Perceptions toward Coastal Retreat: Evidence of Buyout and Rent back Preferences across the U.S. East Coast

Anna Perry

(Under the Direction of Craig Landry)

Abstract

We use survey data to assess coastal residents' willingness to accept (WTA) a property buyout and willingness to pay (WTP) to rent back their property from the state government after a buyout (obviating financial risk of property loss). Placing property loss risk in the expected utility framework, we implicitly define WTA and WTP as a function of flood experience, risk perception, risk preference, affect (worry), income, wealth, and other factors. We utilize univariate and bivariate probit and Cragg models to analyze the data. Cragg model results indicate risk perceptions, economic outlook, and risk aversion influence the probability to accept a buyout or rent back. WTA/sqft is increasing in house age, income, wealth, and risk tolerance and decreasing in negative economic outlook and risk aversion. WTP/sqft is increasing in income. We present a foundation for structural estimation and explore policy implications.

Index Words: coastal retreat, willingness to accept, willingness to pay, buyouts, rent backs, risk preferences

Perceptions toward Coastal Retreat: Evidence of Buyout and Rent back Preferences across the U.S. East Coast

Anna Perry

BA, University of Virginia, 2017

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirement for the Degree

Master of Science

Athens, Georgia

2022

Perceptions toward Coastal Retreat: Evidence of Buyout and Rent back Preferences across the U.S. East Coast

by

Anna Perry

Major Professor: Craig Landry
Committee: Susana Ferreira
Yukiko Hashida

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
May 2022

Dedication

I dedicate this work to my parents, Theresa and Tom, for their endless love and support.

Acknowledgments

I would like to thank my graduate committee for their encouragement and feedback during the thesis process. Thank you to my thesis advisor, Dr. Craig Landry, for generous and continued support and guidance over the course of the Masters Program and particularly in this endeavor. Thank you to Dr. Susana Ferreira for her ongoing support, mentorship, and advice in my Masters research. Thank you to my final committee member, Dr. Yukiko Hashida, for providing valuable expertise and insights to improve this work. Thank you to Rachel Judd, Grace Anne Ingham, and Elena Krasovskaia for being pillars of support throughout the entire program, and to everyone who took the time to show support leading up to and during the defense–it means everything!

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction & Background

U.S. coastal communities face increased frequency and severity of extreme weather events, such as floods and hurricanes, alongside sea level rise. Neumann et al. (2011) estimate that the mid-level sea-level rise (SLR) scenario of 66.9 cm rise by 2100 would result in optimal abandonment of 8,878 square km (3,428 square miles) of otherwise habitable land along U.S. coastlines. Across the U.S. Gulf and East Coasts, an estimated 22 million people are vulnerable to flooding from storm surge alone (Zachry et al. 2015). Global estimates suggest 88 million to 1.4 billion people may be displaced by sea level rise by 2100, with the range bounded by those who are in areas likely permanently inundated versus all areas in low-elevation coastal regions (Mach and Siders, 2021). Meanwhile, the costs of natural disasters are substantial and increasing: the US National Weather Service estimates flooding causes nearly $8 billion in average damages annually in the United States (Koning et al., 2019).

Adaptation measures–such as levees, buffers, and structural elevation–are no longer adequate protection in many vulnerable regions, necessitating the discussion and facilitation of coastal retreat. Coastal retreat–the process of systematically moving assets and resources inland–is not a new concept, but is met with resistance from established communities and homeowners, and viewed by many as a “last resort” management option. Whereas previous adaptation measures such as flood and hurricane insurance and seawalls were incremental forms of risk mitigation, coastal retreat is a permanent, discrete change in an individual’s housing consumption and the risks they face. A global analysis estimates that 13% of the world’s coastline can pursue beach armoring as a robust and cost-effective adaptation strategy, while 65% of the global coastline will minimize costs from allowing retreat in some capacity (Mach and Siders, 2021). Geographic disparities are present: shoreline armoring will be more cost effective in high-income regions with higher property values, while unmanaged retreat presents itself as the more cost-effective option along rural coastlines and small communities or islands (Mach and Siders, 2021).

Historically, federal, regional, and local governments facilitate coastal retreat through buyout options with varying success, which can be attributed to factors such as attachment to place, trust of facilitators, buyout conditions and timeline as well as the level of buyout offers (Kick et al. 2011; de Vries & Fraser 2012; Dundon & Abkowitz 2021) As of 2019, the National Flood Insurance Program–the most widely used flood risk management program in the US–has borrowed more than $20 billion from the US Treasury to meet claim obligations, indicating it is currently a “high risk” public disaster assistance strategy (Frimpong et al., 2020). Buyout programs can be subject to moral hazard, as the expectation of a government bailout post-disaster can encourage homeowners to take on more risk than they would otherwise. This issue is part of a broader phenomenon of perverse incentives in climate change policy, which can contribute to overdevelopment along vulnerable coastal areas (Burby, 2006). Alternatively, successful implementation of buyout programs can lead to broader social benefits by repurposing resultant open space into recreational land, some of which may provide better natural flood mitigation from future risks.

Optimal allocation of resources and funding toward managed retreat and buyout programs requires a stronger understanding of the motivations and hesitations of coastal homeowners. To better assess the characteristics and factors driving willingness to accept a buyout, we analyze stated preference survey data from coastal homeowners in Worcester County, Maryland and Dare County, North Carolina–two counties along the U.S. East Coast facing threats from sea level rise, hurricanes, and storm surge flooding (Figure 1).

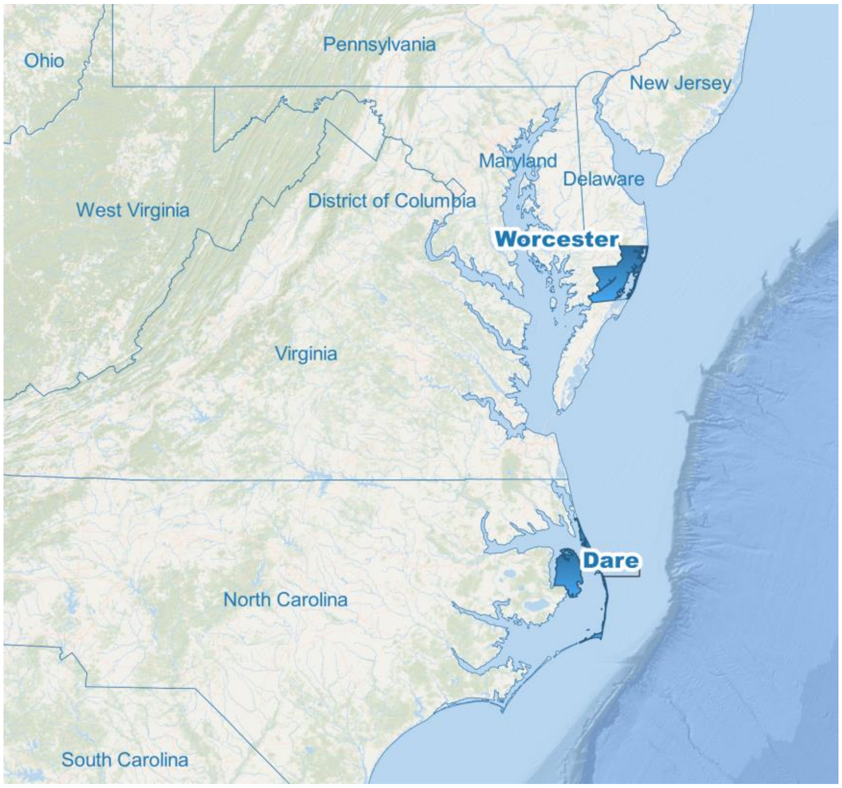


Figure 1. Coastal Housing Survey Counties

Worcester County, Maryland and Dare County, North Carolina are two counties along the East Coast that both a) are vulnerable to climate risks and b) have comprehensive geophysical data available on those underlying risks. Figure 2 shows spatial data from First Street Foundation on the number of properties prone to the 100-year return zone (a 1% annualized flood risk) in 2050. In 2050, more than half of all properties in Worcester and Dare County will be within the 100-year return zone (First Street Foundation, 2021). As of just 2021, nearly 42% of properties at risk in Worcester County, and more than 50% of all properties in Dare County are at risk in the 100-year return zone.

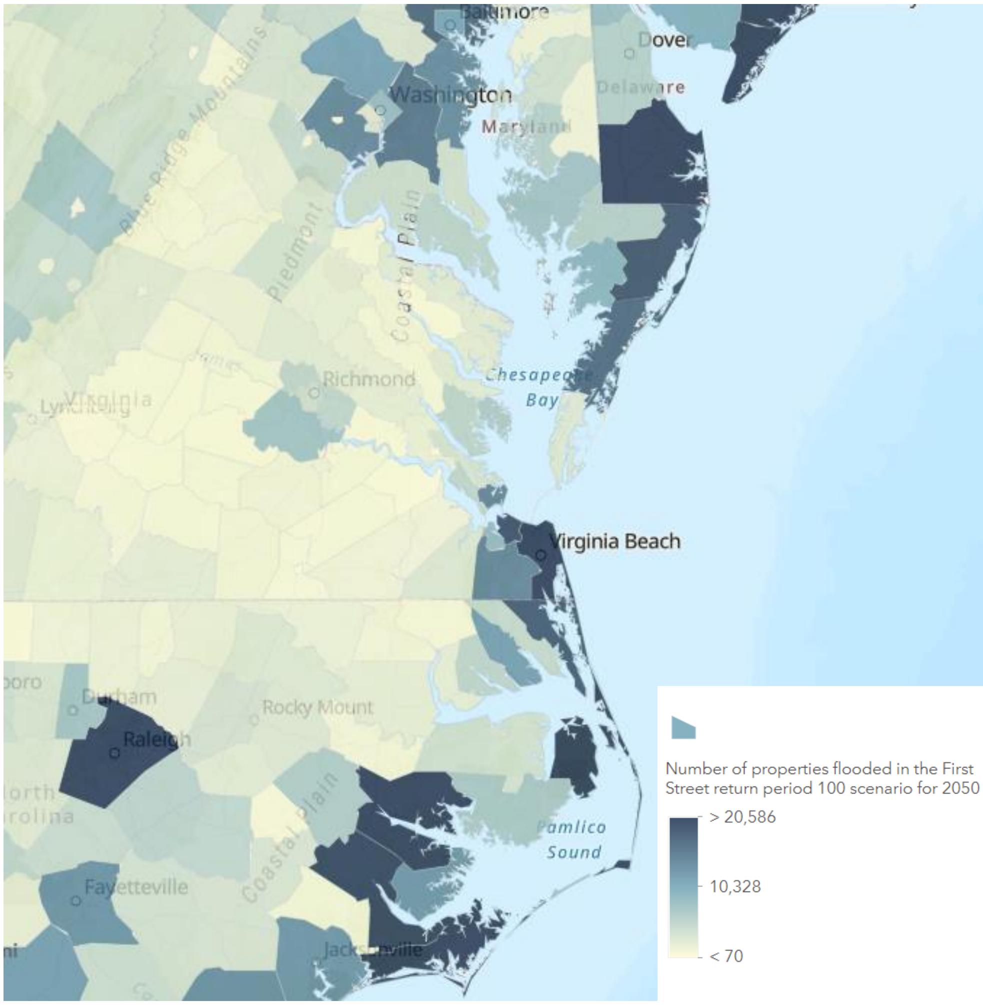


Figure 2. First Street Foundation 2050 Projections: Properties in the 100-year flood zone
Source: (First Street Foundation, 2021)

We anticipate that characteristics such as previous experience with extreme events, income, and risk perception affect both coastal households' willingness to accept (WTA) a buyout, and their minimum WTA. Such characteristics also are likely to influence willingness to pay (WTP) to rent back a property post-buyout. Rent back agreements have been discussed in the design of retreat policy to facilitate coastal adaptation. A buyout followed by a rent back would permit homeowners to inhabit their coastal property while vulnerability remains low but would require them to vacate the premises when a trigger point is reached. Potential trigger points include levels of property damage, environmental change targets, and loss of critical infrastructure support.

