Heterogeneous Climate Beliefs and U.S. Home Price Dynamics: Going Under Water?

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Preliminary. Please do not cite without permission.

7/23/2017

Abstract

How will climate risks affect U.S. housing markets? This paper is motivated by two observations: (1) In the United States, both private and public agents exhibit significant heterogeneity in their beliefs about climate risks. (2) From an asset pricing perspective, it is well-known that heterogeneity in beliefs about future fundamentals can lead to inflated prices and ensuing risks (bubbles, excess volatility, etc.). Consequently, this paper asks how climate belief heterogeneity will affect housing market dynamics and the costs of sea-level rise. We provide both theoretical and novel empirical evidence: First, we build a dynamic housing market model with heterogeneity in home types, consumer preferences, and flood risk beliefs. The model incorporates a Bayesian learning mechanism for agents unsure about flood risks. Second, in order to quantify these elements, we implement a door-to-door survey in Rhode Island. The results confirm significant heterogeneity in flood risk beliefs, and that selection into coastal homes is driven by both lower risk perceptions and higher coastal amenity values. Third, we calibrate the model to simulate home prices across belief and flood risk scenarios. Compared with homogeneous rational expectations, coastal home price devaluations due to increases in flood risks are projected to be more than seven times larger when belief heterogeneity is taken into account. Market volatility similarly increases by an order of magnitude. Studies assuming homogeneous rational expectations may thus substantially underestimate the macroeconomic risks posed by sea-level rise.

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1 Introduction

How will climate risks affect coastal housing markets? In a world with homogenous and rational expectations, home values should adjust smoothly to incorporate the present value of future flood risk increases due to sea-level rise. If, however, agents have *heterogeneous beliefs* about climate risks, the housing market implications may be starkly different. From an asset pricing perspective, it is well-known that heterogeneity in beliefs about the future value of fundamentals can lead to inflated prices and a host of associated risks, including bubbles, excess volatility, overinvestment, and credit crises (e.g., Harrison and Kreps, 1978; Abreu and Brunnermeier, 2003; Scheinkman and Xiong, 2003; Geanakoplos, 2010; Simsek, 2013; etc.). While heterogeneity appears highly empirically relevant for flood and climate risk perceptions in the United States, standard approaches to valuing the economic costs of sea-level rise have assumed homogenous beliefs, thus potentially underestimating its macroeconomic consequences.

This paper studies the implications of heterogeneity in current and future flood risk perceptions for coastal U.S. housing markets. We develop a theoretical framework and implement a field survey in Rhode Island to provide both theoretical and empirical evidence on this question. Our model builds on recent advancements in heterogeneous beliefs and housing markets (e.g., Piazzesi and Schneider, 2009; Favara and Song, 2014, Burnside, Eichenbaum and Rebelo, 2016). Our model adds three main innovations. First, we introduce heterogeneity in the housing stock, differentiating coastal from non-coastal homes. Second, we introduce multi-dimensional heterogeneity in the population, allowing households to differ in both flood risk perceptions and coastal amenity valuations. Third, we introduce a Bayesian learning framework that allows agents to update their flood risk beliefs each period, in line with empirical evidence on response patterns after flood events (Gallagher, 2014). This feature creates the possibility of sharp drops in home prices after floods, again in line with empirical studies (e.g., Hallstrom and Smith, 2005). Lastly, the model thus also features heterogeneity in how agents expect each others' beliefs to evolve.

The central insight from the model is that coastal home prices depend critically on the joint distribution of flood risk beliefs, amenity values, and belief dynamics. In order to calibrate these relationships, we implement a door-to-door survey in Rhode Island. The results confirm significant heterogeneity in flood risk beliefs, and that selection into coastal homes is driven by both risk perceptions and amenity values. Calibrating the model with these data, the central quantitative result is as follows: compared to the standard setting with homogeneous rational expectations, future coastal home price declines are projected to be more than seven times more severe even if only 25% of the population are Bayesian learners. In the survey sample, around 40% of households substantially underestimate coastal flood risks. Consideration of this heterogeneity moreover increases the projected volatility of coastal home prices by close to an order of magnitude.

These results highlight the value of better flood risk information. While the Federal Emergency Management Agency (FEMA) publishes official flood maps, these are often out of date, with 1 in 6 maps being over 20 years old.[1] Even updated maps generally provide backwards-looking risk assessments that do not take climate change into account. According to FEMA, further map modernization would require additional funding. However, the White House's newly proposed budget would cut funding for FEMA's flood mapping products. The results of this paper suggest that the provision of high quality and updated flood risk information may be essential to reducing the risks of overvaluation and sharp future price drops in coastal property markets. In the policy realm, concerns over a future U.S. coastal home price collapse have also been voiced by, e.g., Freddie Mac.[2] This paper provides a formalization and quantification of the potential mechanisms and magnitudes of these risks.

The remainder of this paper proceeds as follows. Section (2) reviews related literatures and provides institutional background on U.S. flood maps and policies. Section (3) presents the model. Section (4) describes the survey design and results to inform the calibration of beliefs and preferences. Section (5) describes current and future expected flood risk in Rhode Island to motivate the calibration of flood risk changes. Finally, the model calibration and simulation results are presented in Section (6), and extensions and robustness in Section (7). Section (8) concludes.

2 Literature and Background

This paper builds on extremely rich literatures, including prior studies on housing prices and dynamics, residential sorting, and empirical work on the impacts of flood risks and events on home prices. First, the vast literature on housing price dynamics spans contributions from macroeconomics, urban economics, and finance (see, e.g., recent reviews by Davis and Van Niewerburgh, 2014, and Glaeser and Nathanson, 2014). Most closely related to our work are several recent papers that incorporate heterogeneous beliefs into housing price models. Both Piazzesi and Schneider (2009) and Burnside, Eichenbaum, and Rebelo (2016, "BER") present (quasi)-linear utility models of housing markets with search-and-matching frictions, and combine their models with Michigan Consumer / American Housing Survey data on households' expectations. Piazzesi and Schneider consider a one-time unanticipated shock that makes all renters optimistic about future prices to study the effects of momentum traders. BER present a detailed analysis of

[1] Authors' calculations based on FEMA National Flood Insurance Program Community Status Book, accessed February 2017: https://www.fema.gov/national-flood-insurance-program-community-status-book

[2] Freddie Mac (2016) "Life's a Beach", URL: http://www.freddiemac.com/finance/report/20160426_lifes_a_beach.html

"social dynamics" in housing markets. With a known probability, each period the fundamental value of homes may change permanently to a new level. Optimists expect this new value to be higher than 'skeptical' or 'vulnerable' agents. However, agents can 'infect' each other with their beliefs, depending on their relative levels of entropy, generating social dynamics in beliefs. Our approach builds on but differentiates itself from BER in several ways. On the one hand, we currently abstract from search-and-matching frictions, a major simplification. On the other hand, we extend BER's model by adding several dimensions of heterogeneity relevant for flood risks, and by allowing beliefs to evolve in response to external shocks (flood events) in a Bayesian learning framework.

Second, another vast literature has studied residential sorting and its implications for hedonic valuations of amenity values, including environmental attributes (Kuminoff, Smith, and Timmins, 2013). While most of this literature has focused on static settings, recent advances include dynamic structural estimation models of neighborhood choice (Bayer, McMillan, Murphy, and Timmins, 2016, "BMMT"). While our framework takes a fundamentally different approach from these studies, some of our results relate closely. For example, Section 4 motivates our survey and calibration approach by noting the importance of (heterogeneous) future home price expectations as a driver of current sorting and equilibrium home prices. Ignoring these dynamic considerations would lead to a biased assessment of future home price dynamics, as explored in Section 6. These results thus echo BMMT's finding that static estimates of amenity values may over- or under-estimate true values if those amenities are expected to change in the future.[3]

Also close in spirit but different in methodology, Kahn and Zhao (2017) present a theoretical framework to study the impacts of climate change skeptics on both incentives for innovation in climate adaptation goods, and spatial equilibrium between two cities with different climate sensitivities. They find that the presence of climate skeptics reduces demand for adaptation innovation, and lowers the price of land in the cooler city less impacted by climate change. In addition, Severen, Costello, and Deschenes (2016) find empirical evidence that land markets incorporate forward-looking beliefs about climate change, but only partly so. They also note heterogeneity in future climate change beliefs, finding that counties with greater belief in climate change incorporate future expectations to a greater degree into land values, relative to counties that have lower belief in future climate change. Our results thus add to a nascent literature on the impacts of climate skepticism on broader economic outcomes.

Third, a rich and growing empirical literature analyzes the impact of flood risk and storm events on home prices, typically using hedonic analysis to decompose the house prices into a property's component amenities and dis-amenities in the spirit of Rosen (1974). Hedonic

[3] See also, e.g., Bishop and Murphy (2011).

studies exist across both coastal and inland United States as well as international locations,[4] In addition to estimating house price impacts, literature addresses rental market impacts (Eves and Wilkinson, 2014) as well as condominiums (Meldrum, 2016). The literature also finds that properties in flood zones experience longer time on the market before a sale (Turnbull, Zahirovic-Herbert, and Mothorpe, 2013). In addition, the hedonic literature has analyzed other water-based values including wetlands (Cohen, Cromley, and Banach, 2015). A meta analysis finds a small but negative effect across the literature (Daniel, Florax, Rietveld, 2009). Other methods to estimate willingness to pay to avoid flood risk include Contingent Valuation (for example, Botzen and den Bergh, 2012). A key empirical challenge exists in the strong correlation between the dis-amenity of flood risk and the amenity value of proximity to water. While recent literature has utilized viewscapes and refined elevation data in an effort data to disentangle these relationships (Bin, Crawford, Kruse, and Landry, 2008; Atreya and Czajkowski, 2016), we implement a survey to disentangle these and other confounding factors affecting demand for coastal housing.

A key finding in the literature centers around the home buyers' flood risk perceptions and the potential role of imperfect information. Studies find flood risk perceptions to increase following a flood event but then to diminish for five years after an event (Atreya and Ferreira, 2015). McKenzie and Levendis (2010) find Hurricane Katrina greatly increased flood risk perceptions in New Orleans, where homes at higher elevations received a larger premium following the landfall, relative to those at lower elevations. McCoy and Chao (2017) also find increases in flood risk perception in NYC following Superstorm Sandy. A 2013 FEMA survey of the U.S. public found that a perception of low flood risk was the dominant motivation to not take precautionary action to mitigate flood risk at the household level (FEMA, 2013). However, difference in risk perception definitions across research as well as empirical methodologies to assess them can make it difficult to compare results across flood risk perception studies (Kellens, Terpstra, and De Maeyer, 2013).

