more appealing (Yiannakoulias et al., 2018). We know from Smith (1968) that an accounting of assets at risk may influence the insurance purchase decision, which in our example reflects the value of the dwelling, however in empirical research, property value has had both a significant positive effect (Brody et al., 2017) and a significant negative effect (Botzen & van den Bergh, 2012) on willingness-to-pay for insurance. Though dwelling value is both an accounting of the asset at risk (and correlated with income), higher dwelling values may encourage self-insurance and self-mitigation if covering losses is easier for wealthy people, reducing the attractiveness of flood insurance (Botzen & van den Bergh, 2012). The experiment is described in detail below.

Methods

Data

A hypothetical-choice experiment was administered through a survey from September 2018 to April of 2019 targeting persons residing in Canada who were 20 years of age or older during the recruitment period. The purpose of this experiment was to examine the effect of coverage on the decision to purchase flood insurance in a controlled scenario. A pre-experiment survey collected demographic information including age, gender, ethnicity, income, education, employment, marital status, homeowner or renter designation, household size and number of dependents, and the post-experiment questions related to flood experience, coping appraisals and threat appraisals.

Recruitment for this research took place in-person and online. In-person recruitment took place at various public spaces around Hamilton, Ontario including Bayfront Park, McMaster University, the Hamilton Public Library and outside various coffee shops. One of the researchers set up a table with a poster indicating that an experiment was being conducted and both passively and actively recruited people and asked if they would be like to participate in a survey that would take approximately 10 minutes of their time. The approximate response rate was about 10% during active recruitment. Participants were provided with their choice of means to complete the survey, either a tablet computer or a paper version of the survey. The researcher was present for the completion of the survey and provided clarification if asked questions but did not guide any response.

Online participants were recruited through handing out business cards, poster recruitment, and social media sharing of the experiment weblink including a brief description of the experiment. The experiment was shared on social media approximately 15 times across Twitter and Facebook. All online participants visited a webpage (https://www.floodingsurvey.ca/) which directed them to a pre-experiment information page outlining the experiment details and the participants "Agreement to Participate in the Survey" notification. At the end of the information section, participants could choose to proceed by clicking a button which sends participants to a randomly assigned experiment options, or persons could choose to exit the page and discontinue. People were incentivized to participate by being entered into a draw for a $250 Amazon Gift Card. The questions contained in both the online and paper versions of the survey were made non-mandatory in order to facilitate voluntary behaviour, though almost every survey was filled out completely and those which weren't typically missed only a single answer with no systemic pattern.

Experiment Design and Hypothesis

The hypothetical-choice experiment was structured as follows:

> *"Imagine that you live in a $DV house. The areas around the city you live in are classified by their flood risk, and your home is located in the 1-in-100 year flood zone, meaning there is a 1% chance that your house will be flooded each year. Your home insurance provider offers a flood insurance add-on to your policy, which is $P per year and provides $C in protection in the event that a flood occurs. Would you buy the flood insurance policy?" [Options: Yes or No]*

where *DV* was a specific dwelling value that was randomly assigned from the options: 250,000; 500,000; 750,000; and 1,000,000. *P* reflects a specific insurance premium randomly assigned from the options: 100, 325, 550, 775 or 1,000, and *C* reflects a coverage equal to the *P* (premium) value times one hundred. For example, a $325 per-year premium provides $32,500 in coverage in the event of a flood.

The scenarios were specifically designed to hold the per-dollar value of insurance constant, meaning no policy was superior to others in cost-effectiveness, while these scenarios also provided *actuarially fair* premiums such that expected costs are equal to policy value over time. One of the benefits of examining purchase decisions with insurance is that the scenario provides a quantifiable amount of monetary protection for a regular premium, enabling the testing of expected value, rationality and is less ambiguous than the expected value from a physical protective measure such as a sump-pump. No deductible was included for any policy to simplify the analysis of cost. Though participants were assigned their *real-world* income in the experiment, participants were assigned one of five different insurance options and one of four different dwelling values, at random. The reason for assigning a housing value instead of using *real-world* housing value occurs due to the inaccuracies and inconsistencies that would be created from self-appraisal of house-value by participants, particularly with a fluctuating housing market. In contrast, income is a variable that participants would readily know, and was determined necessary instead of being randomly assigned due to the importance of understanding individual purchasing power. Participants were not made aware of any alternative pricing nor dwelling value options, so each scenario had no additional framing.