We provide theoretical background on the estimated willingness to accept buyouts and willingness to rent back from the government, presented through an expected utility optimization framework under uncertainty. Using a bivariate probit model to account for unobserved heterogeneity in the joint probability outcomes of participating in a buyout and rent back, we find that risk perceptions, risk tolerance, and expectations for the future are significant predictors of the likelihood to participate in a buyout or rent back program alongside socioeconomic factors such as income and wealth. Relative risk aversion and risk tolerance have the highest predictive power in determining whether a homeowner will be more willing to accept a buyout or rent back, while negative economic expectations play a significant role as well. Wealth has a statistically significant–albeit small–predictive power, with wealthier homeowners less likely to participate in rent backs particularly.

In the Cragg hurdle models, the selection stage equations demonstrate that higher negative economic expectations and higher perceived Category 3 hurricane damage increase the likelihood of accepting a buyout. Conditional on the willingness to participate, risk tolerance, wealth, county (Dare), income, and house age all increase the WTA in $/square foot, while negative economic expectations and risk aversion decrease the WTA in $/square foot. In the selection stage for rent backs, wealth and county (Dare) are negative predictors in likelihood to rent back, while risk aversion, negative economic expectations, and perceived Category 3 hurricane damage are positive predictors. Income is the only significant factor observed in the Tier 2 equation, with increased income associated with higher WTP in $/square foot. The average expected values conditional on willingness to participate in buyouts and rent backs suggest that the average coastal homeowner requires a 37% premium over the assessed value of their home in a buyout, and requires a 62% discount over the fair value rent of their home following a buyout.

The rest of the paper is laid out as follows: Chapter 2 details existing literature on interdisciplinary perspectives toward managed retreat and coastal adaptation, risk perceptions toward climate change and coastal vulnerability, and previous studies on factors motivating perspectives toward voluntary buyout programs. Chapter 3 presents theoretical background on the expected utility framework under uncertainty, and associated willingness to accept and willingness to pay measures for coastal housing. Chapter 4 overviews the coastal housing survey data and related variables used in the analysis. Chapter 5 describes the methods used to estimate willingness to accept a buyout and willingness to pay to rent back, providing background on the single probit, bivariate probit, and hurdle models for our limited dependent variables. Chapter 6 presents the results of our analysis, including marginal effects, and Chapter 7 provides a discussion on the observed results and their implications. Finally, Chapter 8 concludes and outlines future research needed in the economics of coastal retreat.

Chapter 2: Literature

With increasing urgency to prepare and implement adaptation and relocation strategies in parts of the world significantly affected by climate change–especially coastal environments–literature in the social and behavioral sciences field has turned a focus toward threatened inhabitants' risk perceptions, attitudes, and behaviors relating to extreme weather events and their consequences. A 2016 study on a sample of 1,000 US adults found that 57% indicate that weather or climate-related issues would have a moderate to strong influence on whether they relocate in the next ten years (Kim et al., 2021). The two positively related significant predictors in whether a respondent is more likely to move due to climate issues include political affiliation (as Democrat) and higher levels of education (Kim et al., 2021).

2.1 Preferences toward Coastal Adaptation

Coastal climate adaptation is generally categorized into three approaches: retreat, protection, and management/accommodation (Gibbs, 2016). Many coastal regions have coastal adaptation strategies that involve some combination of approaches, but coastal retreat is increasingly seen as a more viable and necessary option to mitigate risk as the severity and frequency of coastal flooding and weather events increase (Gibbs, 2016). Coastal retreat involves physically relocating structures and assets away from areas prone to natural disaster risk and increasingly seasonal flooding inundation, and can be implemented as a systematic, proactive strategy by communities or as a disaster response effort following an extreme weather event to reduce exposure and risk to future events (Gibbs, 2016). Protection approaches, referring to more conventional engineering solutions such as seawalls and levees–and increasingly natural engineering solutions such as wetland construction or restoration–are historically a sufficient and cost-effective approach toward coastal adaptation (Gibbs, 2016). The management approach focuses on the resiliency of existing infrastructure by elevating structures or adopting regulations for new construction for example, which can often leave more of the costs and benefits of the adaptation strategy to the property owner (Gibbs, 2016). Gibbs (2016) assesses political risk as a major factor affecting the successful implementation of coastal adaptation strategies, and identifies the misalignment of perceived and objective risk at the individual and community-level to be a major source of political risk that ultimately sidelines or delays otherwise effective adaptation approaches. Hino et al. (2017) define managed retreat more specifically by the characteristics of intentionality and administration as "the strategic relocation of structures or abandonment of land to manage natural hazard risk", which is implicitly defined in any government buyout or voluntary acquisition program. In evaluating 27 global case studies of managed retreat involving nearly 1.3 million people, Hino et al. (2017) find that the major barriers in managed retreat implementation are attachment to place (or psychological difficulties), legal challenges from the 'levee effect' feedback loop[1], and a distinctly longer time horizon required for benefits to accrue relative to other adaptation strategies.

Kraan et al. (2021) provide the first study evaluating equity issues in managed retreat, specifically voluntary buyout programs, considering potential social justice issues affecting the communities where the buyouts occur, individuals and households participating, residents choosing to stay, and the inland or destination communities. The study highlights policy options for each stakeholder group that could promote equity in buyout programs. At the community-level where the buyouts occur, Kraan et al. (2021) suggest using higher-level government funding to invest in local training and administration of the program in order to promote trust and expand access to participants. Increasing active engagement and support during the planning stages, expediting the buyout process, and expanding compensation for

[1] This phenomenon describes an observed consequence of moral hazard from government spending, whereby development tends to increase behind an investment in structural protection (such as a levee), which in turn provides a greater motivation to continue rebuilding the structural protection (Hino et al., 2017).

buyout-associated (indirect) costs are policy options that could both psychologically and financially benefit potential participants (Kraan et al., 2021). For those residents that choose to stay, the authors note the importance of adequately planning and budgeting for management of the buyout sites in order to promote green and public open spaces rather than potentially lowering the value of nearby properties.

Bohnert and Doberstein (2021) conduct a case-study literature review to investigate the extent to which buyouts are accepted at the community-level using the concept of ‘social license’ and highlight four elements that could improve social acceptability of buyout programs: context-specific design, transparency and clear communication and facilitation with the public, clear rationale for decision-making and eligibility criteria, and specific and tangible co-benefits for the community.

McGuire and Goodman (2020) introduce a value-capture-and-transfer framework for coastal resiliency with the goal of providing a risk-based cost-oriented approach to policy making and land use in vulnerable coastal regions. Historically, coastal areas were viewed as revenue centers with desirable property for which people are willing to pay premiums with relatively unchanging environmental conditions that permitted unfettered coastal development. The proposed framework seeks to incorporate the hazard-risk of coastal areas into more dynamic cost analysis and decision-making by applying a least regrets approach to coastal management and planning (McGuire and Goodman, 2020). In the least regrets approach, vulnerable coastal areas are identified as active hazards or cost centers with a need for maintenance through cost mitigation, specifically by selecting, purchasing and reallocating the coastal hazard value inland toward economically ripe areas (McGuire and Goodman, 2020).

Koerth et al. (2017) provide a systematic review of empirical studies of household-level coastal adaptation measures and preferences, and find that adaptation behavior depends on individual characteristics such as socioeconomic and psychological attributes, personal experiences, and perception of accountability. The review also indicated that non personal characteristics have not been explored as thoroughly in explaining adaptation behavior, and only a handful of studies use behavioral economics models and qualitative research methods to investigate adaptation behavior (Koerth et al., 2017).

Kousky (2014) explores the “wicked problem” of adaptation to sea level rise along coasts, identifying managed retreat as a strategy in the United States with a multipronged approach that may not be preferable everywhere: A) limiting new investment in high risk areas B) allowing property abandonment as inundation takes place and C) optimizing retreat after natural disasters. While rebuilding in place with adaptation measures has been the dominant strategy post coastal disaster, managed retreat challenges this status quo with a focus on management of human expectations and planning, rather than the coastal resources themselves (Kousky, 2014).

Dachary-Bernard et al. (2019) conducted a choice experiment in Southern France to assess coastal and inland residents’ preferences toward various relocation policy measures according to several attributes. Using a latent class logit model, the authors reveal heterogeneous preferences toward relocation based on two categories of risk perception: 1) “unaware individualist”, those generally opposed to relocation and 2) “informed solidarity”, those generally in favor of the policy (Dachary-Bernard et al., 2019). In the results of the stated preference experiment, Class 1 residents indicated a willingness to pay of 76.5 euros/households/year to implement an adaptation policy in a 15-30 year time horizon, while Class 2 residents preferred immediate implementation of adaptation. Some Class 2 residents indicated a need to be compensated as much as 172.4 euros/household/year to postpone implementation to a 30-45 year time horizon. Dachary-Bernard et al. (2019) contribute to a growing consensus in existing literature by finding that individual perception of risk, rather than geographical distance from the coast explains preferences relating to coastal adaptation.

2.2 Risk Perceptions and Attitudinal Factors

A smaller, emerging body of literature focuses on the connection between risk perceptions and attitudes toward risk with preferences and behavior toward coastal adaptation strategies, including coastal retreat. Lemee et al. (2019) studies the relationship between attitudinal factors such as place identity, perceived self-efficacy, anxiety-state and coastal flooding risk perception on coastal inhabitants' tendencies toward active and passive coping willingness. Active coping strategies are characterized by focus and action toward risk reduction, while passive coping strategies are characterized by focus on placation and reduction of internal turmoil, such as anxiety and fear (Lemee et al., 2019). Results supported a direct, positive relationship between respondent's anxiety state and their sense of place identity–or attachment to place–along with passive willingness to cope with coastal risks.

Along the Western coast of France, Lemee et al. (2021) is one of the first studies to measure a direct relationship between coastal risk perception and willingness to cope with the risk of coastal erosion and coastal flooding. Accounting for the possible impact of previous risk experience and personal exposure to risks on the choice of coping strategies, the authors used a Bayesian linear regression and Bayesian t-tests to evaluate four hypotheses relating to risk perception and active and passive willingness to cope for both coastal flooding and coastal erosion (Lemee et al., 2021). Results indicate that coastal erosion is perceived as a greater risk than coastal flooding, and participants with previous experience of coastal flooding are more likely to be willing to adapt their place of residence, 'have established their own prevention plan, and 'follow their own prevention plan' than participants without any risk experience (Lemee et al., 2021).

Using a dataset involving an extreme flooding event in Colorado, Hennighausen & Suter (2020) separate inundated properties from "near misses" in the 100-year floodplain to study the relationship between flood impacts and subsequent flood risk perceptions. Using a triple-difference hedonic framework, they show that flooded properties in the floodplain experienced a decrease in price after the flood, while near misses saw a relative price increase. Results indicate near misses are perceived as relatively less risky properties, suggesting the influence of availability heuristic or Bayesian learning (Hennighausen & Suter, 2020).

2.3 Voluntary Buyout Programs

Government buyouts are often a cost-effective strategy to address solvency issues for increasingly risky and expensive participating homes. In the case of NFIP, buyouts are particularly attractive because many participating homeowners have subsidized policies in which they do not pay the full risk-based premium (Frimpong et al., 2019).

In the last few decades, stated preference and revealed preference studies identified demographic, geographical, psychological, and social characteristics motivating willingness to participate in a voluntary acquisition program or more generally a willingness to relocate from a disaster prone zone. In a 2012-2013 survey on Eastern North Carolina residents' preferences toward property acquisition programs, homeowners indicated their willingness to accept an offer for a government buyout (Robinson et al., 2018). Using logistic regression analysis, Robinson et al. (2018) found that location in a floodplain zone, shorter expected future residence in the home, natural disaster experience, being white, and feeling less in control are all variables associated with an increased probability of accepting a buyout.

Mach et al. (2019) analyze a dataset of more than 40,000 FEMA-funded voluntary buyouts of flood-prone properties across the United States in order to identify spatial and temporal trends. The number of buyouts completed in 1148 counties range from 1 to 2190, with nine counties in Texas, Missouri, Alabama, New Jersey, and North Carolina that each bought out more than 500 properties (Mach et al., 2019). From 1989 to 2017, the six states that have administered the most buyouts are also among the top ten states in terms of cumulative flood-related property damage. States with relatively lower buyout rates include the top three states for cumulative flood damage: Florida, Louisiana, and Mississippi (Mach et al., 2019). Over time, the number of properties bought out has declined while the volume in FEMA grants to support the programs has remained steady, indicating the cost of executing a single buyout–whether it be the price offered or the grant administration– has trended upward (Mach et al., 2019). They hypothesize that retreat will occur more in rural, low-income areas, that buyouts will occur in counties with greater local government capacity, and that buyouts will tend to occur in neighborhoods with greater socioeconomic vulnerability (Mach et al., 2019). Results confirmed the latter two expectations, and the authors found only partial support that retreat occurs in low-income, rural areas. At the county-level, buyouts tend to occur in poorer, rural locations with relatively worse education and greater racial diversity (Mach et al., 2019).