Hallstrom and Smith (2005) postulate that storm events covey information surrounding the underlying risk of extreme flooding, finding that properties nearly missed, and therefore unharmed, by Hurricane Andrew received a 19 percent price drop after the event. Smith, Carbone, Pope, Hallstrom, and Darden (2006) moreover find that homes in high risk areas subsequently appreciated significantly more slowly due to the storm. Atreya and Ferreira (2015) find prices to drop 20-34% for floodplain properties following a 1994 "flood of the century" in Georgia, with

[4] Studies include Connecticut (Cohen, Cromley, and Banach, 2015), Florida (Harrison, Smersh, and Schwartz, 2001), Georgia (Atreya and Ferreira, 2015), Louisiana (Speyrer and Ragas, 1991), Missouri (Posey and Rogers, 2010), North Carolina (Bin and Polasky, 2004; Bin and Kruse, 2006; Bin, Kruse, and Landry, 2008; Bin and Landry, 2013), North Dakota (Zhang, 2016), Texas (Atreya and Czajkowski, 2016), as well as internationally in Australia (Rambaldi, Fletcher, Collins, and McAllister, 2013), the Netherlands (Daniel, Floraz, and Rietveld, 2009), New Zealand (Samarashinghe and Sharp, 2012), and the United Kingdom (Lamond, Proverbs, and Hamond, 2010). Note that these examples are illustrative rather than an exhaustive list of the literature.

prices bouncing back after about five years. Bin and Landry (2013) find a smaller decrease of 5.7% following Hurricane Fran and an 8.8% price drop after Hurricane Floyd. However, the overall impact of homes in a flood zone was between 6 and 20.2% from both events. Similar to Atreya and Ferreira, they find these price discounts last only about 5 to 6 years. Kousky (2010) found that high risk flood zone house prices did not fall significantly following a 1993 flood on the Missouri and Mississippi, but riverfront property prices fell by between 6 and 10%. Pryce, Chen and Galster (2011) provide a stylized framework for these empirical findings, concluding that in a housing market with imperfect information characterized by buyers with myopia and amnesia, the price path for homes at risk for flooding will fall directly following a flood event and then rise again, leading to a cyclical pattern with multiple floods over time. However, they leave a fully calibrated theoretical model for future work. A key question centers on how to model households' flood risk learning. Modeling the process more formally, Gallagher (2014) finds flood risk learning, as it relates to flood insurance purchases, is consistent with a Bayesian model characterized by forgetting or an incomplete history of past flood events. We incorporate these findings from the empirical literature directly into our model and calibration.

2.1 United States Flood Policy

Flooding has long been one of the costliest natural disasters in the United States (NOAA, 2017a). Due to rising damages from flooding and limited private market insurance penetration, Congress enacted the National Flood Insurance Program (NFIP) in 1968 under the Federal Emergency Management Agency (FEMA). The program created important institutions for flood risk information and impacted how flood risk is internalized by property owners through capitalization into home values. To this day, the National Flood Insurance Program remains the dominant insurer for flooding in the United States, with more than five million policies in force as of January 2017 covering more than $1.2 trillion of property and contents (FEMA, 2017a; Moore, 2017). However, even insured households continue to face financial risks from flooding as available policies are subject to various limitations, including a $250,000 property policy limit.[5] Insurance take-up is moreover modest despite subsidies and legal requirements for new home buyers in high risk areas with federally insured or regulated mortgages. By some estimates, less than half of structures in high risk areas are covered by insurance (Harrison, Smersh, and Schwartz, 2001).

The National Flood Insurance Program also created and maintains a comprehensive set of publicly available flood risk maps. These Flood Insurance Rate Maps (FIRMs), key ingredients in determining household eligibility and pricing for NFIP policies, also provide an important

[5] Standard flood insurance policies also do not cover damages due to certain types of impacts (e.g., earth movement due to flooding) or to vulnerable parts of the house such as basement walls and flooring (FEMA NFIP Fact Sheet, 2015).

source of information on flood risk to the public at large.[6] Utilizing NFIP-approved hydrological models, FIRMs assign flood risk categories to land across the United States.[7] Flood risk is categorized broadly in terms of probability of inundation in a given year, where zones having a risk exceeding 1% on average in a given year are known as the Special Flood Hazard Areas (SFHAs). Lower risk zones with a probability of inundation exceeding 1 in 500 or 0.2% per year are also marked.[8] Maps only incorporate current flood risks and may be updated periodically to reflect any flood risk changes or improved assessment of flood risk due to better data. Map updates are instigated either by FEMA, based on a cost-benefit approach, or local communities (FEMA, 2017b). However, due to budgetary constraints, map updating capabilities are limited, and 1 in 6 maps are more than 20 years old. Another concern with FIRMs is that they only describe current flood risk and not how potential future flood risk may evolve.

Just as the NFIP is a source of information, which previous research has shown to impact capitalization into property value on the extensive margin,[9] the NFIP insurance premium structure - particularly subsidies - can impact the degree of capitalization on the intensive margin (Shilling, Simans, Benjamin, 1989). Three main premium subsidy mechanisms existing in the NFIP include properties grandfathered into rates across FIRM updates, Pre-FIRM properties that were constructed before the NFIP was created, and properties within communities in the Community Rating System that provide incentives for mitigation that translate to premium discounts of up to 45% (Kousky, Lingle, and Shabman, 2016).[10] MacDonald, White, Taube, Hurth (1990) provide a theoretical model and empirical evidence of flood risk capitalization into house prices under various insurance pricing schemes. Uncertainty surrounding future NFIP flood zone status has also been shown to decrease the probability that a property is sold (Chang, Dandapani, and Johnson, 2010). While the bipartisan Biggert Waters Act of 2012 was meant to phase out subsidies in the NFIP, it was repealed through bipartisan passage of the 2014 Homeowners Flood Insurance Affordability Act. Preliminary analysis by Villar (2015) shows the passage of the 2012 Act repealing subsidies did depress property prices in affected areas.

In addition to the National Flood Insurance Program, the literature has found that expectations of post-disaster aid to individuals may shape the perceived level of flood risk that is internalized by an individual property owner (Lewis and Nickerson, 1989). Post-disaster aid by FEMA is given to states and localities after a presidential disaster declaration. Typical payouts

[6] Individuals can search the flood risk of any property at *floodsmart.gov*.

[7] A lits of approved hydrological models can be found online at *https : //www.fema.gov/hydrologic−models−meeting−minimum−requirement−national−flood−insurance−program*. Also note that a few locations do not have FIRMs.

[8] A small subset of locations have undetermined flood risk.

[9] See, e.g., Pope, 2008; Hill, 2015; Votsis and Perrels, 2016; Rajapakasa, Wilson, Managi, Hoang, Lee, 2016.

[10] The NFIP Community Rating System has also been shown to impact residential location choice in a sorting model (Fan and Davlasherdize, 2016).

are small - in the thousands of dollars - and are not meant to cover total property damage (Kousky, 2013). Indeed, FEMA assistance is capped at $33k even for eligible individuals whose homes are destroyed by a flood. As homeowners' overestimation of disaster aid could contribute to low flood risk concerns, we elicit and control for these expectations in our survey.

3 Theoretical Framework

This section presents a frictionless model of the housing market. Our setup follows Burnside, Eichenbaum, and Rebelo (2016, "BER") in studying an economy populated by a continuum of agents with linear utility and utility discount rate β. As in BER, agents can own one home or rent, and houses cannot be sold short. Importantly, we introduce new heterogeneity in the housing stock: fraction k_1 of homes are "coastal" properties (empirically later defined as within 400 feet of the waterfront). Overall, there is thus a fixed stock of houses available for sale $k < 1$ of which $k_1 < k < 1$ are coastal.[11] Households are heterogeneous in two dimension, namely their preferences for coastal living and their flood risk perceptions. More formally, each household i has a coastal amenity value ξ^i and an annual flood risk belief π_t^i which follow some joint distribution $f_t(\xi, \pi)$ in the population.

The rental market, as in BER, consists of $1 - k$ houses which are produced by competitive firms charging a rental rate of w per period, and the flow utilities of owning vs. renting a home are given by ε^h and ε^r, respectively. In our framework, coastal homes provide an additional utility value of ξ^i, but incur flood damage cost δ with probability π_t^*. Each period, households thus face the decision of whether to (i) buy a non-coastal home at price P_t^{NC}, (ii) buy a coastal home at price P_t, or (iii) rent. In the frictionless equilibrium, the prices of homes are determined by the valuation of the marginal buyer, who must be just indifferent between his options. Letting

[11] We thus abstract from (endogenous) housing supply. Empirical estimates find coastal supply to be highly inelastic, driven by topographic constraints including land gradient and water body boundaries (Glaeser, Gyourko, and Saks, 2005; Green, Malpezzi, and Mayo, 2005). Paciorek (2013) finds that these supply constraints to be important components in house price volatility, including during price bubbles (Glaeser, Gyourko, and Saiz, 2008). Saiz (2010) estimates MSA-level elasticities, finding Miami, Los Angeles, Fort Lauderdale, and San Francisco to have the lowest supply elasticities at between 0.6 and 0.66. However, this includes properties directly on the coast as well as inland. Our model assumes a fixed supply of coastal homes, as defined by homes within 400 feet of the water's edge, implying all land directly along the coast has been developed. While we have not formally endogenized supply, and specific outcomes would depend on assumptions of suppliers' beliefs regarding future flood risk, etc., the key mechanism should remain the same, namely that the price dynamics of coastal homes are driven by the beliefs and preferences of marginal agents. If inland home supply in coastal cities increases in response to high coastal home prices, this response would presumably lower overall price levels, but could exacerbate the mispricing of coastal homes (relative to fundamentals) as the fraction of coastal homes would decrease. Consequently, the likelihood of an optimistic marginal buyer increases, ceteris paribus. In sum, we conjecture that, with endogenous supply, while home price levels may decrease, coastal prices and volatility would still be greater relative to fundamentals.

m_t index the identity of the marginal buyer at time t for coastal homes, this implies:

$$-P_t + \beta(\varepsilon^h + \xi^{m_t} - \pi_t^{m_t}\delta + E_t^{m_t}[P_{t+1}^{m_{t+1}}]) = \beta(\varepsilon^r - w) = -P_t^{NC} + \beta(\varepsilon^h + E_t^{m_t}[P_{t+1}^{NC}]) \quad (1)$$

where $\pi_t^{m_t}$ is the time t marginal buyer's perception of coastal flood risk at time t, and $E_t^{m_t}[P_{t+1}^{m_{t+1}}]$ is $m_t's$ expectation of the next period's marginal buyer m_{t+1} and coastal home price $P_{t+1}^{m_{t+1}}$. Further defining $e^h \equiv \varepsilon^h - (\varepsilon^r - w)$ as the net flow utility of being a homeowner rather than a renter, (1) thus yields the following pricing condition for coastal homes:

$$P_t = \beta(e^h + \xi^{m_t} - \pi_t^{m_t}\delta + E_t^{m_t}[P_{t+1}'^m]) \quad (2)$$

The central insight that emerges from equation (2) is that coastal home prices depend on both the joint distribution of amenity values and flood risk beliefs $f_t(\xi, \pi)$, and on the (higher order) expectations of agents' own and others' evolution of flood risk beliefs (through $E_t^{m_t}[P_{t+1}^{m_{t+1}}]$). On the one hand, if everyone holds the same and true flood risk belief about π_t, the marginal buyer is determined solely based on their amenity value, and coastal home prices change gradually in anticipation of flood risk changes, as implicitly assumed in standard climate impacts evaluations. On the other hand, if everyone holds the same amenity value $\bar{\xi}$ for living by the water, (2) indicates that coastal home prices will fluctuate in line with the marginal buyer's first and higher order beliefs about flood risks, which may change sharply after storm events if agents are Bayesian learners. In order to analyze this problem more concretely, we assume that the (marginal) distribution of flood risk beliefs is discrete with two types: fraction θ^o of the population is excessively optimistic (π_t^o), and fraction $(1 - \theta^o)$ are realists (π_t^r), with $\pi_t^o \leq \pi_t^r \; \forall t$. We further assume that coastal amenity values and risk beliefs are independently distributed (as is approximately the case in the survey results), with (marginal) amenity value distribution $f_\xi(\xi^i) \sim U[0, \Xi]$, where the parameter Ξ thus denotes the maximum per-period willingness to pay for coastal living.