With all scenarios having an equal probability of flooding (1%), the only thing that differed across scenarios was the random assignment of dwelling value and the random insurance coverage level since the cost is proportionate to value (which is further explained in the subsequent paragraph). It is important to note that conventional demand models quantify the demand for the same product at different prices, however in this case, it is the same product at different *quantities* - more cost means more coverage. Economic theory would suggest that the same item would be demanded less at increasing prices, but since these insurance packages offer the same product at increasing quantities (of coverage) and proportional pricing, differences in demand reflect preferences in coverage. One such analogy would be the decision between purchasing 1 box of Kraft Dinner for \$2.00 or 10 boxes of Kraft Dinner for \$20.00 – any increased demand at some number of boxes reflect a preference for quantity, unaffected by economies of scale.

The insurance pricing is such that the premium is equal to the probability times the coverage. For example, the \$100,000 coverage is purchased through a \$1,000 premium (\$100,000 x 0.01). If over 100 years, we expect to see 1 flood (1% probability), the $1,000 premiums would, over time, accrue to $100,000. Of course, a certain payment of $1,000 is much more feasible than an unexpected $100,000, however it is not made clear through the choice experiment how much coverage is needed. Participants are assigned random premiums (and corresponding coverages) as well as random dwelling values. Though cued with the same type of information, participants may convey different subjective interpretations of the probability (discounted entirely or higher-than-expected), even though it is explicitly provided. From the previous example's cost perspective, the insurer provides a payout maximum of $100,000 equal to the expected cost of $1,000 per year ($100,000 x 0.01). Losses could exceed or fall well below this maximum, and part of any preference may reflect this subjective assessment of coverage need, rather than its cost.

Analysis

The hypothetical-choice question yields a binary purchase decision (yes or no) at each scenario's random price and random dwelling value. To examine factors influencing the purchase decision, a binary logistic regression is used to derive the log-odds (and therefore odds) and probability of purchase based on the predictor variables related to each experiment. The empirical logistic model is as follows:

$$\text{logit}(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_n x_{in}$$

where π_i is the probability of buying the flood insurance for the *i*-th person, β_0 reflects the intercept, β_n reflect the model coefficients and x_{in} are the explanatory variables for the *i*-th person. The independent variables used in the model are *premium (PR)*, which reflects the coverage and cost, *dwelling value (DV)*, and *income (INC)*. The main effects of the experiment can be modelled by Equation 1 below:

$$\text{logit}(\pi_i) = \beta_0 + \beta_1 x_{DV} + \beta_2 x_{PR} + \beta_3 x_{INC} \tag{1}$$

In order to understand the effect of coverage at different housing values, an interaction term between *premium* and *dwelling value* is included, which is given by the following model:

$$\mathrm{logit}(\pi_i) = \beta_0 + \beta_1 x_{DV} + \beta_2 x_{PR} + \beta_3 x_{INC} + \beta_4 x_{PR} x_{DV} \quad (2)$$

where a non-zero β_4 coefficient denotes that the relationship between coverage value and probability of flood insurance purchase depends on dwelling value. Similarly, to Equation 2, an interaction term between *premium* and *income* is added in order to model the effect of coverage dependent on income, given as follows:

$$\mathrm{logit}(\pi_i) = \beta_0 + \beta_1 x_{DV} + \beta_2 x_{PR} + \beta_3 x_{INC} + \beta_4 x_{PR} x_{DV} + \beta_5 x_{PR} x_{INC} \quad (3)$$

where a non-zero β_5 coefficient denotes that the relationship between coverage value and the probability of flood insurance depends on income. I report the main effects and include interaction terms sequentially to guide the understanding of our models.