Bukvic et al. (2015) surveyed New York and New Jersey residents severely affected by Hurricane Sandy in 2012 and found that age, disaster exposure, recovery-related stress, financial concerns, and concern about increased crime and future flooding all increased willingness to consider relocation. Following a liquid gas explosion, Kirschenbaum (1996) surveyed 100 households subject to disaster exposure and determined that income, perceived psychological damage to children, feeling of helplessness, and households in denser neighborhoods all increased the probability of willingness to move away. Reeser (2016) implemented a contingent valuation study of homeowners to examine 1) willingness to sign up for a pre-flood buyout program and 2) willingness to pay for the pre-flood buyout agreement. In the agreement facing surveyed households, the owner would be paid the value of their home pre-flood and must relocate following a flood event that damages more than 50% of the home (Reeser, 2016). Results indicated that the significant drivers of homeowners (in the 100-year floodplain) willingness to participate in the buyout program are longer residential tenure, higher self-reported risk, higher income, greater perceived environmental benefits of buyout, and a previous flood claim of at least $25,000 (Reeser, 2016). The same factors significantly affect willingness to pay for the pre-flood agreement, save residential tenure length and in addition to greater expectation that neighbors would also participate in the program (Reeser, 2016).

More recent literature examines not only which attributes contribute to the decision to accept a buyout, but the price levels at which coastal homeowners are willing to do so. Frimpong et al. (2019) studied stated preferences for buyouts of eastern North Carolina single-family households, hypothesizing that homeowners more likely to be willing to accept a buyout a) are higher-income b) live in the floodplain c) are closer to the coastline d) are offered a buyout post-damage event and e) have lived on the coast for a shorter amount of time (Frimpong et al., 2019). Frimpong et al. (2020) assessed coastal US residential homeowners' stated preferences for buyout and elevation contracts, estimating willingness to accept values based on attributes including property pricing, ownership retention of the lot, transaction timing, and contract options. The study is able to quantify tradeoffs among a variety of subsidized risk mitigation options and provides a benefit-cost analysis based on a buyout simulation (Frimpong et al., 2020). Survey results indicated that homeowners prefer larger payments, a longer timeline to vacate, and a shorter timeline between contract approval and payment, but do not appear to have strong preference for ownership retention of the lot (Frimpong et al., 2020).

Several revealed preference studies in the past ten years have assessed homeowner, psychological and geographic characteristics that increase the probability of participating in a voluntary acquisition program following natural disasters. Using homeowner data from eight repetitive flooding sites in Louisiana, Georgia, North Carolina, and California, Kick et al. (2011) found that greater fear of flooding, greater sense of home and community, requirement of a 25% FEMA match, unfavorable perception of local officials and favorable perception of the condition of the property all reduced probability of acquisition. Fraser, Young et al. (2011) examined the same data and identified the 25% FEMA match, unfavorable perception of local officials, and greater sense of home and community as significant regressors reducing the probability of acquisition, along with lower income and having children. De Vries and Fraser (2012), however, found that lower income increased the probability of a buyout, along with trust in the buyout administration, the presence of alternative choices in the buyout, and a perceived higher importance of family members. Most recently, Seong et al. (2021) analyzed data from Lumberton County, North Carolina following Hurricane Matthew in 2016 and determined that higher-value properties, higher flood and inundation risks, and lower social vulnerability (lower racial diversity) all increased probabilities of accepting a buyout offer. Through an empirical analysis of buyouts funded by FEMA's Hazard Mitigation Grant Program from 1990-2016, Miao and Davlasheridze (2022) find that higher property tax revenues and lower dependence on property taxes in counties leads to increased post flood buyouts. Conversely, a more saturated local flood insurance market and increased levee protection are associated with lower rates of buyouts in flood-prone properties, reinforcing evidence of moral hazard in coastal adaptation strategy, with some flood mitigation and adaptation strategies possibly working against retreat (Miao and Davalsheridze, 2022).

Chapter 3: Theory

Expected utility theory (EUT) proposes that individual agents–or consumers–choose among uncertain options by comparing the expected utility values of their outcomes (Mongin, 1997). The expected utility value can be thought of as the utility gained from an outcome occurring multiplied by the perceived probability of that outcome occurring (Mongin, 1997).

In the case of this application of expected utility theory, the probability of a coastal weather event and the anticipated damages are the two key relevant variables, whereby coastal homeowners weigh the costs of living in a risky zone by their perceived probability of a negative event occurring at some time interval, and their perceived damages (Koning et al., 2019). These two variables can differ among respondents based on the gap between perceived and objective risk and past experience of floods, hurricanes, and subsequent property loss. Stated preferences toward willingness to accept a home buyout and move inland and willingness to pay to continue living on the coast without assuming risk of natural disaster can be framed in terms of an individual’s expected utility function. In this framework, utility is defined over housing consumption, which consists of attributes a, environmental amenities b, and a numeraire commodity x: u(x,a,b). The hedonic rental price of coastal property is given by R(a,b,p), where p is the probability of loss due to coastal risk.

Measuring utility over the time horizon of expected housing consumption gives the following expression for expected utility:

EU = $p \times u((\sum_{t=1}^{T} \delta t\,(yt - R(a,b,p) - l), a_1, b_1) \; + \; (1-p) \times \; u((\sum_{t=1}^{T} \delta t\,(yt - R(a,b,p)), a_2, b_2)$

where $\sum_{t=1}^{T} \delta t\ (yt - R(a,b,p))$ is expected numeraire consumption while inhabiting coastal property, δt is the discount factor, *l* is the net expected loss occurring in some periods t_1 *to* t_k due to damage and repair costs, and a & b may alter in the loss state (attribute improvements due to renovation or loss of amenities due to climate change).

In this framework, we can define willingness to accept a buyout by the following equation:

$$EU\ =\ u((\sum_{t=1}^{T} \delta t\ (yt)\ +\ WTA_{bo}, a = 0, b = 0))$$

Where consumption of current housing ceased after accepting the buyout. Willingness to pay for a rent back, on the other hand, can be implicitly defined as:

$$EU\ =\ u((\sum_{t=1}^{T} \delta t\ (yt\ -\ WTP_{rb}), a, b))$$

In this case, consumption of current housing continues in perpetuity (albeit at the discretion of the new property owner), and the homeowner pays some fixed amount lower than or equal to the utility gained from being absolved of liability for future uncertain damages. The stated preferences for willingness to accept buyouts and willingness to pay to rent back reveals from a limited perspective how each coastal homeowner would choose to maximize their expected utility (while minimizing potential risks and damages). Figure 4 provides a visual representation of the unique latent utility functions of coastal homeowners, for which we can only observe whether an individual's expected utility function crosses the x-axis at some price level for buyouts and rent backs.

Detailed further in the methods section, we estimate expected utility through a proxy unobserved variable of utility y*, where y* > 0 at some level if there is a price level at which a homeowner is willing to accept a buyout or rent back, and y* < 0 for all price levels if they are not, visually represented in Figure 3.

Figure 3a and 3b demonstrate how a coastal homeowner's expected utility function can be uniquely defined by characteristics such as risk perceptions, risk preferences, and expectations.

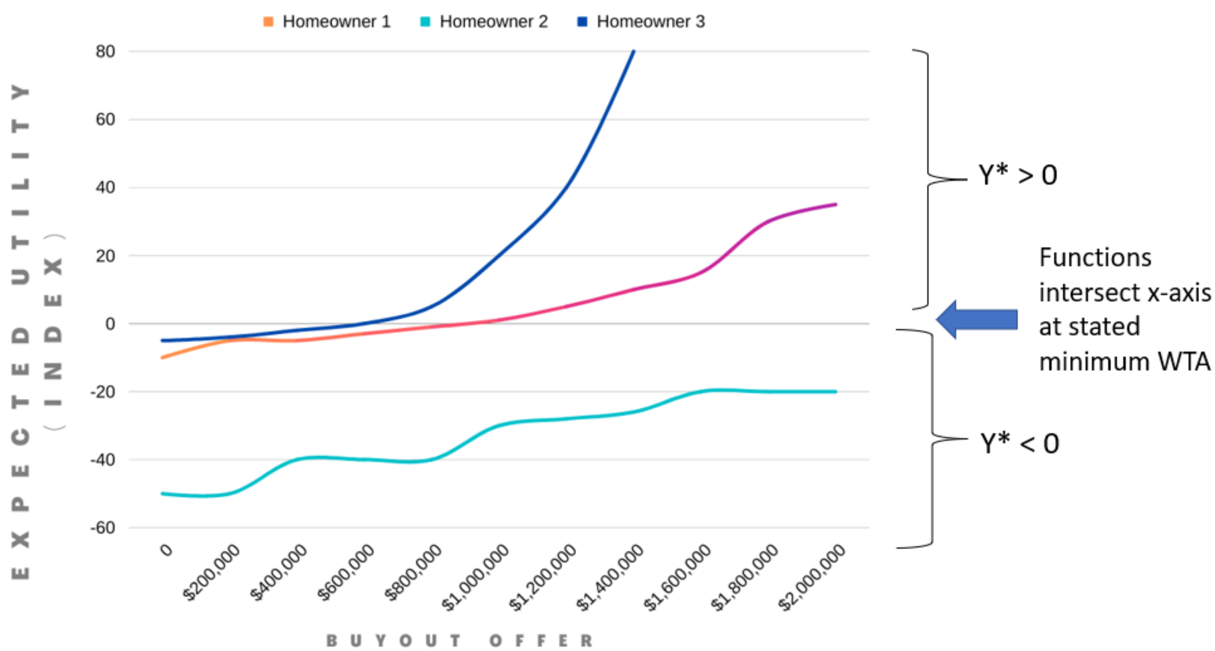


Figure 3a. Representation of Coastal Homeowner Utility Functions for Buyout Offers

Figure 3b. Representation of Coastal Homeowner Utility Functions for Rent back Offers

Note: Assume here each homeowner has the same assessed property value and faces the same fair market rent value. Uniqueness of utility functions are therefore determined by individual factors, such as risk tolerance, risk perceptions, attachment to place, or personal beliefs.

Chapter 4: Survey & Data

The dataset used in this analysis originated from the Coastal Housing Market Survey, an NSF-funded mail survey distributed to homeowners in two coastal counties along the U.S. East Coast. The sample (n=637) includes 367 respondents from Dare County, North Carolina and 270 respondents from Worcester County, Maryland. The surveys were collected in waves in June and July of 2020 and include typical demographic and socioeconomic characteristics, housing and insurance information, and subjective risk metrics identified through a series of framed probability questions about coastal scenarios and Likert-scale questions to identify coastal perceptions.

4.1 Descriptive Statistics

Tables 1 and 2 provide a summary of descriptive statistics on the survey respondents by county. The sample of survey respondents skews toward being whiter, older, and majority male while reporting relatively high levels of wealth and education. The average reported household size is 2.6 with an annual reported income of $181,500. More than 90% of respondents identify as white, followed by less than 2% Hispanic, 1.6% Native American, 1.6% Asian and 1.1% Black. More than two-thirds of the respondents are male and the average age is 56. Nearly 70% of respondents have a bachelor’s degree or higher, with 32% reporting a graduate-level education.

Table 1. Dare County Respondent Demographic Descriptive Statistics

	N	Mean	Std. Dev.	Min	Max
Age	362	55.8	13.5	29	91
Income ($1,000)	347	176.7	110.8	30	392
Wealth	364	12,006	15,801	428.6	142,460
Household size (persons)	364	2.57	1.33	0	10
Square footage	367	1,970	846	600	5,753
Coastal Tenure (years)	359	11.7	12.1	1	30
House Age (years)	367	29.6	16.6	1	121
Flood Damage ($)	367	861	4,433	0	54,000

Table 2. Worcester County Respondent Demographic Descriptive Statistics

	N	Mean	Std. Dev.	Min	Max
Age	267	56.6	13.8	24	80
Income ($1,000)	249	188.30	129	30	452
Wealth	261	9,628	10,421	59	69,000
Household size (persons)	266	2.6	1.3	0	10
Square footage	263	1,896	843	748	5,055
Coastal Tenure (years)	269	9.7	11.4	1	30
House Age (years)	264	29.9	15.2	0	91
Flood Damage ($)	270	472.2	4,960.5	0	75,000

4.2 Coastal Attitudes and Risk Perceptions

We conduct principal components analysis (PCA) for several Likert-scale questions to attain broader defining variables (factors) appropriate for use in analysis. The Likert-scale questions include economic and environmental statements on the current state and future of the coast, as well as tendencies toward worry (see Table 3 and Figure 4).