The marginal buyer in the frictionless equilibrium is the one with the k_1^{st} valuation for coastal properties. There are three general cases to consider. First, if there are more optimists than coastal homes ($\theta^o > k_1$), it is possible that only optimists will live on the coast (Case 1). This case occurs if even the realist with the highest possible amenity value ($\xi^r = \Xi$) assigns a lower value to buying a coastal home than the (then marginal) optimist:

$$\underbrace{\beta(e^h + \Xi - \pi_t^r\delta + E_t^r[P_{t+1}])}_{\text{Maximum WTP for coastal home among realists}} \quad < \quad \underbrace{\beta(e^h + \widehat{\xi^o} - \pi_t^o\delta + E_t^o[P_{t+1}])}_{\text{WTP for coastal home of (marginal) optimist}} \quad (3)$$

In this case, the marginal buyer's amenity value $\widehat{\overline{\xi^o}}$ must clear the market for coastal homes:

$$
\begin{aligned}
\frac{\theta^o}{\Xi}(\Xi - \widehat{\overline{\xi^o}}) &= k_1 \qquad (4)\\
\Xi\left(1 - \frac{k_1}{\theta^o}\right) &= \widehat{\overline{\xi^o}}
\end{aligned}
$$

Rearranging (4) reveals that condition (3) will be met if flood risk perceptions are sufficiently different:

$$
\Xi\frac{k_1}{\theta^o} + \{E_t^r[P_{t+1}] - E_t^o[P_{t+1}]\} < \delta(\pi_t^r - \pi_t^o) \qquad (5)
$$

Next, Case 2 occurs when both optimists and realists buy coastal homes. The marginal buyers' valuations are then equated:

$$
\beta(e^h + \overline{\xi_t^r} - \pi_t^r\delta + E_t^r[P_{t+1}]) = \beta(e^h + \overline{\xi_t^o} - \pi_t^o\delta + E_t^o[P_{t+1}]) \qquad (6)
$$

And the market clearing condition becomes:

$$
\frac{\theta^o}{\Xi}(\Xi - \overline{\xi^o}_t) + \frac{(1-\theta^o)}{\Xi}(\Xi - \overline{\xi^r}_t) = k_1 \qquad (7)
$$

yielding two equations (6)-(7) that jointly pin down the marginal buyer's amenity value for each type ($\overline{\xi_t^r}$,$\overline{\xi_t^o}$). In general, the price of coastal homes at time t, P_t is thus recursively given by:

$$
\begin{aligned}
P_t &= \beta(e^h + \overline{\xi_t^o} - \pi_t^o\delta + E_t^o[P_{t+1}]) \qquad (8)\\
\overline{\xi_t^o} &= \begin{cases} \widehat{\overline{\xi^o}} \text{ if (5) holds} \\ \text{jointly determined by (6) and (7) o.w.} \end{cases}
\end{aligned}
$$

Finally, if there are fewer optimists than coastal homes ($\theta^o < k_1$), the marginal buyer is trivially a realist (Case 3). In this case, the marginal realist's amenity value must clear the market for coastal homes net of the space already occupied by the optimists:

$$
\begin{aligned}
\frac{(1-\theta^o)}{\Xi}(\Xi - \widehat{\overline{\xi^r}}) &= k_1 - \theta^o\\
\Xi\left(1 - \frac{(k_1-\theta^o)}{(1-\theta^o)}\right) &= \widehat{\overline{\xi^r}}
\end{aligned}
$$

The equilibrium price in this setting will then satisfy:

$$
P_t = \beta(e^h + \Xi\left(1 - \frac{(k_1-\theta^o)}{(1-\theta^o)}\right) - \pi_t^r\delta + E_t^r[P_{t+1}])
$$

As the realists are assumed to be informed about true flood risk, and as their risk perceptions π_t^r consequently do not change in response to flood event realizations, coastal home pricing in Case 3 is comparatively uninteresting. While our numerical analysis covers Case 3, the analytic discussions below thus focus on settings where $\theta^o > k_1$.

3.1 Solving the Model

We solve for pricing dynamics through backwards iteration. First, we assume that, at known future time T, new flood maps reflecting the true risk will be released, and the announced π_T^* will then become a commonly held belief. Solving for time $T-1$ prices is then straightforward; solving for $T-n$ prices with $n \geq 2$ requires characterizing a basic form of higher order beliefs. At time $T-1$, the realists and optimists expect this announcement to be $E_{T-1}^r[\pi_T^*] = \pi_{T-1}^r$ and $E_{T-1}^o[\pi_T^*] = \pi_{T-1}^o$, respectively. The evolution of these beliefs is described further below. Once π_T^* becomes common knowledge, both optimists and realists will be in the market for coastal property and the marginal buyer will consequently be the one with the k_1^{st} amenity value $\overline{\xi} = \Xi(1-k_1)$. Consequently, at time $T-1$ realists expect the price of coastal homes at time T and thereafter to be given by the stationary solution to (2):

$$E_{T-1}^r[P_T] = \frac{\beta(e^h + \Xi(1-k_1) - \pi_{T-1}^r \delta)}{(1-\beta)} \tag{9}$$

The optimists reason analogously, but with a different expectation over the flood risk announcement π_{T-1}^o defining $E_{T-1}^o[P_T]$. Given both groups' price expectations, we can then use condition (5) to check the identity of the marginal buyer at $T-1$. In particular, if:

$$\Xi \frac{k_1}{\theta^o} + \left\{E_{T-1}^r[P_T] - E_{T-1}^o[P_T]\right\} < \delta(\pi_{T-1}^r - \pi_{T-1}^o) \tag{10}$$

only optimists are in the coastal real estate market and the market-clearing price at $T-1$ is:

$$P_{T-1} = \beta(e^h + \Xi\left(1 - \frac{k_1}{\theta^o}\right) - \pi_{T-1}^o \delta + E_{T-1}^o[P_T])$$

Conversely, if (10) does not hold, both types are in the coastal market and the price at $T-1$ is:

$$\begin{aligned} P_{T-1} &= \beta(e^h + \overline{\xi^o}_{T-1} - \pi_{T-1}^o \delta + E_{T-1}^o[P_T]) \\ \overline{\xi^o}_{T-1} &= \Xi(1-k_1) - \delta(1-\theta^o)(\pi_{T-1}^r - \pi_{T-1}^o) + (1-\theta^o)\{E_{T-1}^r[P_T] - E_{T-1}^o[P_T]\} \end{aligned}$$

Next, consider P_{T-2} to illustrate the process of finding prices further back in time. At time $T-2$, the identity of the marginal buyer once again depends on whether:

$$\Xi \frac{k_1}{\theta^o} + \left\{ E^r_{T-2}[P_{T-1}] - E^o_{T-2}[P_{T-1}] \right\} < \delta(\pi^r_{T-2} - \pi^o_{T-2}) \tag{11}$$

Importantly, however, each type's expectation of next period prices now depends on his/her expectation of her own as well as others' expectations about the marginal buyer and flood risk beliefs in the subsequent periods, i.e.:

$$\begin{aligned}
E^r_{T-2}[P^{m_{T-1}}_{T-1}] \quad &: \quad \text{If } [\Xi \frac{k_1}{\theta^o} + \left\{ E^r_{T-2}[E^r_{T-1}[P_T]] - E^r_{T-2}[E^o_{T-1}[P_T]] \right\} < \delta(E^r_{T-2}[\pi^r_{T-1}] - E^r_{T-2}[\pi^o_{T-1}])] \\
&\rightarrow \quad E^r_{T-2}(m_{T-1}) = o \\
&\Rightarrow \quad E^r_{T-2}[P^{m_{T-1}}_{T-1}] = \beta(e^h + \Xi \left(1 - \frac{k_1}{\theta^o}\right) - E^r_{T-2}[\pi^o_T]\delta + E^r_{T-2}[E^o_{T-1}[P_T]]) \qquad (12) \\
\text{Otherwise} \quad &: \quad E^r_{T-2}(m_{T-1}) = o\&r \\
&\Rightarrow \quad E^r_{T-2}[P^{m_{T-1}}_{T-1}] = \beta(e^h + E^r_{T-2}[\overline{\xi^o}_{T-1}] - \pi^o_{T-1}\delta + E^r_{T-2}[E^o_{T-1}[P_T]]) \qquad (13) \\
\text{where} \quad &: \quad E^r_{T-2}[\overline{\xi^o}_{T-1}] = \Xi(1 - k_1) - \delta(1 - \theta^o)(E^r_{T-2}[\pi^r_{T-1}] - E^r_{T-2}[\pi^o_{T-1}]) \\
&\quad +(1 - \theta^o)\{E^r_{T-2}[E^r_{T-1}[P_T]] - E^r_{T-2}[E^o_{T-1}[P_T]]\}
\end{aligned}$$

The expectations of the price at time T, in turn, are given by (10) and the analogous expression for optimists, but based on time $T-2$ expectations of the relevant terminal flood risk perceptions, i.e.:

$$E^j_{T-2}[E^i_{T-1}[P_T]] = \frac{\beta(e^h + \Xi(1 - k_1) - E^j_{T-2}[\pi^i_{T-1}]\delta)}{(1 - \beta)} \text{ for } i, j \in \{o, r\}$$