Results

Survey Results

A total of 235 participants completed the survey, with the indicated method of recruitment being 103 in-person (43.8%), 96 through social media (40.9%), 34 notified by a friend, family member or colleague other than the researcher about the survey (14.5%) and 2 responses which appeared to find the experiment through other online searching. The socioeconomic characteristics of participants are summarized in **Table 4**. A considerable proportion of participants were under 40 years of age (74.4%) and slightly more males did the survey than females (54.5%). Roughly 15% of respondents self-identified as visible minorities while another 15% classified themselves as “Other”. Most participants had completed postsecondary education (74.5%); the remainder had completed secondary education (23.8%) or no secondary education (1.3%). Most of the sample were employed (76.6%) with 13.2% stating they were unemployed, and 9.8%

Table 4: Sociodemographic Characteristics of Participants

	Frequency							
	0	1	2	3	4	5	6	7
Age								
1=20-29; 2=30-39, 3=40-49, 4=50-59; 5=60-69; 6=70-79; 7= 80+	-	145	30	21	27	11	0	1
Gender								
1=Male, 2=Female, 3=Prefer Not to Say, 4=Other	1	128	106	-	-	-	-	-
Visible Minority								
1=Yes, 2=No, 3=Other	1	35	192	35	-	-	-	-
Income								
1=Under $19,999; 2=$20,000-$39,999; 3=$40,000-$59,999; 4=$60,000-79,999; 5=$80,000-99,000; 6=$100,000-$149,000; 7=$150,000+	2	70	36	34	31	16	32	14
Education								
1=No certificate, diploma or degree; 2=Secondary (high) school diploma or equivalency certificate; 3=Postsecondary certificate, diploma or degree;	1	3	56	175	-	-	-	-
Employment								
1=Not in Labour Force; 2=Unemployed; 3=Employed	1	23	31	180	-	-	-	-
Ownership								
1=Homeowner; 2=Renter; 3=Other	1	84	124	26	-	-	-	-
Household Size								
1=1 Person, 2=2 Persons, 3=3 Persons, 4=4 Persons, 5=5+ Persons	-	24	57	40	54	60	-	-
Number of Dependents								
1=0 Persons, 2=1 Person, 3=2 Persons, 4=3 Persons, 5=4 Persons, 6=5+ Persons	-	156	26	31	14	5	3	-
Marital Status								
1=Married or living in common law; 2=Not married	-	78	157	-	-	-	-	-

stating they were not in the labour force (not employed and not looking for employment). A large proportion of renters completed the survey (52.8%) while 35.8% were homeowners and 11.1% listed “Other”. Household size (number of people in household) varied in across options between one person and five or more people, with the lowest proportion of people living alone (10.2%) and remainder split somewhat evenly across categories. The number of dependents was overwhelmingly 0 persons at 66.4% of respondents, while 24.3% of respondents had between 1 or 2 dependents and the remainder had 3 or more. Roughly one-third of respondents were married or living in common law, while the remainder were not married.

Choice Experiment Results

Of the 235 participants, 117 (50%) chose to buy the insurance policy and 118 did not, though this varied by dwelling value and insurance policy. The results of the experiment are described in the model description below and summarized in **Table 5** (Note: house value is in thousands of dollars while coverage and income are in ten-thousands of dollars).

Model 1 Results

In the main effects model (*Model 1*), the house value has a positive and statistically significant relationship to the purchase decision. Income is positively related to the probability of purchase, as one might expect, though the coefficient is near 0. Coverage has a small negative effect on the probability of purchase.

Table 5: Summary of Hypothetical Choice Experiment Modelling

	Model 1		Model 2		Model 3	
	β	SE	β	SE	β	SE
Intercept	-0.64207	0.41139	0.40280	0.64071	0.50499	0.67797
House Value	0.00104*	0.00049	-0.00070	0.00095	-0.00069	0.00096
Coverage	-0.01270	0.04296	-0.22987*	0.11298	-0.25025*	0.12159
Income	0.00857	0.02735	0.00795	0.02757	-0.01256	0.05210
House Value * Coverage			0.00036*	0.00017	0.00035*	0.00017
Income * Coverage					0.00415	0.00896

*P-value: *** < 0.001, ** < 0.01, * < 0.05*

Overall, *Model* 1 suggests that individuals consider the value of the house at risk prior to determining whether or not to buy flood insurance, with a preference to protect higher valued dwellings. On average, the negative effect of coverage may suggest that though the price per dollar of insurance is equal, higher coverage (*and subsequently yearly premium*) decreases the probability of purchase. Income has a weakly positive relationship to the probability of purchase. This may suggest that income may increase flood insurance purchase probability through greater affordability of insurance possibilities. The modelled relationship between coverage and purchase probability is represented visually in **Figure 7**, with the income held constant at the sample mean ($58,112).