Table 3. Coastal Perception and Expectation Questions

Question	**Statement**
Please indicate your agreement or disagreement with the following statements about the coast:	The coastline in my city is overdeveloped
	The price of coastal housing is too high
	The price of coastal insurance is too high
	The coast needs better roads, bridges, utilities, and ferries
	Building regulations stifle the coastal economy
	Elevated housing provides ample protection from flood risks
	The coast is changing in ways that threaten current development
	Local government policies have helped alleviate flood and erosion risk
Please indicate your agreement or disagreement with the following expectations for the coast for the next 10-20 years:	Insurance prices will increase
	Housing prices will increase
	Property taxes will increase
	Coastal erosion will get worse
	Beach nourishment (adding sand to the beach) will preserve beaches
	Coastal storms will get worse
	Coastal armoring (sea walls and rock piles) will protect property from storms and flooding
	Parts of the coast will need to embrace retreat, moving houses and roads

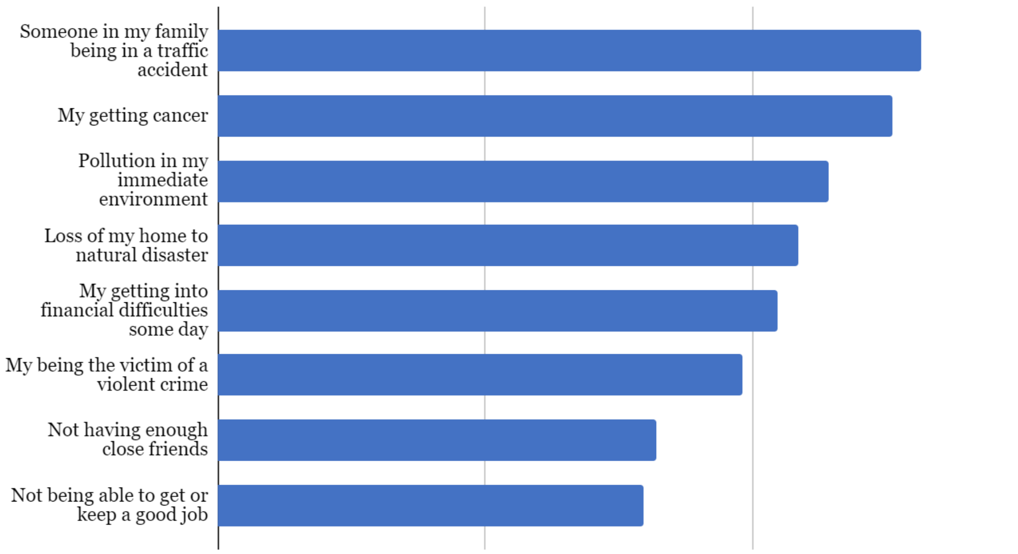


Figure 4. Relative Worries on the Likert Scale

Figure 4 details respondents' relative worries about certain persistent or acute negative life events when asked how much they worry or fear the listed events. Average responses to the statements indicate a car accident, cancer, and local pollution rank highest for coastal residents' worry, with loss of home to a natural disaster following in fourth.

PCA allows us to reduce the dimensionality of the observed data by combining survey responses into broader factors–or components–that ease the interpretation of the data while minimizing the loss of information. For each set of statements on the current state of the coast, the future expectations for the coast, and fear toward events, we construct new uncorrelated variables that retain the maximum amount of variation in the data, thereby preserving the necessary information for analysis.

We retain components with eigenvalues greater than one to preserve the maximum amount of heterogeneity (dimensionality) in the responses to the Likert-scale questions in Table 3. We can then characterize the components by patterns and correlations among responses. For example, for statements concerning worry, we find some respondents tend to agree with most statements, signaling potentially an 'anxious' type, while others express worry only for events that may be perceived as more in their control, such as keeping a job and having close friends. Similarly, the statements regarding the future of the coast could be characterized as 1) negative economic outlook 2) negative environmental outlook and 3) general positive outlook using adaptation strategies. The statements about the current state of the coast could be characterized as 1) pessimistic view of the coastal economy 2) optimistic view on existing coastal adaptation strategies and 3) anti-development stance on the coast. We use the negative economic expectation component as a variable in the analysis, which was characterized by high positive correlations between the statements that housing prices, insurance prices, and property taxes would all increase in the next 10-20 years along the coast.

Table 4. Subjective & Risk Perception Metrics in Dare and Worcester County.

Variable	**Mean**	**Min**	**Max**
Dare County			
Natural Disaster Worry (Scale 1-4, least to most)	2.2	1	4
Coastal Economic Outlook (Index, high is cynical)	0.16	-4.88	3.52
Relative Risk Aversion (Index, > 0 is risk loving)	0.16	-1	1.42
Perceived Category 3 Hurricane Damage ($ loss from direct hit)	$64,471	$0	$545,360
Perceived Category 3 Hurricane Probability (%)	.42	0	1
Worcester County			
Natural Disaster Worry (Scale 1-4, least to most)	2.1	1	4
Coastal Economic Outlook (Index, high is cynical)	-0.22	-6.07	3.52
Relative Risk Aversion (Index, > 0 is risk loving)	0.31	-1.01	1.84
Perceived Category 3 Hurricane Damage ($ loss from direct hit)	$59,654	$0	$724,455
Perceived Category 3 Hurricane Probability (%)	.23	0	1

Table 4 provides descriptive statistics on respondents' subjective risk perceptions and objective risk, revealing coastal homeowners tend to significantly overestimate the likelihood of a hurricane event, as well as the property damage expected from a hurricane or flood event. For example, the average annual

Category 3 Hurricane probability in the two counties is 4%, well below the average perceived likelihood of 42% and 23% in Dare and Worcester County, respectively.

4.3 Analysis Variables

Table 5 provides an overview and definition of key variables taken or constructed from the survey dataset to use in analysis. All price and income variables are adjusted to 2020 dollars, normalized with a CPI base of Worcester County, MD. The two outcome variables of interest–willingness to accept a buyout and willingness to pay to rent back– are calculated using stated preference survey responses and last sold housing price data and are normalized per-square-foot of home. The buyout levels were presented as discrete ranges of percent in assessed home value, from 5% to more than 200%, while the rent back levels were presented as discrete ranges of rent in dollars per month, from less than $200 to more than $5,000. For example, a Worcester County homeowner with a 2000 square foot house last sold at $200,000 in 2020 who reports a willingness to accept a buyout at 125-149% of assessed value would be coded as: ($200,000*1.37)/2000 = $137, or willing to accept a home buyout worth $137 per square foot. A respondent who indicates “I would not accept any amount of money for a buyout” is coded as a 0 response. On the rent back question, respondents indicate a monthly range they would be willing to pay as rent following a buyout, from which the midpoint of the range is taken and normalized by housing square footage. Those respondents who indicate “I would not be willing to rent back my house” are coded as a 0 response.

Table 5. Key Analysis Variables & Description

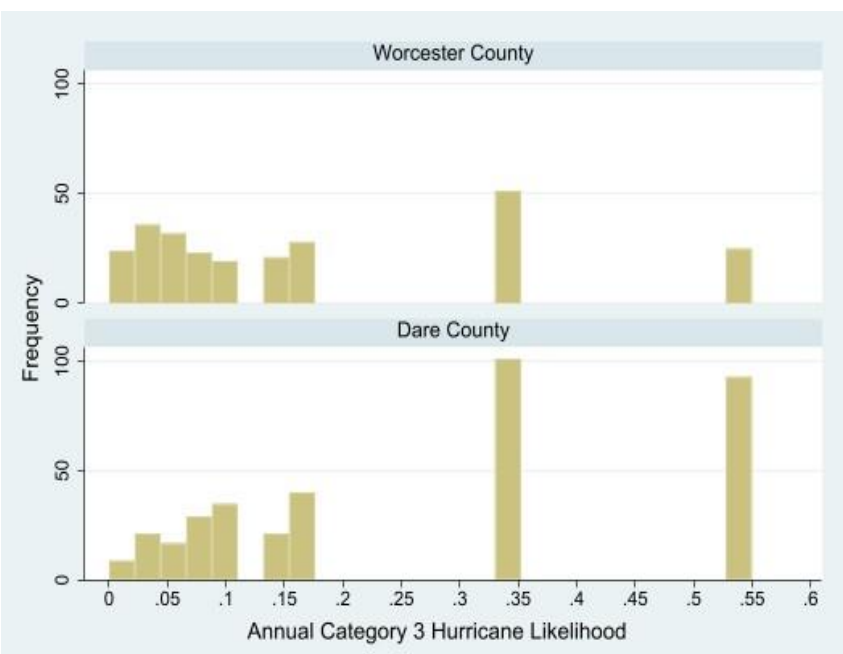
Variable	Type	Description
WTA in $/square foot	Continuous	Willingness to accept buyout per square foot
WTP in $/square foot	Continuous	Willingness to renback after buyout per square foot
Square ft.	Continuous	Household square footage
House age	Continuous	Difference between 2020 and year house built
Category 3 damage	Continuous	Perceived property damage in dollars from Category 3 hurricane impact
Category 3 probability	Continuous	Perceived annual likelihood of Category 3 hurricane
Flood severity experience	Continuous	Reported previous damage in $ from a flood event
CRRA	Discrete	Coefficient of relative risk aversion
General Worry	Continuous	Tendency to worry about/fear negative events occuring
Income	Discrete	Self-reported annual household income
Wealth	Continuous	Estimated total assets in $
Coastal Tenure	Continuous	Reported number of years living on the coast
Dare	Indicator	County of Residence (Dare vs. Worcester)

We use several self-reported demographic variables, such as income, county, and coastal tenure, directly from survey responses. As described above, we construct the general worry variable using PCA of the Likert scale responses to capture psychological tendencies and perceptions. Other key variables constructed indirectly using survey responses include the coefficient of relative risk aversion (CRRA) and wealth. Wealth–distinct from the income variable–reflects an approximation of a respondent's aggregate assets based on a survey question regarding the effect of a 100% property loss on their total wealth.

The coefficient of relative risk aversion for each respondent is estimated using an incentive compatible instrument from the survey, in which respondents were initially offered $10 to return a completed survey and later in the survey were offered the option to forego the $10 and instead participate in lottery options. The survey offered four alternative lottery options contingent on the occurrence of future weather events (naturally stochastic outcomes) with the historical chance of the occurrence presented. For example, the most extreme lottery option offered in place of the $10 with certainty: a) receive $450 if July high temperature = 89 degrees F (2.5% historical chance) b) receive $0 if July high temperature ≠89 degrees F (97.5% historical chance). Respondents' preferred choice is then transformed to a discrete index to measure relative risk aversion.

Figure 5 presents a county-level distribution of homeowner responses on the annual likelihood that a Category 3 Hurricane would impact their property, showing a significant cluster in both counties below 20% chance, with a jump to a 33% chance followed by a significant number of responses at more than 50%. This wide range underscores the potential importance of subjective risk perception in decision-making, including willingness to accept a buyout.

Figure 5. Respondent Perceptions toward Hurricane Risk



Chapter 5: Methods

We use a series of limited dependent variable models to estimate willingness to accept a coastal home buyout and willingness to rent back from the government. With probit and Cragg hurdle models, we assess respondents' expected utility from coastal residency under supply uncertainty. In the single and bivariate probit models, the outcome variables are measured as 1) willingness to accept a buyout and move inland (coastal retreat) and 2) willingness to rent back (a willingness to pay measure) from the government to eliminate any individual asset risk.

To the best of our knowledge, this is the first stated preference survey specifically assessing both willingness to participate in rent backs and rent back price sensitivity alongside buyouts. Given the body of literature on preferences toward coastal retreat and specifically preferences toward buyout programs, we hypothesize certain demographic and risk perception variables will be significant indicators in a homeowner's likelihood to accept a buyout and/or rent back to the government.