Going through the analogous calculations for the optimists yields their expectations $E^o_{T-2}[P_{T-1}]$. Given each type's respective price expectations, we can then use (11) to identify the marginal buyer at time $T-2$, and use (8) to solve for the market-clearing P_{T-2}. Defining the notation $\mathbf{E}^{i,j,..i}_{s:t} \equiv E^i_s[E^j_{s+1}[....E^i_t[.]]]$, the algorithm to solve for a general P_{T-n} follows the same procedure and can be summarized as follows:

$$\underbrace{\begin{pmatrix} \mathbf{E}^{r,r,...}_{T-n:T-2}[\pi^r_{T-1}] & \mathbf{E}^{r,r,...}_{T-n:T-2}[\pi^o_{T-1}] & ... \\ \mathbf{E}^{r,o,...}_{T-n:T-2}[\pi^r_{T-1}] & \mathbf{E}^{r,o,...}_{T-n:T-2}[\pi^o_{T-1}] & ... \\ \mathbf{E}^{o,r,...}_{T-n:T-2}[\pi^r_{T-1}] & \mathbf{E}^{o,r,...}_{T-n:T-2}[\pi^o_{T-1}] & ... \\ ... & ... & ... \end{pmatrix}}_{2^n \text{ nodes}} \rightarrow \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,...r}_{T-n:T-1}[P_T] & \mathbf{E}^{r,r,...o}_{T-n:T-1}[P_T] & ... \\ \mathbf{E}^{r,o,...,r}_{T-n:T-1}[P_T] & \mathbf{E}^{r,o,...,o}_{T-n:T-1}[P_T] & ... \\ \mathbf{E}^{o,r,...,r}_{T-n:T-1}[P_T] & \mathbf{E}^{o,r,...,o}_{T-n:T-1}[P_T] & ... \\ ... & ... & ... \end{pmatrix}}_{2^n \text{ nodes}} \tag{14}$$

$$\& \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,...}_{T-n:T-3}[\pi^r_{T-2}] & \mathbf{E}^{r,r,...}_{T-n:T-3}[\pi^o_{T-2}] & ... \\ \mathbf{E}^{r,o,...}_{T-n:T-3}[\pi^r_{T-2}] & \mathbf{E}^{r,o,...}_{T-n:T-3}[\pi^o_{T-2}] & \\ \mathbf{E}^{o,r,...}_{T-n:T-3}[\pi^r_{T-2}] & \mathbf{E}^{o,r,...}_{T-n:T-3}[\pi^o_{T-2}] & \\ ... & & \end{pmatrix}}_{2^{n-1} \text{ nodes}} \rightarrow \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,...r}_{T-n:T-2}[P_{T-1}] & \mathbf{E}^{r,r,...o}_{T-n:T-2}[P_{T-1}] & ... \\ \mathbf{E}^{r,o,...,r}_{T-n:T-2}[P_{T-1}] & \mathbf{E}^{r,o,...,o}_{T-n:T-2}[P_{T-1}] & ... \\ \mathbf{E}^{o,r,...,r}_{T-n:T-2}[P_{T-1}] & \mathbf{E}^{o,r,...,o}_{T-n:T-2}[P_{T-1}] & ... \\ ... & ... & ... \end{pmatrix}}_{2^{n-1} \text{ nodes}}$$

$$\& \ ... \quad \rightarrow \begin{pmatrix} E^r_{T-n}[P_{T-n+1}] \\ E^o_{T-n}[P_{T-n+1}] \end{pmatrix} \& \begin{pmatrix} \pi^r_{T-n} \\ \pi^o_{T-n} \end{pmatrix} \Rightarrow P_{T-n}$$

where the computation of the flood risk expectations is as described below. In sum, the calculation of the P_{T-n} market-clearing price thus requires the imputation of $2 \times \left(\sum_{k=0}^{n-1} 2(2^k) \right) - 2$ expectations, highlighting the curse of dimensionality at play in the model. For example, the computation of the P_{T-30} year price requires iteratively imputing 8.6 billion expectations. This setup raises both computational and conceptual questions, particularly whether it makes sense to assume higher oder sophistication in a model where agents are misinformed about the first order issue of the flood risks they face. We thus solve for prices assuming different levels of sophistication, as described below.

3.1.1 Flood Risks and Beliefs

The benchmark model imposes the following structure. First, flood risk is initially at a baseline level of π^L for T_1 periods, and then increases to a new level π^H. Based on the empirical results, we assume that both realists and optimists anticipate that a flood risk change will happen in the future. However, only realists know the true flood risk level at all points in time ($\pi^r_t = \pi^L$ for $t < T_1$, $\pi^r_t = \pi^H$ for $t \geq T_1$). Realists consequently do not update their beliefs in response to flood events. Their beliefs are further assumed to be common knowledge. In contrast, while optimists also know the initial flood risk ($\pi^o_t = \pi^L$ for $t < T_1$), they become Bayesian learners at time T_1. This modeling choice is motivated by the empirical literature evaluating flood event impacts that has found evidence consistent with Bayesian learning and forgetting (e.g, Gallagher, 2013). Our updating framework is an adaptation from Dieckman (2011) for the present setting. Optimists have a prior belief about the probability q^o_t that flood risk has become high (π^H), but believe that it may still be low (π^L) with probability $(1 - q_t^o)$. Their estimate of the flood risk at time $t \geq T_1$ is thus:

$$\pi_t^o = q_t^o(\pi^H) + (1 - q_t^o)(\pi^L)$$

Each period, optimists update their prior based on whether or not a flood event occurs:

$$\begin{aligned} q_{t+1}^o|_{\text{Flood}=1} &= \Pr(\pi^H|_{\text{Flood}=1}) = \frac{\pi^H \cdot q_t^o}{\pi^H q_t^o + (1 - q_t^o)\pi^L} \\ q_{t+1}^o|_{\text{Flood}=0} &= \Pr(\pi^H|_{\text{Flood}=0}) = \frac{(1 - \pi^H) \cdot q_t^o}{(1 - \pi^H)q_t^o + (1 - q_t^o)(1 - \pi^L)} \end{aligned} \quad (15)$$

Figure 1 presents an example sequence of flood risk beliefs that change in response to underlying risk changes as well as flood events:

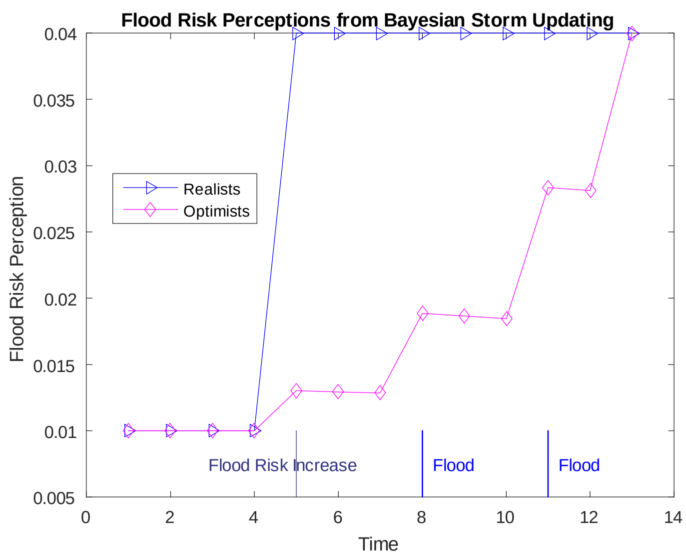

Figure 1

Several empirical studies on flood events and home prices have found impacts that declined back to baseline within 5-6 years (e.g., Bin and Landry, 2013; Atreya and Ferreira, 2015), and Gallagher (2013) finds insurance demand impacts that decline to baseline within 9 years. Within our framework, the standard Bayesian updating model does not match such fast rates of decline. Consequently, we also consider a behavioral extension of (15) that includes an 'overreaction' parameter γ:

$$\widetilde{q}^o_{t+1}|_{\text{Flood}=1} = \Pr(\pi^H|_{\text{Flood}=1}) = \frac{(\pi^H \cdot q^o_t)\cdot(1+\gamma)}{\pi^H q^o_t + (1-q^o_t)\pi^L} \tag{16}$$
$$\widetilde{q}^o_{t+1}|_{\text{Flood}=0} = \Pr(\pi^H|_{\text{Flood}=0}) = \frac{((1-\pi^H)\cdot q^o_t)\cdot(1-\gamma)}{(1-\pi^H)q^o_t + (1-q^o_t)(1-\pi^L)}$$

Figure 2 illustrates three examples of how optimists' flood risk perceptions evolve over time in response to three simulated flood events with different levels of overreaction.

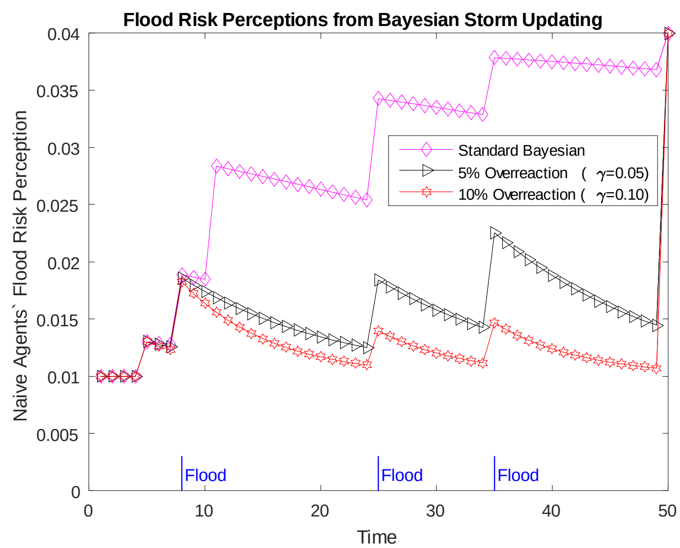

Figure 2

Next, we also consider two cases with regards to higher order beliefs. The benchmark model assumes a mixed case where realists have rational higher order expectations of optimists' belief changes, meaning they take into account that, each period, with probability π^r_t, a flood will occur and change optimists beliefs according to (15). In contrast, optimists are myopic about future changes in their beliefs, including with regards to their expectations of realists' future beliefs about their (optimists') flood risk perceptions. Together, the benchmark case thus implies that, for example:

$$E^o_t[\pi^o_{t+1}] = \pi^o_t \tag{17}$$
$$E^r_t[\pi^o_{t+1}] = \pi^r_t\left[(q^o_{t+1}|_{\text{Flood}=1})(\pi^H) + (1-q^o_{t+1}|_{\text{Flood}=1})(\pi^L)\right]$$
$$+(1-\pi^r_t)\left[(q^o_{t+1}|_{\text{Flood}=0})(\pi^H) + (1-q^o_{t+1}|_{\text{Flood}=0})(\pi^L)\right]$$

The behavioral extension below also considers a case where both realists and optimists are myopic about future changes in optimists' flood risk beliefs, implying that $E_t^o[\pi_{t+1}^o] = E_t^r[\pi_{t+1}^o] = \pi_t^o$. We do not (at present) consider a third case where both realists and optimists are fully rational about optimists' expected changes in future flood risk beliefs, as it seems incongruous to ascribe such sophistication to optimists when they are naive about the first order issue of coastal flood risks. Nonetheless, even in this third case we would expect qualitatively similar results as optimists would still assign too low of a probability to a flood occurring that changes their beliefs, implying that even their higher order beliefs would remain excessively optimistic.

Finally, Section (7) also discusses the possibility that agents engage in ex-post rationalization of their residential choice by updating their flood risk beliefs *differentially* after moving to a coastal home.