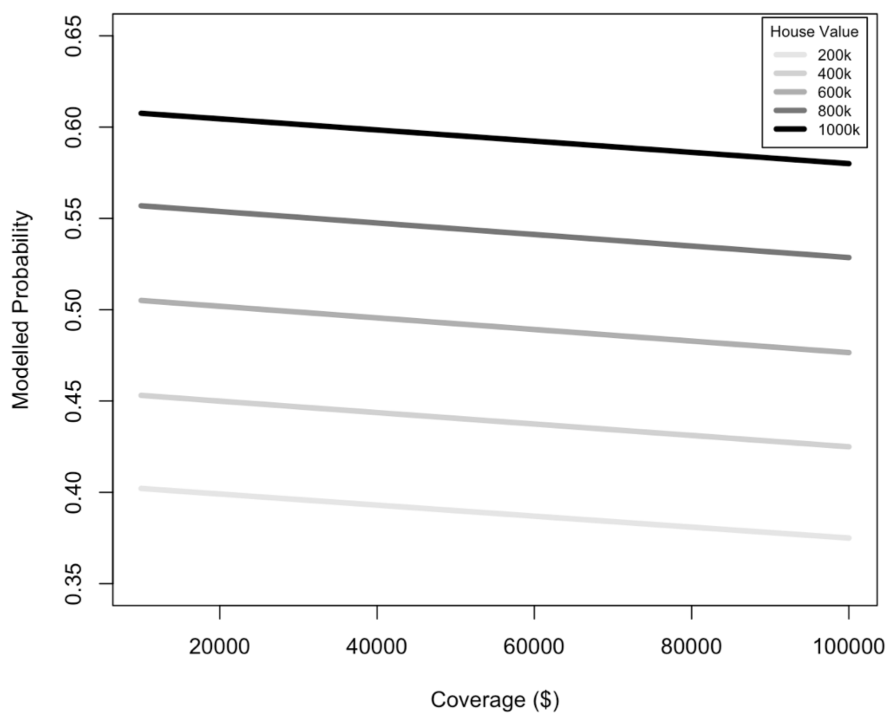

Figure 7: Main Effects Model of Flood Insurance Purchase Probability by Coverage

From Figure 7, the effect of housing value becomes apparent – a clear pattern of predicted probability of purchase emerges, with increasing house value associated with increasing probability of flood insurance purchase. Across coverage levels, there is a 20.5% higher probability of flood insurance purchase for the $1,000,000 dwellings compared to the $200,000 dwellings, with the former more likely to buy than the latter. The effect of coverage is comparatively subtle and negative – across the $90,000 range of coverage options, we observe only a 2% decline in probability with increasing coverage from the lowest to highest coverage.

Model 2 Results

In the second model, the interaction term between house value and coverage is positive and significant (**Table 5**). When modelled (using the sample income average), we observe the positive effect of the house value and coverage interaction (**Figure 8**), where increasing amounts of coverage increase the probability of purchase for higher-valued dwellings, despite the negative effect of the coverage term. As with Model 1, income appears to have little effect on the probability of flood insurance purchase.