Expected Factors Increasing Likelihood of WTA Buyout:

- Higher income and wealth
- Shorter coastal tenure
- Older house
- Past flood damage experience
- Lower risk tolerance
- Higher relative risk perceptions

While individual risk perceptions and risk aversion may affect the willingness to rent back to the government in the same ways as a buyout, other demographic characteristics may have an opposing influence. For example, wealthier individuals may be more likely to accept a buyout because the costs of mobility and transition are not as burdensome, but less likely to accept a buyout and rent back to the government due to the loss of status as a homeowner.

Expected Factors Increasing Likelihood of WTP Rent back:

- Lower income and wealth
- Longer coastal tenure
- Older house
- Past flood damage experience
- Lower risk tolerance
- Higher relative risk perceptions

While many studies have used revealed preference methods to estimate probit models ex-post on the decision to participate in a buyout, fewer studies have estimated average willingness to accept and willingness to pay estimates and price sensitivity in these decisions. This two-pronged analysis helps to characterize the factors influencing an individual's likelihood to take a relatively lower or higher buyout offer, and similarly their likelihood to be willing to pay a relatively lower or higher rent for their current property.

5.1 Probit Model

In the probit model, we are interested in binary dependent variables in which the outcome can take on a value of either 0 or 1. In this case, we have stated preference survey responses from coastal homeowners indicating they are either willing to accept a buyout at some price (y=1) or they are unsure or not willing to accept a buyout at any price (y=0). Rent backs follow the same format; coastal homeowners are either willing to rent back their home at some cost per month (y=1), or they are unsure or unwilling to rent back (y=0). The probit model uses a nonlinear function *G* to estimate the likelihood a response takes on a value of 1. In the probit model, *G* represents the standard normal cumulative distribution function, ensuring all estimated values are strictly between 0 and 1 (Wooldridge, 2012):

$$[1.1]\ G(z) = \Phi(z) = \int_{-\infty}^{z} \phi(v)dv\ ;\ where\ \phi(z) = (2\pi)^{-1/2} exp(-z^2/2)$$

The probit model is representative of a latent variable model, in which:

$$[1.2]\ y* = \beta_0 + x\beta + e, y = 1[y* > 0]$$

Here, y* represents an unobserved (latent) variable of interest- in our case, a coastal homeowner's expected utility maximization problem from a buyout or rent back scenario. If the coastal homeowner's expected utility from accepting a buyout is positive (y* > 0), the indicator function 1[.] will take on an observed value of one. If the expected utility from accepting a buyout is negative (y* ≤ 0), the indicator function will take on an observed value of zero.

In equation 1.2, *e* represents the unobserved error, which is assumed to have the standard normal distribution (symmetrically distributed around zero) in the probit model (Wooldridge, 2012). Using the underlying theory of the latent variable model, we can estimate a response probability for y* (the likelihood that a homeowner will accept a buyout or rent back given a set of explanatory variables *X* (Wooldridge, 2012):

$$[1.3]\ P(y = 1|\ x) = P(y* > 0|x) = P[e > -(\beta_0 + x\beta)|x] = 1 - G[-(\beta_0 + x\beta)|x] = G(\beta_0 + x\beta)$$

From 1.3, we can identify estimates of our explanatory variables' effect on the probability of observing the response y=1. Because the effects of the vector X on the binary response are nonlinear in nature, the beta coefficients cannot be interpreted plainly as in OLS or multiple linear regression. We must calculate the partial (or marginal) effects of the explanatory variables on the likelihood that an individual may buyout or rent back by taking the partial derivative of the cumulative density function with respect to our variable of interest x_j (Wooldridge, 2012):

$$[1.4]\ dp(x)/dx_j = g(\beta_0 + x\beta)\beta_j;\ where\ g(z) = dG/dz\,(z)$$

The maximum likelihood estimator of the binary response variable is described by:

$$[1.5]\ f(y|xi\beta) = [G(xi\beta)]^y[1 - G(Xi\beta)]^{1-y}, y = 0, 1$$

Equation 1.5 clearly demonstrates a function of probability, as the observed value when y=1 is $G(xi\beta)$ and when y=0 is $1 - G(Xi\beta)$. The log-likelihood function for the maximum likelihood estimator is the log of equation 1.5:

$$[1.6]\ \vartheta i(\beta) = y_i log[G(x_i\beta)] + (1 - y_i)log[1 - G(x\ _i\beta)]$$

The log-likelihood of a sample of size *n*, which is the value being maximized with maximum likelihood estimators, is obtained through the summation of all observations in equation 1.6:

$$[1.7]\ \vartheta i(\beta) = \sum_{i=1}^{n} \vartheta i(\beta)$$

The probit estimators $\widehat{\beta_J}$ provides the parameter estimates that maximize the likelihood of the sample occurring.

5.2 Bivariate Probit Model

In the bivariate probit model, we are modeling two binary outcomes that may be interrelated, or not completely independent of one another. Our two binary outcomes–the decision to buyout and the decision to rent back–are endogenous to one another, as the decision to rent back implicitly accepts a buyout but is contingent on remaining in the same home rather than relocating. If the correlation between the decision to accept a buyout and the decision to rent back is significant, a bivariate probit model is the proper model specification.

The latent variables of interest–expected utility from accepting a buyout or renting back (y_1* and y_2* respectively) are specified in the bivariate probit model as:

[2.1] $y_1 \ = \{1 \ if \ y_1 * > \ 0; \ 0 \ if \ y_1 * \leq \ 0\}$

$y_2 \ = \{1 \ if \ y_2 * > \ 0; \ 0 \ if \ y_2 * \leq \ 0\}$

[2.2] $y_1{}^{h}_{.} = \{ WTA_{bo} \ if \ y_1 * > \ 0; \ 0 \ if \ y_1 * \leq \ 0\}$

$y_2{}^{h}_{.} = \{ WTP_{rb} \ if \ y_2 * > \ 0; \ 0 \ if \ y_2 * \leq \ 0\}$

In the single probit models, we estimate the probabilities and marginal effects of accepting a buyout and renting back independently. In the bivariate probit model, we can estimate the joint probabilities of the two outcomes and the respective marginal effects for the joint probability of–for example–an individual being willing to accept a buyout but not willing to rent back ($P(y_1 = 1 \cup y_2 = 0)$).

5.3 Cragg Hurdle Model

For those who reported a willingness to accept a buyout or rent back, we can assess the level at which they are willing to do so. The hurdle (Cragg) model has an additional layer of flexibility in assessing the limited dependent variable by allowing for variability in factors that explain those who report a positive value within a continuous distribution for willingness to accept a buyout and willingness to rent back. The hurdle model addresses a censored dependent variable with positive and censored (those unwilling to participate at any level) responses using a two-step process that separately characterizes nonzero responses from censored responses. The motivation for a hurdle model comes from the notion that a binomial probability model determines a zero versus positive observation, and if the realization is positive, the "hurdle" is crossed and the conditional distribution of the positive observations uses a truncated-at-zero count data model.

In the context of this analysis, the hurdle model is the appropriate model specification if the underlying characteristics and motivations of respondents who are not willing to participate in a buyout or rent back at any price are fundamentally different from those who are.

The general equation form for the hurdle model is:

[3.1]

$$L = \prod_{i \epsilon \Omega_0} 1 - F_1(\beta_1) \prod_{i \epsilon \Omega_1} \frac{f_2(y, \beta_2) F_1(\beta_1)}{F_2(\beta_2)}$$

Where $\mathbf{\Omega}_0 = \{i|y_i = 0\}$, $\mathbf{\Omega}_1 = \{i|y_i \neq 0\}$, and $\mathbf{\Omega}_0 \cup \mathbf{\Omega}_1 = \{1, 2, \ldots, N\}$. Here, $F_1(B_1)$ represents the probability that the hurdle is crossed (in this case, that the homeowner is willing to buyout or rent back at some price level), while $f_2(y, B_2)F_1(B_1)/F_2(B_2)$ represents the conditional distribution of positive value (stated buyout and rent levels).

We estimate the parameters of the hurdle model by fitting two components (independent models) separately: the binomial probability model (or a probit model) and a truncated normal model for those observations where homeowners are willing to accept a buyout at some price, or willing to rent back at some positive level (Burke, 2009):

$$[3.2]\ f(w, y|x_1, x_2) = \{1 - \Phi(x_1\gamma)\}^{1(w=0)}[\Phi(x_1\gamma)(2\pi)^{(-1/2)}\sigma^{-1}exp\{-(y - x_2\beta)^2/2\sigma^2\}/\Phi(x_2\beta/\sigma)]^{1(w=1)}$$

Where *w* is a binary variable equal to 1 if a homeowner has a positive willingness to accept a buyout or rent back, and 0 otherwise (the first hurdle). In this model, independent vectors γ and β separately determine the probability of y > 0 and the conditional value of y given y > 0 (Burke, 2009). This allows for the vectors of explanatory variables to vary depending on whether we are estimating the likelihood that a homeowner will accept a buyout or estimating the level at which they accept a buyout. For example, x_1 may be a vector set of variables that capture inherent traits of coastal homeowners that would make them categorically different from one another, while x_2 may be a vector set of variables pertaining more to the level at which they are willing to buy out or rent back, such as income or wealth.

The tobit model is nested within the Cragg model. We observe that the models become identical when the vectors $x_1\ and\ \ x_2$ are identical, and when $\gamma = \beta/\sigma$ (Burke, 2009). The Cragg model then provides the same expected values and probabilities as the tobit model (Burke, 2009):

$$[3.3]\ P(y_i = 0|\, x_{1i}) = 1 - \Phi(x_{1i}\gamma)\ ;\ P(y_i > 0\,|\, x_{1i}) = \Phi(x_{1i}\gamma)$$

The expected value of y, conditioned on y > 0, becomes:

$$[3.4]\ E(y_i > 0\,|\, x_{2i} = x_{2i}\beta + \sigma \times \lambda(x_{2i}\beta/\sigma)$$

Where $\lambda(c)$ is the inverse Mills ratio (IMR) and ϕ is the standard normal probability distribution function (Burke, 2009):

$$[3.5]\ \lambda(c) = \phi(c)\Phi(c)$$

Equation 3.4 yields our estimates for average willingness to accept buyout and willingness to pay (rent back) estimates, conditional on a homeowner being willing to participate ($\omega = 1$). Finally, we can examine the partial effects of explanatory variables in x1 and x2 on the probability that y > 0 [3.6a] and the expected value of y given y > 0 [3.6b], respectively (Burke, 2009):

$$[3.6a]\ dP(y > 0|x_1)/dx_j = \gamma_j\phi(x_1\gamma)$$

$$[3.6b]\ dE(yi \mid yi > 0, x_{2i})/dx_j = \beta_j[1 - \lambda(x_2\beta/\sigma)\{x_2\beta/\sigma + \lambda(x_2\beta/\sigma)\}]$$

Chapter 6: Results

6.1 Overview of Preferences toward Buyouts and Rent backs

Of surveyed coastal homeowners, 77.8% are willing to accept a buyout at some price, and 55.2% are willing to rent back their home at some price (Figure 6). Surveyed homeowners that reported experience of flood damage followed a similar breakdown to the larger sample, with nearly 76% willing to accept a buyout and 58% are willing to rent back their home.

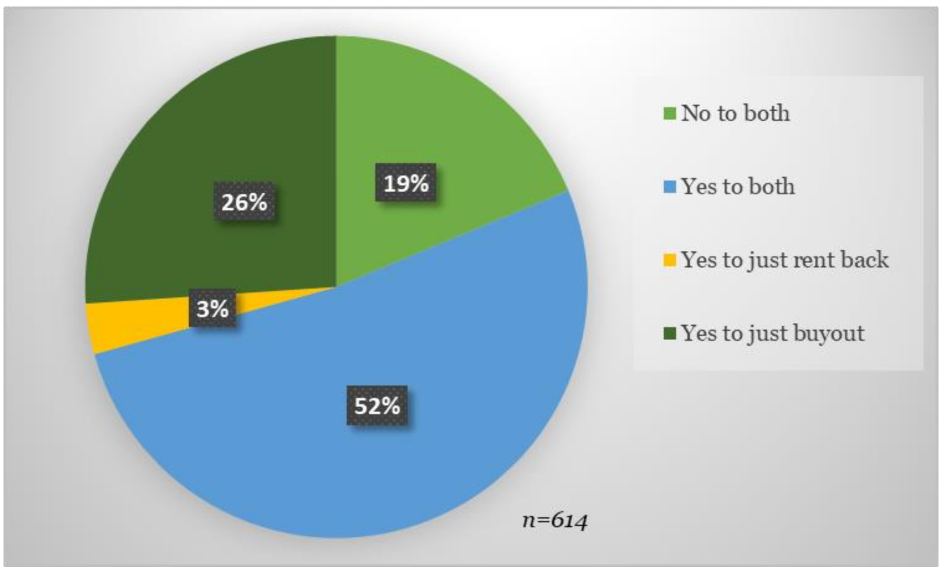


Figure 6. Respondents' WTA Buyouts and Rent backs

Figure 7 displays the distribution in price sensitivity for those willing to accept buyouts in terms of a percentage of the homeowners' most recently assessed property value.