4 Field Survey

4.1 Motivation

In order to gauge the quantitative importance of heterogeneous beliefs for the costs of climate change in coastal property markets, it is necessary to estimate the joint distribution of amenity values and flood risk beliefs. While an extremely rich hedonic literature has valued the home price impacts of coastal and flood zone living, observed equilibrium price differences should reflect both heterogeneity in amenity values and flood risk beliefs. Through the lens of the model, the coastal home premium at any point in time t is given by:

$$PREM_t^{\text{Coast}} \equiv (P_t - P_t^{NC}) = \beta \left(\xi^{m_t} - \pi_t^{m_t}\delta + E_t^m[P_{t+1}^{m_{t+1}} - P_{t+1}^{NC}] \right) \tag{18}$$

In words, (18) indicates that, in the cross-section, the net coastal home premium includes (i) the time t marginal buyer's amenity value ξ^{m_t}, (ii) the marginal buyer's expected current flood risk $\pi_t^{m_t}$, and (ii) the marginal buyer's expectation of the future coastal home premium, which, in turn, encompasses both his expectations of future flood risk $\pi_{t+1}^{m_{t+1}}$ and his (higher and first order) beliefs about others' future flood risk perceptions. In reality, heterogeneity in expectations over flood damages δ or government assistance that would mitigate these costs would further be expected to enter empirically observed coastal home premia. Indeed, Bayer, McMillan, Murphy, and Timmins (2016) demonstrate the potential importance of dynamic considerations in hedonic estimation in sorting models.

In our framework, even changes in the coastal home premium after flood events would be expected to induce several changes above and beyond the direct impact on contemporaneous flood risk beliefs. Let $\mathbf{E}[\mathbf{\Pi}]_{t:T}$ denote the set of matrices of first- and higher-order flood risk and home price expectations that determine the equilibrium price in period t as per (14). A flood event in period $t-1$ would change optimists' beliefs not only in period t but also thereafter, as well as realists' expectations of optimists' current and future flood risk perceptions (as per (15) and (17)). Informally and in an abuse of notation, we would expect these changes $\frac{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}}{\Delta \text{Flood}_{t-1}}$ to enter the period t coastal premium through the following channels:

$$\frac{\Delta PREM_t^{\text{Coast}}}{\Delta \text{Flood}_{t-1}} \sim \beta \left(\frac{\Delta \xi^{\Delta m_t}}{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}} \frac{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}}{\Delta \text{Flood}_{t-1}} - \frac{\Delta \pi_t^{\Delta m_t}}{\Delta \text{Flood}_{t-1}} \delta + \frac{\Delta E_t^{\Delta m_t}[P_{t+1}^{m_{t+1}} - P_{t+1}^{NC}]}{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}} \frac{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}}{\Delta \text{Flood}_{t-1}} \right)$$

In words, observed changes in coastal home prices after a flood event would thus be expected to include (i) changes in the marginal buyer's amenity value due to compositional changes in coastal residents $\Delta \xi^{\Delta m_t}$, (ii) changes in the marginal buyer's contemporaneous flood risk expections (through changes in the identity and/or value for the marginal buyer $\Delta \pi_t^{\Delta m_t}$), (iii) changes in (higher and first order) expectations about future prices and beliefs $\Delta E_t^{\Delta m_t}[P_{t+1}^{m_{t+1}} - P_{t+1}^{NC}]$. Given the need to evaluate heterogeneity in flood risk beliefs separately from amenity values, and given the need to assess potential confounders such as expectations of government flood aid, we thus design a field survey to elicit these values directly from respondents.

4.2 Design

We conduct in-person surveys through a door-to-door campaign in Rhode Island, targeting communities with both coastal (defined as within 400 feet of the coast) and non-coastal homes. The full surveyor script and survey files are provided in the Appendix. The key components of the survey are as follows. First, we elicit households' willingness to pay (WTP) for living within 400 feet of the water using a double-bounded dichotomous choice (DBDC) choice contingent valuation mechanism (Hanemann, Loomis, and Kanninen, 1991). Guided by the literature on efficient starting bid design (Kanninen, 1993; Alberini, 1995), the three starting bids of \$150, \$250, and \$350 were chosen based on an estimation of the annualized waterfront living premium in the United States and New England coastal areas based on a hedonic analysis of the U.S. Census American Housing Survey data for 2013 performed by the authors. The DBDC question was asked early in the survey to avoid bias due to priming with flood risk information and following best practices in contingent valuation (Arrow et al., 1993; Carson and Mitchell, 1995).

Second, we elicit coastal flood risk perceptions. In line with best practices in the risk elicitation literature (Manski, 2004), we consider both quantitative and qualitative subjective risk measures. The quantitative elicitation asks subjects about their perception of the probability of experiencing at least one flood over the course of the next 10 years. Coastal residents are asked about their homes specifically, whereas non-coastal residents are asked to consider a home like theirs located within 400 feet of the waterfront in their community. As a visual aid, subjects are shown a table of both natural frequencies and probabilities (see Appendix). Next, as a qualitative measure we ask subjects to indicate how worried they are on a 10-point scale about the risk of a flood affecting their or a coastal home over the next 10 years. This question format is motivated by the findings of Schade, Kunreuther, and Koellinger (2012) that such a worry scale performs significantly better as a predictor of demand for insurance against low probability disasters than subjective probability measures.

Third, the survey asks subjects about several potential confounders that could affect concern about flooding even in the absence of heterogeneity in flood probability beliefs per se, including expectations over flood damages, insurance reimbursements, and government assistance. We also ask about flood experiences and intentions to sell or buy a home in the next five years. Finally, the survey asks subjects about their beliefs about changes in future flood risk and the climate. We supplement demographic information elicited in the survey with publicly available information on home characteristics from tax assessor records.

4.3 Survey Results

This section reports results from $n = 187$ in-person interviews (52% coastal, 48% non-coastal) conducted with households in several coastal Rhode Island communities. First, we find strong evidence of heterogeneity in flood risk perceptions. In line with the sorting mechanism implied by (2), we find that coastal residents appear significantly *less* concerned than non-coastal residents when asked about their coastal flood risk perceptions, as shown in Figure 3:

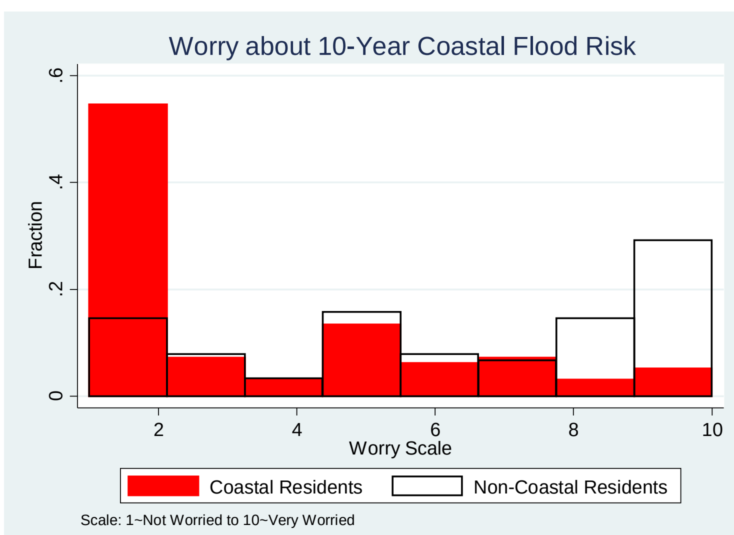

Figure 3

Perhaps more strikingly, we also find that those living in official FEMA high-risk flood zones appear significantly *less* worried about flood risks than those whose homes are outside the flood zone, as shown in Figure 4:

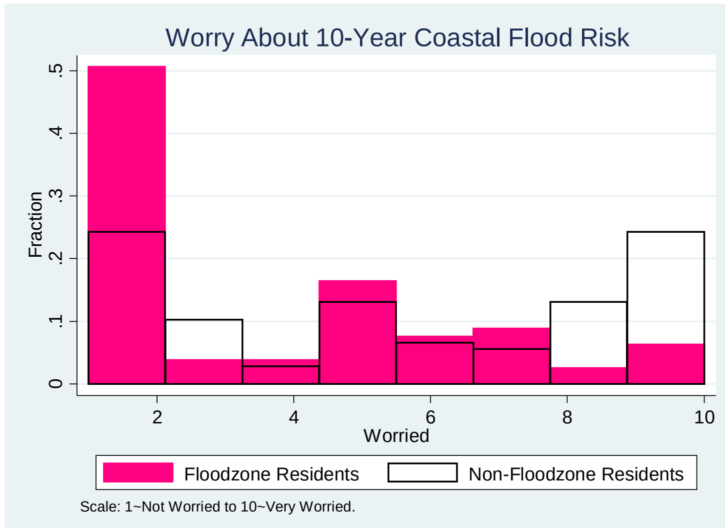

Figure 4

Of course one may be concerned that a low degree of worry could be driven by differences in expectations over losses conditional on a flood, rather than flood risk itself. Figure 5 showcases the distribution of expected flood damages (as percentage of home value) net of expected insurance reimbursements and government assistance.[12] While floodzone residents generally expect slightly lower damages, they also have lower expectations for insurance and government assistance (see Table 1). The net damage expectations are thus very similar across the two groups, and the means are statistically indistinguishable, suggesting that differencecs in flood worries are not driven by differential expectations of damages or ex-post flood assistance.

[12] Households whose estimates imply flood damages in excess of 100% of home values are re-coded as 100% damage estimates.

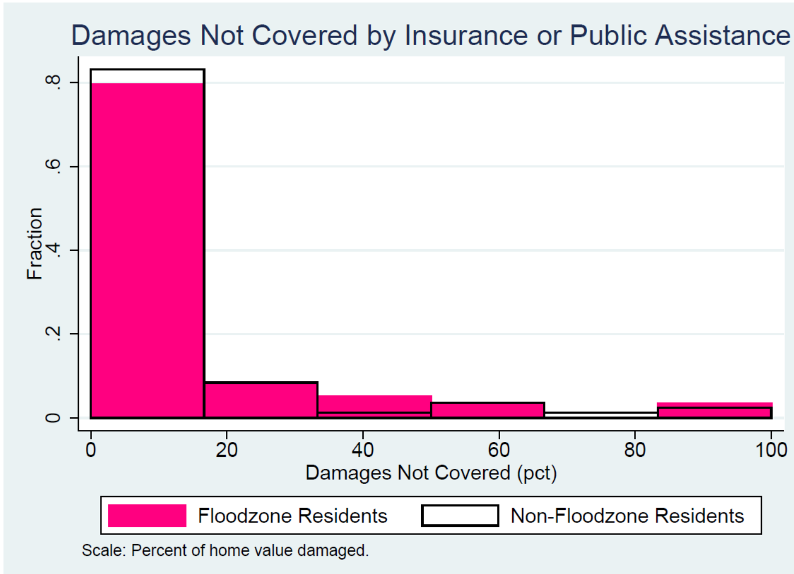

Table 5

In order to evaluate these as well as other potential differences across floodzone and non-floodzone residents more formally, Table 1 presents differences in means and t-tests for their significance across the two groups. Both demographics and home characteristics appear similar across the two groups. Beyond exhibiting highly significantly *lower* flood risk concerns, floodzone residents differ from non-floodzone residents in having slightly smaller households, and in expecting a *lower* flood damage recovery rate from insurance. The central take-home point is thus that we find evidence of heterogeneity in concerns about flooding that does not appear to be driven by differences in confounders such as government or insurance assistance expectations.