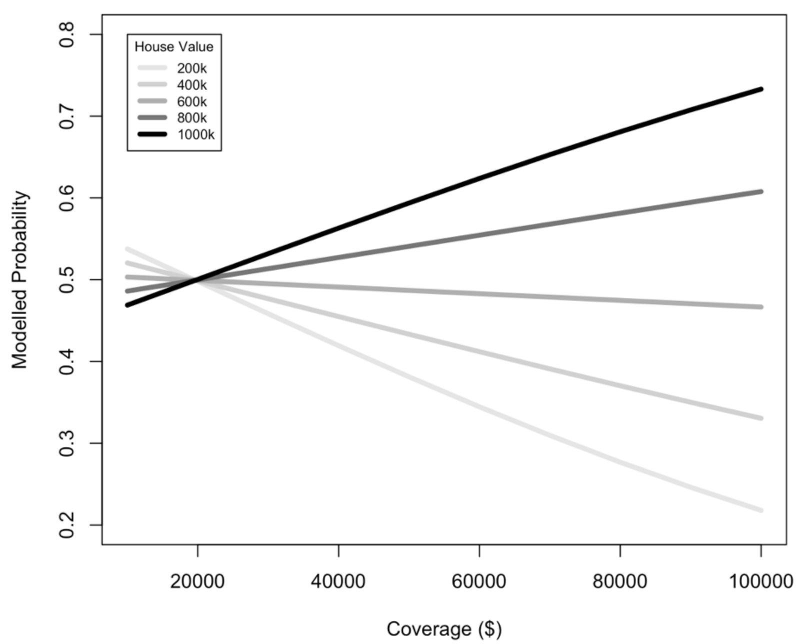

Figure 8: Model of Flood Insurance Purchase Probability by Coverage Including Interaction

The house value-dependent effect of coverage on preference for flood insurance may seem intuitive as it suggests that, controlling for income and holding price of coverage constant, people in lower valued dwellings demand less coverage. However, it is important to note that high-value homeowners appear less interested in low coverage insurance. Assuming high-value homeowners desire protecting their home through insurance, the low demand at lower coverage suggests an inconsistency towards risk. In other words, we observe risk aversion when the coverage is high (*resulting in higher probability of purchase*), but risk-seeking when coverage is low.

It is worth noting that the 0.5 probability is a modelled prediction of flood insurance purchase, and one should be hesitant to suggest this reflects *indifference* between buying or not buying. Rather, the decision made in the choice experiment directly reflects an *individual* preference on the *buy* option; this model predicts the probability overall resultant from odds. In other words, looking at Figure 3, there is a 50% modelled probability of purchase for all dwelling values at $20,000 in coverage (with a $200 premium per year), and at increasing levels of coverage higher dwelling values have a higher probability of purchase and lower dwelling values have a lower probability of purchase. Deviations in probability away from 0.5 in either direction reflect an effect of the treatment information on some factor of the decision.

Model 3

The description of Model 3 is limited as the inclusion of the income and coverage interaction term had a very small effect size, and this result closely resembles and approximates Model 2.

Discussion

This study made use of a choice experiment to examine the effect of dwelling value and coverage amount on the probability of flood insurance purchase. This research seeks to address an emerging trend for high-probability flood areas – the limiting or capping of coverage for flood insurance policies. To date, it is not clear how this coverage maximum may influence demand, particularly when alternatives such as self-insurance and self-protection exist. The findings of the research are discussed in more detail and in the context of findings from other research below.

The results of the choice experiment reveal that flood insurance demand is influenced by both coverage amount and dwelling value. In general, coverage is negatively related to the flood insurance purchase decision, however, probability of purchase increases with coverage for people with higher-valued dwellings. This is not to suggest that people prefer less coverage, as we can assume that if free, people would always elect for the maximum coverage possible. Instead, this suggests that a trade-off exists: the home is an asset, and spending more money for proportionally more coverage is an investment into protecting this asset. This is in line with Brody et al. (2017) who found that respondents with higher-valued homes were more likely to purchase voluntary flood insurance than people in lower-valued homes. Similarly, Kousky (2010) found that the amount of coverage purchased increases with the value of a home. The explanation for this finding was that people who have the financial capacity to afford more expensive homes are more likely to take actions to protect their investment (Brody et al., 2017). Compared to the real insurance market, the choice experiment *assigned* dwelling values to participants at random, however a clear preference emerged from the experiment that people in high-valued dwellings demand more coverage.

Conversely, higher amounts of coverage are less likely to be purchased amongst people with lower-valued dwellings. This negative relationship between coverage and purchase may be a preference for monetary wealth over investing into the property if the property is not viewed in the same manner as a wealth investment. The trade-off for consumers may seem worthwhile when protecting a high-value asset, but much less for lower-valued homes. Of course, one must also consider the cost of the yearly premium when considering this effect. Kousky (2010) found a negative relationship between poorer households and coverage levels, noting that poorer households are likely to have lower valued homes and subsequently choose lower coverage levels to keep premiums lower. We may be able to infer that lower value homes may choose lower amounts of coverage for practical reasons of cost saving, or not seeing the need for excessive amounts of coverage relative to the home value. Reduced purchase of higher-coverage policies could be explained if individuals were liquidity constrained and could only afford a small premium or none at all, however the models controlled for income and saw little influence of income on probability.