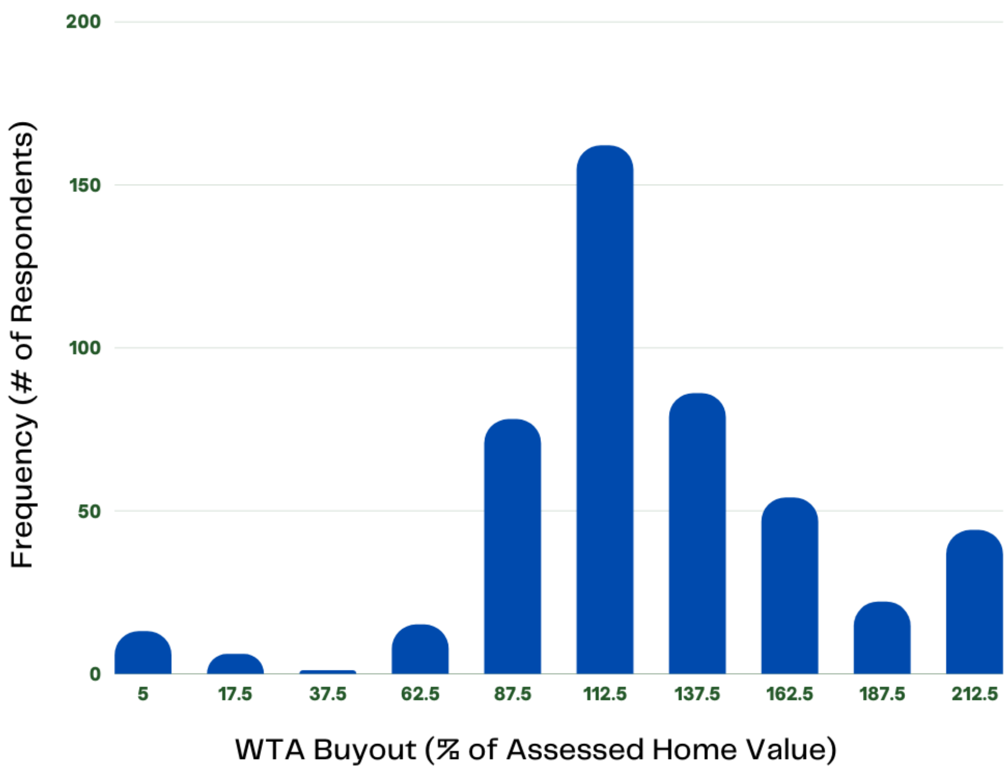


Figure 7. Distribution in Price Sensitivity for Coastal Homeowners' WTA Buyouts

Most of those homeowners willing to accept a buyout at some level require a premium on the assessed value of their home, indicating they require some kind of compensation for moving or retreating given the circumstances. A substantial portion of homeowners willing to participate did indicate they would accept a lower amount than the assessed value of their home.

6.2 Bivariate Probit Results

The models for both the single and bivariate probit models contain demographic, socioeconomic, structural, and other factors relating to historical experience, such as length of coastal tenure and experience of previous flood damage. The model fit (log-likelihood) improved substantially for both models when including variables relating to risk perceptions, risk aversion and future expectations. The appendix provides the output table for single and bivariate probit models for comparison.

The bivariate probit model is the appropriate model specification if the coefficients are statistically different from those in the single probit models–otherwise the single probit models are sufficient. Confirmed with the Wald test on the correlation measure between rent back and buyouts, the coefficient estimates vary statistically, indicating there is endogeneity in the decision to accept buyouts and to rent back. In other words, willingness to accept buyouts and rent backs are correlated in unobserved ways (not explained by the variables in the model).

Negative economic outlook, perceived Category 3 hurricane damage, risk aversion, worry of a natural disaster, coastal tenure, and flood damage experience all have a statistically significant relationship in the likelihood of accepting a buyout. House size, wealth, county, flood damage experience, negative economic outlook, risk aversion, and risk seeking behavior have a statistically significant relationship on a coastal homeowner's likelihood of renting back.

Because the probit models are nonlinear in nature, we cannot interpret the beta coefficients beyond the directional sign and statistical significance (see Appendix). In the bivariate probit model, a more negative economic expectation, higher hurricane damage perceptions, greater risk aversion, and longer coastal tenure increase the probability that a homeowner will accept a buyout and participate in coastal retreat. Conversely, higher concern about natural disasters and flood damage experience decreases the likelihood that a homeowner will accept a buyout and retreat. House size, negative economic outlook, and risk aversion all increase the likelihood a coastal homeowner will agree to rent back at some price, while higher wealth, county residency, risk-seeking behavior and flood damage experience decrease the probability of engaging in a rent back scheme. Discussion of the statistically significant factors motivating a coastal homeowner's decision to participate in a buyout or rent back is provided in the next section

Proceeding with the bivariate probit model results, we examine the partial effects of an individual's likelihood to accept a buyout or rent back their coastal home. Observing relationships at the means, we estimate the incremental change in probability of accepting a buyout or renting back for the joint probability outcomes. That is, we can assess the factors affecting the likelihood (joint probability) of a coastal homeowner being willing to both buyout and rent back, participate in neither, and buyout but not rent back.

Table 6 presents the marginal effects of each joint probability at the means, with the means for each variable presented in the first column for reference. As we should expect, statistically significant factors in the likelihood of a homeowner's willingness to accept a buyout and rent back are also statistically significant factors in the likelihood of homeowner's unwillingness to accept a buyout and rent back, in opposing directions.

Table 6. Conditional Joint Probability Marginal Effects at the Means

Variable	Means	(1) Buyout, Rent back	(2) Buyout, No Rent back	(3) Rent back, No buyout	(4) No Buyout, No rent back
Square feet	1,996	4.92e-05	6.36e-05**	1.21e-05	2.4e-06
		(1.49)	(-2.09)	(1.64)	(0.11)
L(income)	5	-0.03	0.05	-0.01	-0.01
		(-0.75)	(1.34)	(-1.19)	(-0.27)
L(wealth)	8.9	-0.07**	0.08***	-0.01**	0.003
		(-2.07)	(2.63)	(-2.06)	(0.14)
Damage Experience ($1000)	0.5	-0.019*	0.012	-0.001	0.008**
		(-1.79)	(1.20)	(-0.58)	(2.48)
Coastal Tenure	10.8	1.67e-04	0.0025	-7.77e-04*	-0.0019
		(0.08)	(1.49)	(-1.91)	(-1.41)
House Age	29.9	-9.47e-04	0.0023*	-5.67e-04*	-8.18e-04
		(-0.59)	(1.67)	(-1.71)	(-0.72)
Worry- Nat Disaster	2.2	-0.011	-0.034	0.012*	0.033
		(-0.33)	(-1.19)	(1.68)	(1.56)
Negative Economic Outlook	.04	0.055***	-0.021	-0.0018	-0.032***
		(3.52)	(-1.58)	(-0.60)	(-3.32)
Risk Averse	-0.36	0.213***	-0.109**	0.002	-0.106***
		(3.68)	(-2.32)	(0.18)	(-2.79)
Risk Seeking	0.49	-0.104***	0.075**	-0.0074	0.037
		(-2.61)	(2.05)	(-0.87)	(1.40)
Perceived Cat 3 Hurricane Damage ($1000)	63.70	7.32e-04*	-4.34e-05	-9.36e-05	-5.95e-04**
		(1.91)	(-0.13)	(-1.09)	(-2.19)
Perceived Cat 3 Hurricane Probability	.36	-0.023	0.011	-8.10e-05	0.012
		(-0.40)	(0.23)	(-0.01)	(0.31)
N		458	458	458	458

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

(1) Willing to Accept a Buyout & Rent Back

For a 1% increase in wealth at the mean (cumulative assets beyond income), a coastal homeowner is 0.07% less likely to accept a buyout and rent back. The average flood property damage experience–incorporating those who have never experienced flood damage–is around $500. For each additional $1,000 of flood damage experienced, a homeowner is 2% less likely to accept a buyout and rent back. A homeowner's outlook on the future of the coastal economy is one of the most statistically significant predictors in likelihood to accept a buyout and rent back. This negative expectation variable is characterized by respondent answers to Likert-scale statements, indicating they believe the future of the coastal economy includes higher housing prices, higher insurance prices, and higher property taxes. For an incremental increase in the index of negativity toward the future of the coastal economy, we estimate a 5.5% increase in the likelihood a homeowner will both be willing to accept a buyout and rent back. Homeowners' perception toward the property damage severity from a Category 3 hurricane hitting directly has a statistically significant effect on the probability of accepting a buyout and renting back. At the mean, each additional $10,000 in perceived property damage from a hurricane event increases the likelihood that a homeowner will both accept a buyout and rent back by 0.7%.

Relative risk aversion of an individual is both significant statistically and in magnitude. A risk averse homeowner is 21% more likely to belong to this category than a risk neutral homeowner, while a risk-loving individual is 10.4% less likely to belong to this category.

(2) Willing to Accept a Buyout, Unwilling to Rent Back

House size, wealth, risk aversion and risk tolerance are the statistically significant factors affecting the probability a coastal homeowner will be willing to accept a buyout but unwilling to rent back. The average household in the sample is nearly 2,000 square feet. An additional 1,000 square feet for a coastal homeowner decreases the likelihood a coastal homeowner will fit into this category by more than 6%. Every additional decade in the age of a coastal resident's home is associated with a 2% increase in the probability the homeowner will only be willing to accept a buyout. For relative wealth, an additional 1% increase in wealth from the mean increases the probability of observing this outcome by 8%. Relative to a risk neutral individual, a risk averse homeowner is 11% less likely to belong to this group, while a risk-seeking homeowner is 7.5% more likely to belong to this group.

(3) Unwilling to Accept a Buyout & Unwilling to Rent Back

The final common category we may observe is a coastal homeowner that is not willing to accept a buyout or rent their home back at any price level. Flood damage experience, coastal economic outlook, risk aversion, and perceived hurricane property damage motivate the likelihood that we observe a coastal homeowner in this group. A $1,000 increase in property damage experienced from a flood increases the likelihood a homeowner will belong to this category by 0.7%. An incremental increase in negativity toward the future of the coastal economy decreases the likelihood a homeowner will be unwilling to participate in both options by 3%.

The average expected property damage from a Category 3 hurricane is nearly $64,000. A $1,000 increase in expected damage from this mean decreases the likelihood a homeowner belongs to this group by less than 1%. We estimate a risk averse individual is 11% less likely than a risk neutral homeowner to belong to this category.

6.3 Cragg Hurdle Results

We use the results of the bivariate probit model to inform the selection of the explanatory vector set x_1 in the Cragg models for buyouts and rent backs. We maintain the explanatory vector set used in the bivariate probit models to estimate the truncated normal distribution of positive values ($y > 0$ when $w = 1$). The two-tiered results for the buyout and rent back models are presented in Table 7. Tier 1 results for the buyout indicate negative economic expectations and higher perceived hurricane damage significantly increases the likelihood that a homeowner will be willing to accept a buyout at some price level. Tier 2 results demonstrate that a more expansive set of factors affect the level at which a homeowner is willing to accept a buyout. Higher income and wealth, being a resident of Dare County, higher risk tolerance, and older house age all increase the price level at which a respondent is willing to accept a buyout. More cynical economic expectations and risk aversion motivate a lower willingness to accept level.

In the rent back model, negative economic outlook, greater relative risk aversion, and higher perceived hurricane damage severity increase the probability a homeowner is willing to rent back their home at some price level. Those with higher wealth levels and Dare County residents are less likely to be willing to rent back their home at all. Tier 2 results–estimating the willingness to pay a monthly rent as a distribution of positive values for those willing to rent back at some price–indicate that higher income is associated with a willingness to pay higher rent levels.