Table 1: Differences in Sample Means: Floodzone Residents

Variable	Non-Floodzone	Floodzone	Difference (SE)
Flood Worry Index (1-10)	5.62	3.65	1.97 (0.46)***
Flood Probability (midpoints)	0.27	0.24	0.02 (0.05)
Age	53.09	52.74	0.34 (2.25)
Household Income	118.72	130.39	-11.67 (9.37)
Education Index (1-9)	6.92	7.00	-0.08 (0.31)
Household Size	3.10	2.55	0.55 (0.20)***
Property Area (square feet)	10,884	8,049	2,835 (932)***
Flood Damages % of Perceived Home Value	41.7%	33.5%	8.2% (6.3%)
Flood Damages $ '000's:	194.1	117.9	76.2 (51.0)
Expectation of Gov't Assistance: % of Flood Damages	15.1%	10.6%	4.5% (3.5%)
Expectation of Insurance: (% of Flood Damages)	63.1%	50.3%	12.9% (5.1%)**

** (***) $\sim$ significant difference for two-sided t-test at 5% (1%) level.

The results presented thus far focus on flood risk perceptions measured by a worry index, motivated by the findings of Schade, Kunreuther, and Koellinger (2012). However, we also elicit numerical flood risk perceptions. Figure 6 compares these perceptions with respondents' homes' actual 10-year flood risk obtained by our storm surge elevation risk estimation (described in Section 5). Importantly, this estimation takes into account each property's elevation. The sample is restricted to coastal homes so that responses also reflect flood risk estimates specific to respondents' homes. If their assessments agreed with the storm surge model, they should be near the 45° line. However, most answers lie beneath the 45° line, again suggesting that many coastal residents underestimate the flood risks they face.

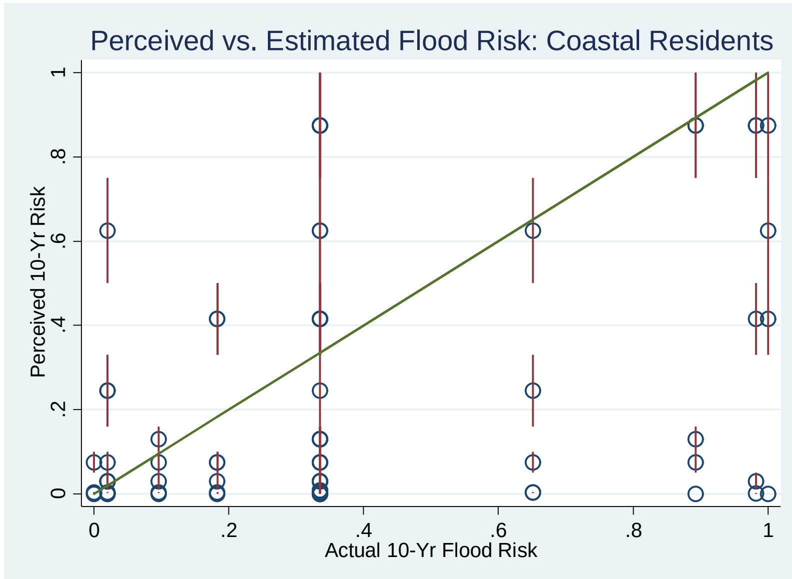

Figure 6. Note: Red lines span range of 10-year flood risk probability in respondent's answer (e.g., 5-10%) on the y-axis, with blue circles marking the mid-points of each range.

With regards to flood risk perceptions, the survey also provides suggestive evidence on two additional elements of the model. First, households that have experienced a naturally caused flood at their homes - including from rainfall - are significantly more likely to be concerned about flooding (see Appendix Figure A1). Second, coastal residents that are very worried about flooding appear considerably more likely to plan on selling their homes within the next five years (see Appendix Figure A2). Both results are in line with the model's central mechanisms that households learn about flooding from past events, and are more likely to select of coastal property markets as their flood risk perceptions increase.

The second main goal of the survey is to assess household-specific willingness-to-pay (WTP) for living within 400 feet of the waterfront. Importantly, the survey question asks households about their WTP assuming that all other home attributes - including environmental risks - remain unchanged compared to their current homes. If households ask for clarification, surveyors were instructed to explain that this includes flood risks, and that the question asks strictly about the amenity value of living by the water without changes in flood risks or insurance requirements. Detailed estimation results are presented in the Appendix.

Figure 7 plots the joint sample distribution of coastal amenity values and coastal flood risk perceptions among coastal (circles) and non-coastal (x's) residents. The results indicate that selection into coastal housing markets is driven by a combination of higher amenity values and lower flood risk concerns, in line with the core mechanisms of the model.

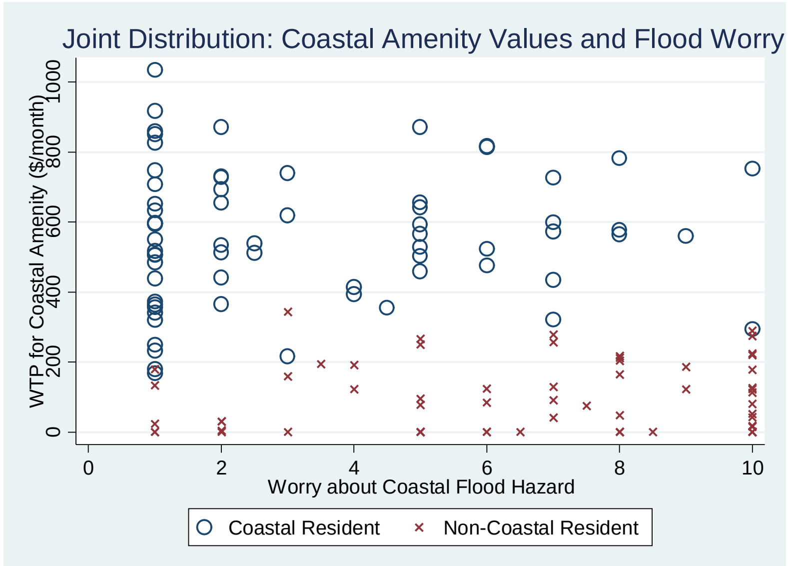

Figure 7

In order to examine whether the coastal amenity value distribution differs across risk belief types, we classify respondents as 'optimists' if they underestimate coastal 10-year flood risk by at least ~50%. Specifically, respondents are 'optimists' if their subjective coastal 10-year flood risk assessment is between $0 - 5\%$. In reality, FEMA high flood risk zone residents' annual flooding probability is at least 1%, implying a 10-year probability of at least one flood around 9.6%.[13] Figure 8 compares amenity value distributions for optimists and realists in our sample.

[13] While not all coastal homes in our sample are currently in a FEMA flood zone due to their elevation, other homes' risks exceed 1% per year. As we estimate the average annual flood risk for coastal homes in our sample to exceed 1% per year (see Section 5), using a 1% figure is thus conservative.

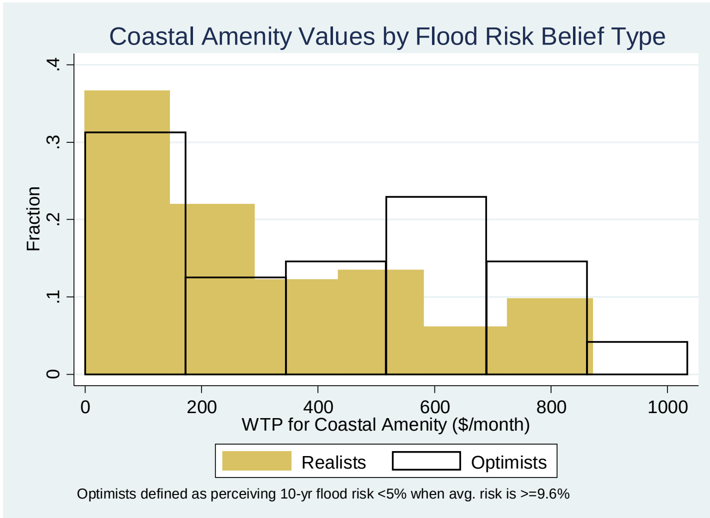

Figure 8

While the mean of amenity values is higher for optimists than for realists, the distributions appear sufficiently similar in the two populations that we maintain the assumption of equal ξ distributions as a benchmark in the calibration below.[14] Finally, the results indicate that the majority of respondents in our current sample expects future flood risks to be at least "Somewhat Greater" than current risks. Figure 9 plots the distribution of these beliefs across current flood risk belief types. Perhaps not surprisingly, realists are more likely to assume higher future flood risk increases than optimists. However, even the majority of optimists anticipates an increase in flood risks. Informed by these results, the model assumes that optimistic agents anticipate the possibility of a future flood risk increase at time T_1, and become Bayesian learners at this time with some prior belief on the probability that flood risks have indeed risen.

[14] Formally incorporating different ξ distributions in the populations would be a straightforward extension that would not materially alter the results.

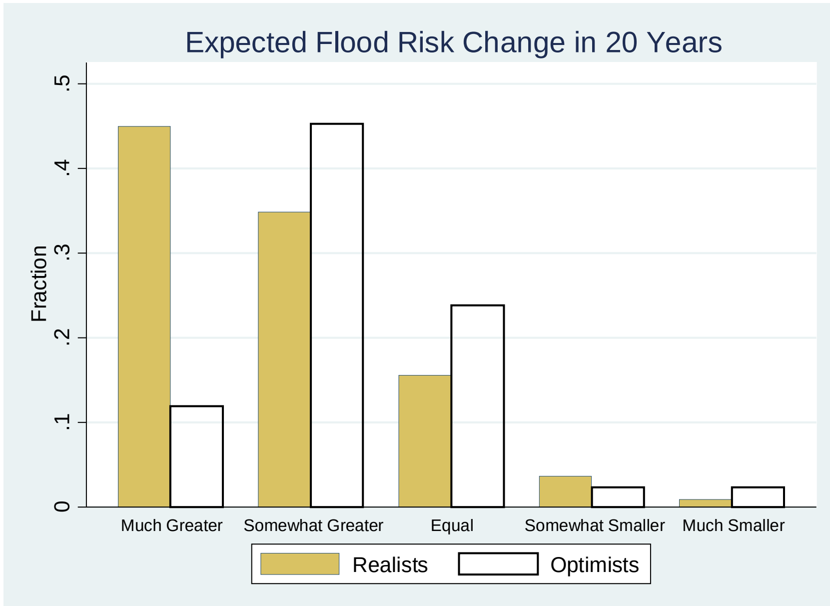

Figure 9

5 Flood Risk and Climate Change

This section describes the available evidence on future and current flood risks in our survey area. Broadly speaking, climate change can impact coastal flood risks through two main channels, first by increasing global sea levels, thereby increasing coastal flood risk through high tide impacts and inundation (Rahmstorf, 2007), and second by impacting tropical cyclone and other storm characteristics (Emanuel, 2005; Emanuel, Sundararajan, and Williams, 2008; Knutson et al, 2010), thereby increasing coastal flood risk through storm surge from extreme events (Lin et al., 2012). While the second channel has greater uncertainty across projections (Knutson et al., 2010), the clearest increase in hurricane power is expected in the North Atlantic ocean basin, with corresponding implications for the United States (Mendelsohn et al., 2012).[15]

Local sea level rise may differ from global sea level rise due to factors including land subsidence, ocean currents, and local winds (NOAA, 2017b). Historical rates of sea level rise in Rhode Island from 1930 to 2015 have averaged 2.22mm/year in Providence and 2.72mm/year in Newport (NOAA, 2017c). This is a faster rate than the global average of 2.08mm/year over the same period. Sea level rise has accelerated globally in recent years, now approximately 3.2mm per year since 1993 (NOAA, 2017d). Future projections of sea level rise vary. Two main sources

[15] Additional atmospheric and hydrological channels exist, such as changes to precipitation patterns that can impact the probability of flooding (see for example Trenberth, 2011), but are not considered in this study.

of projections for the United States are the U.S. Army Corps of Engineers (USACE, 2013) and the National Oceanic and Atmospheric Administration (Blank, Lubchenco, and Dietrick, 2012). Appendix Table 1 presents projections of sea level rise for Newport, RI estimated by both organizations. Estimates for 2100 range from a 0.8 to 6.8 feet rise under the NOAA high scenario.