The explanation of high dwelling-value homeowners demanding more coverage as a function of protecting their dwelling as a financial investment falls short of consistent rationality. Namely, *if a homeowner is willing to spend $1,000 for $100,000 in coverage, why wouldn't the same person want to spend $100 for $10,000 in coverage?* If motivated by risk aversion, both policies reflect a trade-off of wealth to the potentially flooded state, and at no additional cost per unit of insurance. This suggests an apparent disinterest in low coverage from high-value dwelling homeowners, despite its identical cost. In isolation, the observed behaviour for high-value homeowners against low-coverage aligns with Kahneman and Tversky's (1992) prospect theory, in that risk seeking is often observed when choosing between a sure loss and the substantial probability of a larger loss. If the premium is viewed as a sure loss under prospect theory, then homeowners may forego this loss and take a chance at losing nothing. Interestingly, the high demand at high coverage runs counter to this, however, and suggests asymmetry in approaching risk aversion.

Two possible explanations emerge for this phenomenon. First, the risk-seeking behaviour that high-value homeowners exhibit towards low-coverage insurance may be a matter of framing; the lower payout may be subjectively interpreted by the homeowner as flooding having a low expected damage. In contrast, the risk-aversion towards flooding when provided with high coverage insurance may cue a subjective interpretation that the potential flooding could cause damage worthy of a $100,000 maximum. Though the study design does not permit such an interpretation to be proven, framing could be a possible explanation, however in such a case we would expect to see a positive relationship between coverage and purchase more generally.

Second, the negative effect of coverage (as per the modelling) suggests participants are more influenced negatively by the premium cost than positively by the proportional increase in coverage. However, it is important to interpret this finding with the risk assessment—homeowners are making a subjective assessment of the flood probability, and if expected damage is very low the policy would not seem like a good use of money. In other words, risk aversion assumes a *risk*; if subjectively this risk is small or non-existent, we would observe 'risk-seeking' behaviour. Since premiums are actuarially fair and participants are not provided more than one option, the only reason for a risk-averse person to forgo insurance (controlling for income) would be if the subjective assessment of the flooding risk was that damage would be substantially less than the coverage provides, such that bearing the risk of inundation without insurance was better.

It is also possible that the results suggest that there may be an optimal *proportion* of coverage in relation to dwelling value, but it exists outside any cuing through the experimental design. For example, in the choice experiment, the probability of flooding is explained as being 1% each year, however no flood damage estimate is provided. For the $1,000,000 dwellings, the modelled probability of purchase increases from 46.9% at $10,000 in coverage to 73.3% at $100,000 in coverage. For $200,000 dwellings, this change is from a 54.6% probability at $10,000 in coverage to 17.3% at $100,000 in coverage. For high-valued dwellings, this effect could be due to the desire to protect the more valuable asset compared to the lower-valued dwelling, or rather the estimation that such a high proportion of coverage for the lower-value dwelling is unnecessary. Without a damage estimate, people choose whether or not to buy flood insurance based on the treatment information, and a subjective interpretation of the flooding damage possibilities.

Property owners in high-risk areas face few options when it comes to reducing the risk of flooding. Flood insurance, when available in high-probability areas, occurs at largely unaffordable prices and/or is limited in total payout. The results from this study have implications for the high flood-risk community, which has been shown in Calgary to be on average wealthier and comprised of higher-valued dwellings (Darlington, Yiannakoulias, Elshorbagy, 2019). This may mean that a pool of wealthy homeowners in expensive dwellings have a high demand for large amounts of coverage, however insurers will have to evaluate the risk they are capable to take on in such regions. In the case of flooding, there are very few cases where the *entirety* of a house is lost from flooding in Canada, though historically these properties have been offered to be bought out by government (CBC, 2013). It is more common to see a finite amount of damage, usually contained to the basement of a home at an average of $43,000 (Evans & Feltmate, 2019).