Table 7. Cragg Hurdle Results for Buyouts and Rent backs

	WTA Buyout		WTP Rent back	
	Tier 1 (Selection)	Tier 2	Tier 1 (Selection)	Tier 2
Damage Experience ($1000)	0.012	6.4	-0.048	-0.068
	(0.26)	(0.99)	(-1.47)	(-1.59)
Coastal Tenure	0.005	0.044		0.005
	(0.75)	(0.05)		(1.57)
Worry-Nat Disaster	-0.078	0.913		0.064
	(-0.67)	(0.07)		(1.12)
Negative Economic Outlook	0.156^{***}	-11.31^{*}	0.16^{***}	0.014
	(3.04)	(-1.93)	(3.64)	(0.43)
Risk Averse CRRA	0.3	-51.92^{**}	0.45^{***}	-0.13
	(1.61)	(-2.18)	(2.80)	(-1.19)
Risk Seeking CRRA	0.066	31.98^{**}	-0.166	0.023
	(0.45)	(2.20)	(-1.44)	(0.39)
Perceived Cat 3 Hurricane Damage ($1000)	0.00254^{*}	0.0735	0.0018^{*}	7.06e-04
	(1.77)	(0.59)	(1.72)	(1.37)
L(wealth)		85.13^{***}	-0.29^{***}	-0.0018
		(5.17)	(-3.33)	(-0.04)
Dare		83.11^{***}	-0.32^{**}	0.031
		(3.82)	(-2.30)	(0.36)
L(income)		57.09^{***}		0.167^{*}
		(3.67)		(1.89)
House age		1.88^{*}		-0.004
		(1.91)		(-1.40)
Perceived Cat 3 Hurricane Likelihood		-20.66		0.113
		(-0.83)		(1.17)
N	429		418	
AIC	5007.0		820.9	
BIC	5100.4		917.7	

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4 Conditional Marginal Effects and Estimates for Buyout and Rent back Levels

The partial effects in Tier 2 of the buyout and rent back equations indicate the incremental influence of our explanatory variables on WTA and WTP in $/square foot at the mean. For buyouts, income, wealth, house age, and risk tolerance all increase the level at which a homeowner is willing to accept. A 1% increase in income at the mean is associated with a $43.63/square foot increase in WTA, while a 1% increase in wealth is associated with a $65.05/square foot increase in WTA. Each additional year in house age corresponds with a $1.44/square foot increase in WTA. Negative economic expectation is associated with a $8.64/square foot decrease in WTA a buyout. Relative to a risk neutral homeowner, a risk averse homeowner is estimated to accept $39.67 less per square foot, and a risk-seeking homeowner is estimated to require $24.44 more per square foot.

For rent backs, we find income to be the only significant predictor in price sensitivity for willingness to pay. For those homeowners willing to rent back to the government, a 1% increase in income from the mean is associated with a $0.12/square foot/month increase in willingness to pay. Table 8 provides estimates for all conditional marginal effects at the mean.

Table 8. Hurdle Conditional (Tier 2) Partial Effects for Buyouts and Rent backs

WTA Buyouts		WTP Rent backs	
Variable	Mean	Variable	Mean
Square feet	-0.05*** (-4.26)	Square feet	-2.8e-04*** (-4.37)
L(income)	43.63*** (3.67)	L(income)	0.12* (1.89)
L(wealth)	65.05*** (5.17)	L(wealth)	-0.001 (-0.04)
Damage Experience	.005*** (0.99)	Damage Experience	4.7e-5 (-1.59)
Coastal Tenure	0.03 (0.05)	Coastal Tenure	0.004 (1.57)
House Age	1.44* (1.91)	House Age	-0.003 (1.40)
Worry- Natural Disasters	0.70 (0.07)	Worry- Natural Disasters	0.044 (1.12)
Negative Economic Expectation	-8.64* (-1.93)	Negative Economic Expectation	.01 (0.43)
Risk Averse	-39.67** (-2.18)	Risk Averse	-0.09 (-1.19)
Risk Seeking	24.44** (2.20)	Risk Seeking	0.016 (0.39)
Cat 3 Damage	5.6e-05 (0.59)	Cat 3 Damage	4.92e-07 (1.37)
Cat 3 Probability	-15.79 (-0.83)	Cat 3 Probability	.079 (1.17)

Z statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The hurdle models allow us to develop estimates for mean willingness to accept buyouts and mean willingness to pay for rent backs, conditional on the coastal homeowner crossing the first hurdle of participation. Table 9 presents these estimates in terms of $/square foot (normalized) as well as an average for a 2,000 square foot house, which is approximately the average house size in the sample. The conditional estimates indicate that even those homeowners who are willing to participate in a buyout or rent back program at some price require an 37% premium for a buyout and a 62% discount for a rent back on average, respectively. The rent back conditional values are calculated using the average of the range of conventionally proposed ratios for rent to housing value: 0.95% (between 0.8% and 1.1% per month).

Table 9. WTA and WTP Estimates for Buyouts and Rent backs

	Conditional Mean Housing Value	Average Estimated Buyout/Rent back Value	Premium/Discount
WTA Buyout ($/sqft)	$193.44	$273.57	37% premium
WTA Buyout* ($)	$386,880	$547,140	
WTP Rent Back ($/sqft/month)	$1.80	$0.80	62% discount
WTP Rent Back* ($/month)	$3,600	$1,600	

*Estimate for 2,000 square foot house
Note: All values reported in 2020 $

Chapter 7: Discussion

The results of the probit and double-hurdle models are predicated on the assumption that all coastal homeowners are maximizing expected utility for coastal housing consumption given uncertainty surrounding the ability and quality of consumption in the future. However, the good in question–coastal housing and amenity value–may not be viewed as a normal, substitutable good to all homeowners. With a stated preference to not accept a buyout *at any price*, some homeowners are consequently treating their property as an irreplaceable asset with a value that is theoretically undefined. We attempt to address this categorization issue by using hurdle models, and focus solely on the conditional ($y^* > 0$) expected value of buyouts and rent backs as our willingness to accept and willingness to pay for rent back measures.

Both the bivariate probit and Cragg models provide evidence that risk aversion, economic outlook, and risk perceptions can all be significant predictors in the probability that a coastal homeowner will participate in a buyout or a rent back. Socioeconomic and positional factors–explanatory variables not necessarily inherent to the individual–are likely significant in predicting the level at which a homeowner will accept a buyout or rent back.

Endogeneity presents a concern in the model specifications, as risk perception in the form hurricane and flood likelihoods and expected severity may be influenced or determined in part by psychological traits and damage experience. Other stated preference surveys and studies on voluntary buyout programs have found that the timing of the contract–whether the buyout is offered post-extreme event or under business-as-usual circumstances–is a significant factor in participation. This study does not account for the timing of the offer, and homeowners' both stated and true willingness to accept and rent back may alter significantly right after an extreme event–a commonly observed consequence of heuristic availability.

7.1 Economic Expectations, Flood Damage Experience & Natural Disaster Worry

While we find the negative economic expectation component is a significant positive predictor in likelihood to accept a buyout and rent back, the timing of the survey is important to consider in how short-term perceptions may have been skewed. Respondents answered survey questions just a few months after the start of the coronavirus pandemic, at a time when most of the country was under lockdown and vaccine development was still underway. Despite the time horizons in the Likert-scale questions being decades, individuals' risk perceptions, risk tendencies, and expectations may have all been affected by this major event.

The experience of flood damage (severity measured in $) and self-reported worry on the loss of home to natural disaster are two factors that presented seemingly counterintuitive directional relationships with the outcome variable. We may expect those homeowners who have experienced property damage from a coastal event to be prone to recall bias and a sense of risk aversion specific to incurring further property damage. The bivariate probit results reveal that flood damage experience (in $) is a significant negative predictor of the probability that a coastal homeowner will accept a buyout and rent back. Several phenomena could explain this. One may connect back to the moral hazard issue; if these homeowners have received government assistance in the past to rebuild, they may expect to receive it again, thereby reducing their risk aversion to a future natural disaster. Another explanation may be the gambler's fallacy; people may tend to believe if they have experienced a major flooding event or flooding damage already, they are less likely to experience it again. In other words, homeowners are not treating flooding events as independent occurrences. Additionally, if we consider sample bias, this negative relationship also may become more realistic; we are unable to observe any coastal homeowners who chose to accept a buyout or move away following a natural disaster event, because they are no longer living along the coast. Therefore, the coastal residents in our sample reporting experience of property damage from flooding are those who still choose to live along the coast despite their experience. This group may be a relatively small portion of the coastal population that has experienced flood damage in their home but weighs heavily in the sample because they represent the portion of the population least likely to be willing to move following a natural disaster.

For both the single and bivariate probit models, increased worry about loss of home to a natural disaster is a significant predictor that a coastal homeowner will be *less* willing to accept a buyout at any price. We may assume that increased anxiety surrounding natural disaster occurrence would increase the likelihood that a homeowner is willing to move away or to rent back and absolve themselves of the risk of loss– either in order to relieve the concern or because they hold an overly inflated risk perception toward the severity or frequency of such an event. In conducting a principal components analysis of the Likert-scale questions on worry about independent life events, we constructed a generalized factor for an 'anxious type' individual, who is generally worried about the occurrence of all types of events, including a family member getting cancer, not having any friends, and getting into financial trouble. The 'anxious type' factor did not yield any significant predictor effect in any of the model variations, indicating that those *specifically* relatively worried about losing their home to a natural disaster are resistant to buyouts and rent backs. This may be explained by a psychological tendency to worry more about events to people or places that we care more deeply for; those reporting higher relative worry about losing their coastal home to a natural disaster may have a stronger attachment to place, rather than holding a higher risk perception for the occurrence. In this case, the coastal homeowner does not weigh the probability of the event as much as the severity of harm from the event.

7.3 Equity Considerations

A limiting factor in the study that is important to highlight as coastal retreat literature grows is the demographic of the sample relative to other coastal populations along the U.S. coast. The sample is exceptionally white and rich, with more than 90% of respondents identifying as white and an average reported annual income of more than $180,000. Contextually, Dare County is more than 90% white and Worcester County is 83% white, with both counties' *median* household income reported at around $65,000, with poverty levels at 8% and 11% respectively (U.S. Census Bureau, 2021). While coastal homes in each county tend to carry a premium for amenity value, many coastal communities in the U.S. face significantly higher poverty rates and lower annual incomes. Further research may target price sensitivity to buyouts and rent backs in relatively poorer coastal communities.

Chapter 8: Conclusion

Coastal retreat is an increasingly viable and necessary adaptation strategy for coastal communities facing acute stressors such as hurricanes and floods, and ongoing stressors such as sea level rise and erosion. No one adaptation strategy will provide a silver bullet moving forward, but managed retreat and asset risk management along vulnerable coasts are imperative strategies to research and implement as part of a robust coastal adaptation strategy.

This study provides one of the first analyses of stated buyout and rent back preferences in two vulnerable counties along the U.S. East Coast, revealing potential latent classes of homeowners whose willingness to accept a buyout and rent back are motivated by a separate group of factors. Through variations of probit models, results indicate willingness to accept a buyout is motivated by income, wealth, perception of expected acute property damage from a Category 3 hurricane, and geographic location. These relationships echo patterns from other stated preference surveys on buyout sentiments. Willingness to pay to rent back to the government–a novel measure–appears to be motivated by more psychological factors, including relative risk aversion, worrying tendencies, and risk perceptions. Renting back from the government presents a distinguished set of tradeoffs from accepting a buyout and permanently moving; while residents get to continue living in their home without assuming risk for future damage, they lose property ownership and forfeit control over any timeline to retreat in the future. The downsides imply a new set of uncertainty, in which the resident is no longer in control of how long they may reside on the coast even though their expected costs are minimized.

8.1 Further Research

Willingness to rent back is a novel measure in stated preference surveys on coastal retreat, and our understanding of this measure will benefit from additional stated preference surveys focused on willingness to rent back price sensitivities and reasons for a homeowner's resistance toward rent backs. Rent backs should not be viewed as a permanent but rather an interim adaptation strategy in coastal retreat, as many properties may face nonrecoverable impacts which force a permanent retreat.

Dare and Worcester counties represent relatively wealthy, white populations along the coast with relatively higher-value assets. Price sensitivity to buyout and rent back offers in lower-income coastal regions are not well-studied, and significant discrepancies in the variables motivating price level sensitivity may exist between wealthy and poor coastal communities. Stated preference surveys are only able to capture a static snapshot in time of homeowner preferences; research on buyout preferences could benefit from intentionality toward developing panel data of stated and revealed preferences toward buyouts pre and post disaster.