Translating sea level rise to coastal inundation is an important analytical task. The Rhode Island Shoreline Change Special Area Management Plan (Beach SAMP), a collaborative effort between the Rhode Island Coastal Resources Management Council, the University of Rhode Island Coastal Resources Center, Rhode Island Sea Grant, and partners including the USDA and NOAA, have created STORMTOOLS, a set of current and future inundation maps under various projections of sea level rise. While FEMA FIRMs display current inundation probabilities at the 1 in 100 and 1 in 500 change of annual inundation, STORMTOOLS includes return rates of 1, 2, 3, 5, 10, 25, 50, 100, and 500 years, as well as estimates of historical storm surge inundation from large historical hurricanes including in 1938, 1954 (Carol), 1991 (Bob), and 2012 (Sandy) (SAMP, 2017).[16] Inundation maps, available online as GIS shapefiles, estimate historical inundation levels and return rates using data on water levels at Newport, RI and using NOAA's Sea, Lake, and Overland Surges from Hurricanes model to simulate storm driven coastal inundation under current sea level conditions. Sea level rise is assumed to be linearly additive (a "bathtub" model) given local elevation.[17] In total, 53 inundation layers under various returns rates and assumptions of sea level rise are publicly available. While the STORMTOOLS approach is arguably the most comprehensive publicly available sea level rise inundation layer for Rhode Island, some limitations do occur. Namely, the approach does not account for future changes in storm surge height, other than what is currently occurring plus the assumed additive height from sea level rise. This, if storm surge increases with changes in mean average temperature, as is likely in the Northeastern United States (Lin et al., 2012), these estimates are a lower bound on inundation. The methodology also does not account for local flood mitigations strategies that may change over time. Figure 10 displays land surrounding upper Narragansett Bay at risk for coastal inundation with probability 1 in 100 in a given year, assuming zero and three foot sea level rise.

[16] For the 1, 2, 3, 5, and 10 year inundation layers, the mean (50%) water levels are mapped. Thus, with 50% probability, water levels will exceed these levels in the given return period. For the major events with return rates of 25, 50, 100, and 500 years, water levels at the 95% level are used, implying that the levels would be exceeded with only 5% probability. Thus, we also follow these assumptions in this analysis.

[17] A full methodology can be found here $http://www.rigis.org/data/stormtools$.

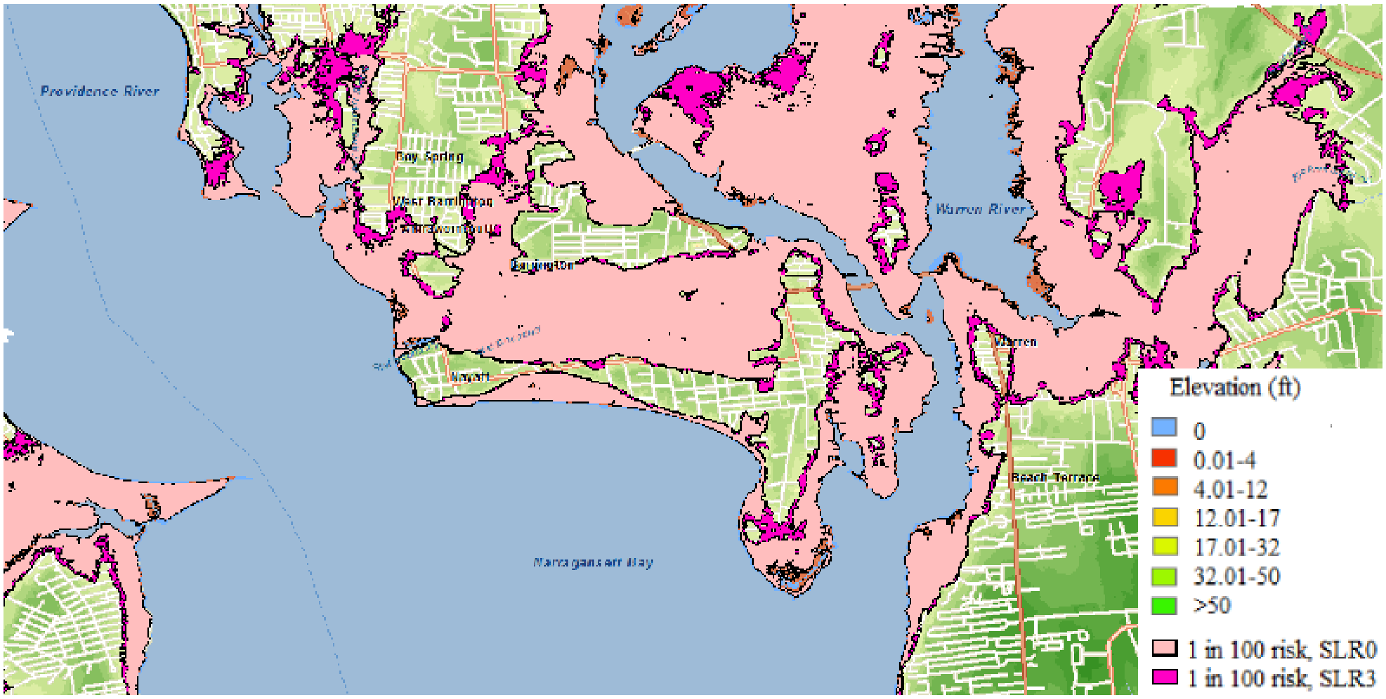

Figure 10

We use these estimates to project both current and future annual flood risks for each of the coastal homes in our survey. Figure 11 presents the resulting distribution of properties in our sample at their projected annual flood risk with different estimates of sea level rise, including 0 (current), 1, 2, 3, and 5 feet. We note that as sea level rise increases, the distribution of homes will shift right, reflecting the increased probability of inundation across our sample, especially at the high risk tail.

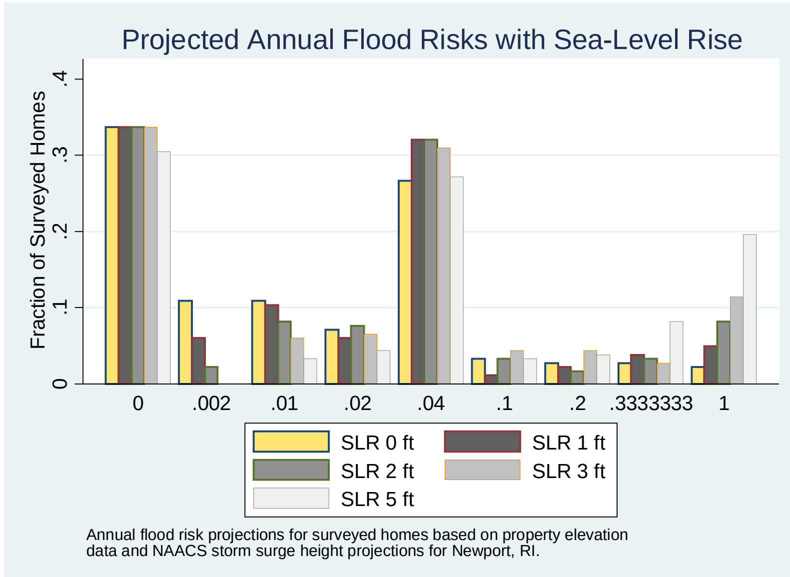

Figure 11

While our analysis focuses on Rhode Island, it is important to note that current and future coastal flood risks affect large areas of the United States. Neumann et al. (2000) estimate that 50 cm (or 1.6 feet) of sea-level rise would result in inundation of approximately 13,000 square miles of land in the United States and a 7,000 square mile (38%) increase in U.S. flood zones. The authors estimate the associated costs to be between $20 and $150 billion under efficient adaptation. However, our results suggest that, by assuming homogeneous beliefs, these figures may understate the costs of sea-level rise. Another recent estimate found that Miami, New York-Newark, and New Orleans have an estimated $970 billion ($2001USD, PPP) in physical assets exposed to coastal flooding and that this figure will increase to $6.7 trillion across the three cities by 2070 (Hanson et al., 2011). For Rhode Island, currently 18,256 properties (4.5% of all RI properties) are at risk for coastal inundation with probabilities exceeding 1 in 100 annually.[18] Even at average Rhode Island home prices($247,400 as per Zillow's Home Value Index), this implies $4.5 billion of property currently at risk.[19] Assuming constant home prices and no new construction or renovations, the value of property at risk is estimated to increase to $5.1 billion under one foot of sea level rise and $6.2 billion under three feet of sea level rise. Thus, while our analysis currently focuses on a small survey area, coastal inundation is an important and significant issue facing coastal communities across the United States.

[18] These numbers are calculated by the authors using STORMTOOLS and data on all residential properties in Rhode Island. Note that this number reflects coastal inundation and not inland flood risk.

[19] Zillow Home Value Estimate accessed by the authors in March 2017 online at *https://www.zillow.com/ri/home-values/*. Note that coastal property values typically exceed inland values, so this is a lower bound on the actual value of property at risk.

6 Model Simulations

Based on the survey and flood risk assessment results, this section presents a calibration and simulation results for the model. Table 3 summarizes the key parameters for the benchmark calibration.

Table 3: Benchmark Model Calibration

Parameter		Value	Source
k_1	Share of coastal homes	0.2	American Housing Survey (Boston MSA); FEMA (RI)
θ^o	Share of optimists	0.35	Survey: Share estimating $\pi_{10yr}^{Flood} < 5\%$
Ξ	Max. coastal amenity ξ (\$/yr)	\$7.7k	Survey: Max WTP within 10% of med. home price
δ	Flood damages (\$)	\$65.65k	Survey: Med. damage/price × Med. price
π_L	Initial annual flood risk	1%	FEMA
π^H	New higher flood risk	4%	STORMTOOLS; elevation mapping
e^h	Net value of living in own home	1.2	Match initial med. coastal home price \$410k
β	Annual discount factor	0.98	
$q^o_{T_1}$	Optimists' prior $\Pr(\pi = \pi^H)$ at T_1	0.1	

Several points should be noted with regards to the calibration. First, for computational reasons, we run the model with one period corresponding to two calendar years, and adjust the relevant calibration parameters accordingly.[20] Next, the benchmark flood risk probability is chosen as follows: On the one hand, based on property elevation and STORMTOOLS simulations, the average property in our sample actually faces a baseline annual flood risk of over 7%. However, flood events here are defined as the water level reaching the ground height of the property structure or higher, so that not all flood events would cause serious damage. Consequently, we adopt the FEMA lower bound on flood event risk of 1% as a conservative measure of baseline risk. As for the new high risk, we focus on a 1 foot of sea level rise scenario, which is likely to occur over the time horizon considered in our simulation (see Appendix for sea-level rise projections in Rhode Island). At 1 foot of sea level rise, the average coastal flood risk in our sample as per STORMTOOLS increases to 15%. Again, however, in order to more conservatvely represent the probability of a serious flood event, we consider a risk increase to 4% in the benchmark. Below, we also consider 2% and 6% as alternative values. Finally, the benchmark share of optimists represents a coastal home share re-weighted average of our survey population to correct for its over-sampling of coastal homes (i.e., (0.2)(50%) + (0.8)(30%), see Table 6 below for details).