Flood insurance may continue to evolve in the Canadian market in response to climate change. Insurance depends on the ability to quantify risk, however climate change increases the potential to suffer larger or unexpected losses from flooding and can lead to a market failure (Lamond & Penning-Rowsell, 2014). To capture this risk, it is possible insurers may raise premiums, exclude more properties from coverage or lower caps on payouts. From this research, it appears that homeowners with higher-valued dwellings will demand more insurance than lower-value dwellings.

Limitations

Generalizability is almost always a concern for hypothetical choice experiments. Not only do the decisions in the experiment take place *in the hypothetical*, but also under experimental settings. Though participants were requested to answer as they would actually behave in the real world, the translation of intention into action especially when costs are involved is not clear. The objective of the research to gain an understanding of flood insurance policies on insurance demand is one that would be difficult to pursue in a non-experimental setting, as the artificial limiting of coverage to different amounts raises ethical questions, let alone controlling for the probability of flooding and other characteristics.

The sample of people used in this research contain a high proportion of young people and renters. Though economic experiments frequently rely on students or other convenience samples, this is not without issues. Perhaps the biggest sampling constraint present is that due to the high proportion of renters, the participants may lack typical levels of knowledge about home insurance purchase decisions. Flood insurance specifically is a new product in Canada, and even experienced homeowners may be unaware of such a product, however the general provision of resources to protect one's home would be more readily apparent for a current homeowner than otherwise.

Due to the *buy* or *not buy* nature of the experiment, we do not gain as rich of data as may be possible through multi-question scenario testing. Though such testing would be prone to framing effects, one may be able to gain a richer explanation for the reasoning behind the observed findings. In particular, multi-scenario testing could enable the analysis of input factors and further examine the reasoning behind the purchase decision.

Conclusion

The observations from the experiment indicate that demand for flood insurance is dwelling-value dependent, with demand being negatively related to the amount of coverage for people in low-value dwellings, and demand being positively related for high-value dwellings. This result has been observed in other research (Kousky, 2010; Brody et al., 2017), with the explanation that people with the financial capacity to afford more expensive homes are more likely to protect their investment. Though other research has found a positive relationship between household income and coverage (Landry, Jahan-Parvar, 2011), the effect of income was not significant in the modelling from this research.

The main finding of this research is the inconsistent demand for flood insurance, dependent on dwelling value and independent of income. The results suggest that high-value homeowners are risk-seeking when provided low-coverage policies and risk-averse when provided high-coverage policies. Since no indication of expected damage was provided and flood insurance cost was constant, we would expect low-coverage demand if high-coverage was demanded. This asymmetry is interesting and suggests a disinterest in low coverage policies. The effect may be due to framing, if people assume maximum coverage to represent an approximation of damage, however the study design does not permit proving such a theory. It is also possible that people may adopt some sort of proportional approach to insurance, where some amount of coverage is ideal, relative to the house value. The flood insurance market currently limits total coverage available in high-flood areas, which may have impacts on homeowners of higher-value dwellings who wish to insure with greater amounts of coverage. For capped insurance policies going forward, uptake would be higher for lower-coverage policies amongst lower-valued dwellings, which may be a market opportunity for small coverage provisions in Canada. However, expensive dwelling homeowners will, if insurance is demanded, prefer greater coverage.

CHAPTER 4: CONCLUSION

This research provides a thorough exploration of two components of flooding in Canada – social vulnerability to flooding and flood insurance preferences. These chapters address two key components related to flood risk mitigation financing in the future. First, using Calgary as an example, it appears that the highest flood hazard areas are comprised of the people of highest wealth, in terms of both real estate and income. From a flood management standpoint, the elimination of government relief as the singular financial means of support following a disaster opens up a new market for insurance-financing opportunities. From a market standpoint, based on the findings of Chapter 3, this means that high coverage of overland flood insurance will be most demanded by wealthier homeowners. Though the experimental results found no meaningful effect of income on the flood insurance purchase decisions, other research has found a strong effect on willingness-to-pay. Regardless, dwelling value was a clear predictor of insurance demand at greater levels of coverage, which in practice, will generally be comprised of people with higher incomes.