Finally, the existing inefficiencies in federal national disaster relief largely stem from susceptibility to the moral hazard dilemma; 3.8% of policyholders in the National Flood Insurance Program are repetitive-loss homeowners that account for more than 30% of the total $52 billion in claim payments made by the agency between 1978 and 2015 (Wagner, 2019). Analysis of the characteristics of repetitive loss policyholders and how they align with the characteristics observed in this study can support a more cost-effective strategy in targeting buyouts toward repetitive-loss homeowners.

8.2 Managed Retreat: Equity, Efficiency, and Policy Implications

Understanding motivations in willingness to accept buyouts and willingness to pay for rent backs provides valuable information in implementing cost-effective buyout programs and supporting coastal residents in vulnerable positions. Future research is needed to understand preferences toward rent backs and inherent trait discrepancies between those willing to accept a buyout at some level and those unwilling to at any price. Similarly, further research is needed to characterize those coastal residents who are willing to accept a buyout, but not a rent back. Risk perceptions–especially in the form of anticipated damage from acute weather events–appear to have some influence in an individual's preference toward buyouts and rent backs, so further research will be helpful to understand the formation of risk perceptions and their influence on decision-making at a broader scale. Stated preference surveys in lower-income communities can reveal the most effective places to target voluntary buyout and rent back programs, while considering equity issues, attachment to place, and public safety.

References

Bohnert, S., & Doberstein, B. (2021). *Enhancing the Acceptability of Buyouts for Climate Change Adaptation: Exploring a Social License Approach for Erie Shore Drive, Ontario* (SSRN Scholarly Paper ID 3973770). Social Science Research Network. https://doi.org/10.2139/ssrn.3973770

Bukvic, Anamaria, Andrew Smith, and Angang Zhang. "Evaluating Drivers of Coastal Relocation in Hurricane Sandy Affected Communities." *International Journal of Disaster Risk Reduction* 13 (September 1, 2015): 215–28. https://doi.org/10.1016/j.ijdrr.2015.06.008.

Burby, R. J. (2006). Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing About Wise Governmental Decisions for Hazardous Areas. *The ANNALS of the American Academy of Political and Social Science, 604*(1), 171–191. https://doi.org/10.1177/0002716205284676

Burke, W. J. (2009). Fitting and Interpreting Cragg's Tobit Alternative using Stata. The Stata Journal, 9(4), 584–592. https://doi.org/10.1177/1536867X0900900405

Dachary-Bernard, Jeanne, Hélène Rey-Valette, and et Bénédicte Rulleau. "Preferences among Coastal and Inland Residents Relating to Managed Retreat: Influence of Risk Perception in Acceptability of Relocation Strategies." Journal of Environmental Management 232 (February 15, 2019): 772–80. https://doi.org/10.1016/j.jenvman.2018.11.104.

De Vries, D. H. de, and J. C. Fraser. “Citizenship Rights and Voluntary Decision Making in Post-Disaster U.S. Floodplain Buyout Mitigation Programs.” *International Journal of Mass Emergencies and Disasters* 30 (2012). https://dare.uva.nl/search?identifier=aafa3ebb-287f-41a1-a75e-8fe0554254d3.

Dundon, L. A., & Abkowitz, M. (2021). Climate-induced managed retreat in the U.S.: A review of current research. *Climate Risk Management*, *33*, 100337. https://doi.org/10.1016/j.crm.2021.100337

First Street Foundation. (2021). *Flood Factor risk statistics (v1.3)—FEMA Comparison—Overview* [Map]. https://www.arcgis.com/home/item.html?id=8b8c1bc5b7bf4b32958b3419113feebb

Frimpong, E., Kruse, J., Howard, G., Davidson, R., Trainor, J., & Nozick, L. (2019). Measuring Heterogeneous Price Effects for Home Acquisition Programs in At-Risk Regions. *Southern Economic Journal*, *85*(4), 1108–1131. https://doi.org/10.1002/soej.12341

Frimpong, E., Howard, G., & Kruse, J. (2020). *Homeowner Preference for Household-level Flood Mitigation in US: Analysis of a Discrete Choice Experiment*. 32.

Gibbs, Mark T. “Why Is Coastal Retreat so Hard to Implement? Understanding the Political Risk of Coastal Adaptation Pathways.” *Ocean & Coastal Management* 130 (October 2016): 107–14. https://doi.org/10.1016/j.ocecoaman.2016.06.002.

Hennighausen, Hannah, and Jordan F. Suter. “Flood Risk Perception in the Housing Market and the Impact of a Major Flood Event.” *Land Economics* 96, no. 3 (August 2020): 366–83. https://doi.org/10.3368/le.96.3.366.

Hino, Miyuki, Christopher B. Field, and Katharine J. Mach. "Managed Retreat as a Response to Natural Hazard Risk." *Nature Climate Change* 7, no. 5 (May 2017): 364–70. https://doi.org/10.1038/nclimate3252.

Kick, E. L., Fraser, J. C., Fulkerson, G. M., McKinney, L. A., & De Vries, D. H. (2011). Repetitive flood victims and acceptance of FEMA mitigation offers: An analysis with community-system policy implications. *Disasters*, *35*(3), 510–539. https://doi.org/10.1111/j.1467-7717.2011.01226.x

Kim, Byungdoo, David L. Kay, and Jonathon P. Schuldt. "Will I Have to Move Because of Climate Change? Perceived Likelihood of Weather- or Climate-Related Relocation among the US Public." *Climatic Change* 165, no. 1 (March 6, 2021): 9. https://doi.org/10.1007/s10584-021-03026-y.

Koerth, Jana, Athanasios T. Vafeidis, and Jochen Hinkel. "Household-Level Coastal Adaptation and Its Drivers: A Systematic Case Study Review." *Risk Analysis* 37, no. 4 (2017): 629–46. https://doi.org/10.1111/risa.12663.

Kirschenbaum, Alan. "Residential Ambiguity and Relocation Decisions: Population and Areas at Risk." *International Journal of Mass Emergencies and Disasters* 14, no. 1 (March 1996): 79–96.

Kousky, C. (2014). Managing shoreline retreat: A US perspective. *Climatic Change*, *124*(1), 9–20. https://doi.org/10.1007/s10584-014-1106-3

Kraan, Caroline M., Miyuki Hino, Jennifer Niemann, A. R. Siders, and Katharine J. Mach. "Promoting Equity in Retreat through Voluntary Property Buyout Programs." *Journal of Environmental Studies and Sciences* 11, no. 3 (September 1, 2021): 481–92. https://doi.org/10.1007/s13412-021-00688-z.

Lemée, C., Fleury-Bahi, G., & Navarro, O. (2019). Impact of Place Identity, Self-Efficacy and Anxiety State on the Relationship Between Coastal Flooding Risk Perception and the Willingness to Cope. *Frontiers in Psychology*, *10*, 499. https://doi.org/10.3389/fpsyg.2019.00499

Lemée, C., Navarro, O., Guillard, M., Krien, N., Chadenas, C., Chauveau, E., Desse, M., Coquet, M., Lamarre, M., & Fleury-Bahi, G. (2021). Impact of risk experience and personal exposure on coastal flooding and coastal erosion risk perception and coping strategies. *Journal of Risk Research*, *0*(0), 1–16. https://doi.org/10.1080/13669877.2021.1962952

Mach, Katharine J., Caroline M. Kraan, Miyuki Hino, A. R. Siders, Erica M. Johnston, and Christopher B. Field. "Managed Retreat through Voluntary Buyouts of Flood-Prone Properties." *Science Advances*, October 2019. https://doi.org/10.1126/sciadv.aax8995.

Mach, K. J., & Siders, A. R. (2021). Reframing strategic, managed retreat for transformative climate adaptation. *Science*, *372*(6548), 1294–1299. https://doi.org/10.1126/science.abh1894

McGuire, Chad J., and Michael Goodman. "Coastal Resiliency through Value Capture and Transfer: A Framework Proposal." *Coastal Management* 48, no. 2 (March 3, 2020): 57–76. https://doi.org/10.1080/08920753.2020.1728205.

Miao, Q., & Davlasheridze, M. (2022). Managed Retreat in the Face of Climate Change: Examining Factors Influencing Buyouts of Floodplain Properties. *Natural Hazards Review*, *23*(1), 04021063. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000534

Neumann, J., Hudgens, D., Herter, J., & Martinich, J. (2011). The economics of adaptation along developed coastlines. *WIREs Climate Change*, *2*(1), 89–98. https://doi.org/10.1002/wcc.90

Robinson, Celine S., Rachel A. Davidson, Joseph E. Trainor, Jamie L. Kruse, and Linda K. Nozick. "Homeowner Acceptance of Voluntary Property Acquisition Offers." *International Journal of Disaster Risk Reduction* 31 (October 1, 2018): 234–42. https://doi.org/10.1016/j.ijdrr.2018.05.002.

Seong, Kijin, Clare Losey, and Shannon Van Zandt. "To Rebuild or Relocate? Long-Term Mobility Decisions of Hazard Mitigation Grant Program (HMGP) Recipients." *Sustainability* 13, no. 16 (August 5, 2021): 8754. https://doi.org/10.3390/su13168754.

Smith, V. Kerry. "Option Value: A Conceptual Overview." *Southern Economic Journal* 49, no. 3 (January 1983): 654. https://doi.org/10.2307/1058707.

Smith, V. Kerry. 1985. "Supply Uncertainty, Option Price, and Indirect Benefit Estimation." *Land Economics* 61(3):303. doi: 10.2307/3145845

Wagner, K. (2019). Adaptation and Adverse Selection in Markets for Natural Disaster Insurance. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3467329

Wooldridge, J. M. (2012). *Introductory Econometrics: A Modern Approach*. 910.

Appendix: Single Buyout and Rent back Probit Models

Table A1 provides a comparison of the coefficients and their observed t-statistics for the single and bivariate probit models. The bivariate probit model–while the differences in coefficient magnitudes appear minor–is a better model fit, as indicated by a rejection of the null hypothesis that rho equals zero. Rho was estimated to be 0.715 with a chi-square value of 55.9, indicating buyout and rent back decisions are strongly correlated.

Table A1. Single and Bivariate Probit Results

	Willingness to Accept Buyout		Willingness to Rent Back	
	(1) Single	(2) Bivariate	(1) Single	(2) Bivariate
Square feet	-0.0000369	-0.0000552	0.000156*	0.000157*
	(-0.37)	(-0.56)	(1.71)	(1.75)
L(income)	0.0526	0.0629	-0.108	-0.101
	(0.45)	(0.54)	(-0.99)	(-0.94)
L(wealth)	0.0487	0.0441	-0.204**	-0.216**
	(0.50)	(0.44)	(-2.24)	(-2.38)
Dare	-0.0470	-0.0636	-0.250*	-0.253*
	(-0.31)	(-0.43)	(-1.84)	(-1.90)
Damage Experience	-0.0000248**	-0.0000249**	-0.0000402	-0.0000509*
	(-2.03)	(-2.07)	(-1.20)	(-1.66)
Coastal Tenure	0.00873	0.0102*	-0.00139	-0.00156
	(1.38)	(1.66)	(-0.26)	(-0.29)
House Age	0.00540	0.00531	-0.00270	-0.00388
	(1.05)	(1.01)	(-0.65)	(-0.92)
Worry- Nat Disaster	-0.166*	-0.173*	0.00184	0.00218
	(-1.68)	(-1.74)	(0.02)	(0.02)
Negative Economic Outlook	0.142***	0.131***	0.138***	0.136***
	(2.99)	(2.94)	(3.29)	(3.27)
Risk Averse	0.392**	0.397**	0.552***	0.550***
	(2.26)	(2.32)	(3.60)	(3.60)

Risk Seeking	-0.0922	-0.113	-0.304***	-0.286***
	(-0.73)	(-0.91)	(-2.76)	(-2.66)
Perceived Cat 3 Hurricane Damage	0.00000242*	0.00000264**	0.00000152	0.00000164
	(1.80)	(2.03)	(1.51)	(1.62)
Perceived Cat 3 Hurricane Probability	-0.0464	-0.0444	-0.0725	-0.0589
	(-0.26)	(-0.25)	(-0.47)	(-0.39)
N	458	458	460	458
AIC	452.0	981.6	605.2	981.6
BIC	509.8	1101.3	663.0	1101.3

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$