In Calgary, we see that the people most at risk of flooding are, on average, the wealthiest and least socially vulnerable by measures of socioeconomic, dwelling and other demographic characteristics. This provides an interesting question for policymakers – *what should we do with this information?* On the surface, one may consider the alternative – had we found that people in high-flood hazard areas were, in general, the *most* socially vulnerable, *what would we do?* First, we know that most floods have a predictable geography and occur (by definition) in these high flood hazard areas. Regardless of the social vulnerability of these communities, we can expect that people living in high flood hazard areas will be exposed to continual flooding risk every year. If these communities were more vulnerable to the effects of flooding based on social characteristics, we would expect that in general, coping with the aftermath of flooding would be more difficult. This may include factors such as preparation efforts, recovery efforts, and flood mitigation but also relates to accessibility of other services and opportunities which enable recovery.

It is not difficult to see that, with communities that are more socially vulnerable, a key political effort moving forward would be providing pre- and post-disaster support to assist those who may otherwise be unable to cope with the aftermath of flooding. As suggested by Masozera et al (2007) this may include access to reconstruction or relocation support, investment funds, and safe housing as well as financial support. Buyback of flood-damaged properties has occurred in the past in Canada (CBC, 2013), though it is not clear that those who chose not to be bought out will have the same opportunity in the future. Regardless, it is clear that there should be support for victims of flooding, and this may take the form of the provision of services and/or financial support. However, the introduction of flood insurance suggests that government relief following flooding disasters may be less focused on homeowners and implies a change in the overall flood risk management landscape.

The findings presented here suggest that there may be some opportunity for flood insurance to manage flood risk, as there is a population of wealthy residents with high-value dwellings in high hazard areas that are going to want insurance protection. The greatest implementation challenge may be the form that flood insurance policies will take—for example, the packaging of flood insurance for these communities, including coverage maximums.

The adverse selection problem is well known in insurance and occurs well-beyond the scope of flooding, but it poses a particularly difficult task due to the predictability and recurrence of floods by geographic area. The highest demand for flood insurance, likely comprised of the people who would prefer the most coverage, have the least accessibility to flood insurance, and elsewhere there is very low demand. These homeowners will have to decide if they are prepared to pay an incredibly high premium for coverage or adopt other flood mitigation strategies (*including moving)*.

In the hypothetical choice experiment, the probability of flood insurance purchase was negatively related to coverage, except for homeowners of high-valued dwellings.

This asymmetry in demand, with an apparent disinterest in low coverage, shows risk-seeking when provided low-levels of coverage and risk-aversion when provided high levels of coverage. This finding is interesting and may be worth investigating in future research, particularly to determine whether this was the effect of framing. Regardless, the results show inconsistencies in risk behaviour – if it was believed the high coverage is valuable, the lower coverage would be as well.

Though there was a proportional value to the insurance premiums, participants were more likely to buy *some* coverage and least likely to buy high amounts of coverage when having a lower-valued dwelling. This would suggest that small policies for some homeowners may be an effective insurance strategy in the Canadian insurance market, despite potentially falling short of paying for the entirety of the average flooded basement cost (Evans & Feltmate, 2019). However, insurers face an interesting dilemma for the provision of coverage to potentially high-cost customers – selling overland flood insurance in some denomination and face potential reputational risk when damages exceed small policy caps, or provide no coverage and face the same risk. A greater risk awareness of flooding may be emerging for the Canadian public, so demand for insurance may increase for some, however the accessibility of such insurance may be low for those who truly need it and demand it.

This thesis provided a detailed examination of two aspects of flooding in Canada. Though the findings of the insurance chapter are largely consistent with past research, notably that demand for flood insurance increases with dwelling value, the geographic pattern of social vulnerability is opposite. The flood hazard areas in Calgary reflect a wealthier, higher-income population that likely prefers the amenities of near-water property. This wealth may enable market solutions for flood management, however such demand for solutions requires that a willing supply side is there to meet it. This research contributes both to the understanding and estimating of social vulnerability from flooding, and consumer approaches to flood insurance. Taking this research and applying it to flood planning and mitigation may help efficiently provide support and enable flood resilient communities in the future.

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