Figure 12 presents the main results. We run the model varying the percentage of optimistic agents in the population from 0% (homogeneous rational expectations) to our benchmark pop-

[20] The bi-annual calibration features $\beta' = 0.9702$, $\pi'_L = 1.99\%$, $\pi'_H = 7.84\%$, and flow values doubled.

ulation estimate of $\widehat{\theta^o} = 35\%$. Table 4 summarizes the results numerically. The central finding is that, compared to the homogeneous rational expectations baseline (black line with stars), projected future home price declines due to sea-level rise are significantly more severe once heterogeneity in beliefs is taken into account. Intuitively, the presence of naive agents prevents coastal home prices from fully incorporating expected future flood risk changes, causing them to be and remain higher initially, but falling more steeply later on as agents learn of the true risks.

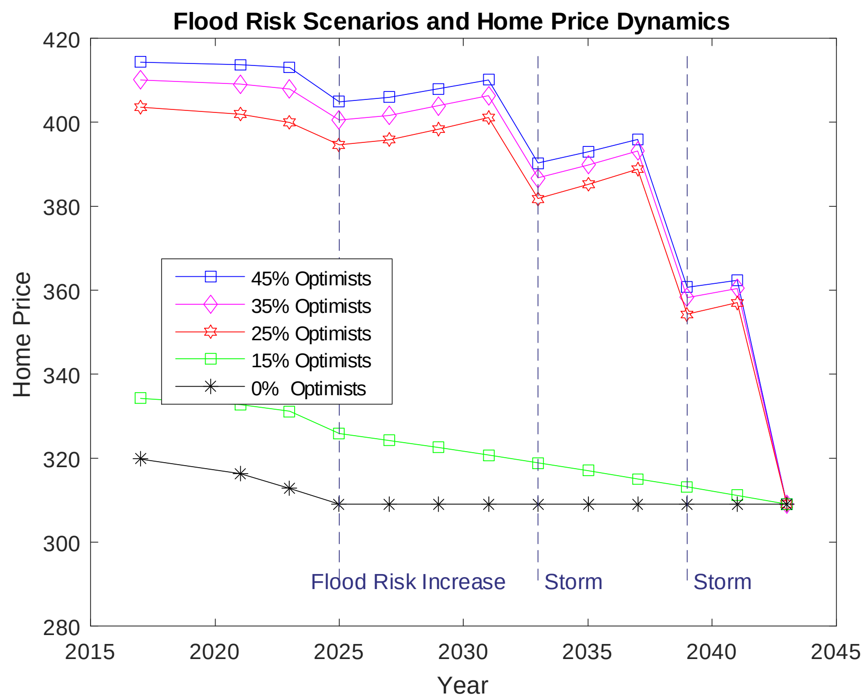

Figure 12

First, if all agents are perfectly informed about future flood risks (0% optimists), home prices are projected to decline only modestly (−3.4%) due to future flood risk increases. Intuitively, this is because the present value of these changes is already smoothly capitalized into home prices leading up to T_1. Allowing for even 15% of the population to be optimistic Bayesian learners more than doubles this projected decline (−7.6%), but maintains a modest overall impact as there are fewer optimists than coastal homes. In contrast, if 25% of the population are optimistic Bayesian learners, the projected future home price decline due to flood risk changes increases to −23.4%. For our benchmark value of 35% misinformed agents, we would expect coastal home prices to drop by −24.6%. To put this figure in context, during the Great Recession, the median U.S. home sale price decline from peak (Q1 2007) to trough (Q1 2009) was about 19%.[21] Consideration of

[21] Source. U.S. Federal Researve (FRED) Median Sales Price of Houses Sold for the United States, 2000-2016.

heterogeneity in climate risk beliefs thus increases projected coastal home price declines by a factor of 7, compared to the standard homogeneous expectations setting. Table 4 summarizes these results.

Table 4: Benchmark Simulation Results

Scenario	Future $\%\Delta P$	Var($\%\Delta P$)
0% Optimists	-3.4%	0.27
15% Optimists	-7.6%	0.10
25% Optimists	-23.4%	21.4
35% Optimists	-24.6%	23.0
45% Optimists	-25.4%	23.8

Flood risk increase from 1% to 4% in 2025.
Risk becomes common knowledge at T=2043.

In order to bein gauging the sensitivity of the results to the chosen parameters, Figure 13 plots the projected evolution of coastal home prices for different flood risk increase scenarios, comparing the homogenous rational scenario with the benchmark $\widehat{\theta}^o = 35\%$ in each case. While the level of price declines is highly sensitive to the projected flood risk increase, consideration of heterogeneity increases the projected price declines by a factor of 6-8 in each scenario.

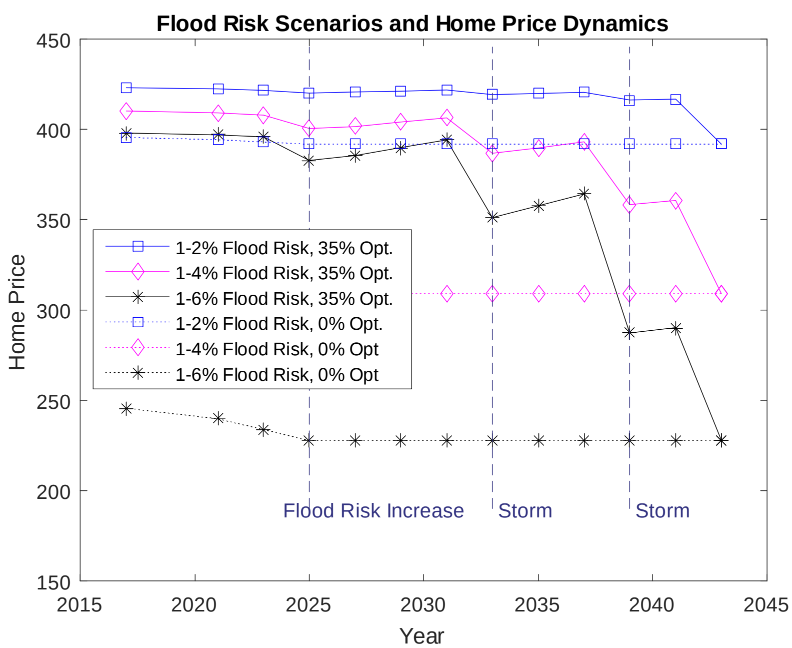

Figure 13

Table 5: Flood Risk Sensitivity		
Scenario	Future $\%\Delta P$	
	$\pi_H = 2\%$	$\pi_H = 6\%$
0% Optimists	-0.9%	-7.3%
35% Optimists	-7.3%	-42.8%

To summarize, the central quantitative findings is that consideration of heterogeneity in flood risk beliefs dramatically increases the extent to which coastal homes are expected to be overvalued, and, by the same token, the price declines that will result from future flood risk changes. Projected volatility in coastal home prices similarly increases by close to an order of magnitude once heterogeneity in flood risk beliefs is taken into account.

7 Extensions and Robustness

7.1 Ex-Post Rationalization vs. Ex-Ante Belief Heterogeneity

Our main analysis assumes that households' flood risk perceptions evolve principally based on the realization of flood events, or the lack thereof. One potential concern with interpreting observed flood risk belief heterogeneity in this way is that coastal residents could also be changing their beliefs *differentially* after moving to the coast in order to rationalize their sorting choice ex-post. In order to address this concern, this section first extends the model to illustrate how ex-post rationalization could change the empirical implementation of the model, and then reviews the survey evidence through the lens of this modified structure. The central finding is that ex-post rationalization effects should not fundamentally alter the main results as long as there are misinformed agents among the potential marginal buyers of coastal homes, which we empirically find likely to be the case. That is, while ex-post rationalization may create a class of 'entrenched' coastal residents whose home valuations exceed the market price for coastal homes (and who are consequently not marginal *sellers*), mispricing of coastal homes that are being sold (e.g., by fully informed agents) will continue as long as there are misinformed agents among the potential marginal buyers. Empirically, we moreover find that a substantial fraction of currently non-coastal agents (30%) underestimate coastal flood risks.

In order to formalize the idea of ex-post rationalization, we first continue to assume that there are both Bayesian learners or optimists, as well as fully informed realists in the population. For ease of illustration, assume that the world starts in a neutral state where nobody has yet purchased or rented a home, and all optimists o initially have common flood risk belief π_0^o. The initial sorting in period 0 is thus the same as in the benchmark model.

We focus on the most interesting and empirically relevant *Case 2* where both optimists and realists are initially in the coastal home market. In period 0, the market-clearing coastal home price P_0 equates both the marginal optimist's and realist's willingness to pay:

$$P_0^* = \beta(e^h + \overline{\xi_0^r} - \pi^r\delta + E_0^r[P_1]) = \beta(e^h + \overline{\xi_0^o} - \pi_0^o\delta + E_0^o[P_1]) \tag{19}$$

If no storm occurs in period 0, both coastal and non-coastal optimists (or Bayesian learners) update their flood risk estimates downward. Importantly, however, coastal residents may further change their beliefs differentially in response to having moved to the coast (ex-post rationalization). Specifically, let $\pi_1^{o,C_{0,1}}$ denote the period 1 flood risk belief of optimists that lived on the coast from period 0 to 1 ($C_{0,1}$), and $\pi_1^{o,NC_{0,1}}$ analogously for optimists who did not live on the coast ($NC_{0,1}$). Beliefs evolve according to:

$$\pi^r > \underbrace{\pi_0^o > \pi_1^{o,NC_{0,1}}}_{\substack{\text{Bayesian}\\\text{Updating}}} \underbrace{> \pi_1^{o,C_{0,1}}}_{\text{Rationalization}} \tag{20}$$

Beliefs (20) imply the following changes. First, the coastal home price valuation of optimists already living on the coast has increased more than other agents', indicating that they will retain the highest willingness to pay and remain in their coastal homes. Consequently, measure $\frac{\theta^o}{\Xi}(\Xi - \overline{\xi^o}_0)$ of coastal homes remains occupied by their initial optimist residents. Second, the period 0 marginal optimist's contemporaneous coastal home price valuation has increased, i.e.:

$$\overline{\xi_0^o} - \pi_1^{o,NC_{0,1}}\delta > \overline{\xi_0^o} - \pi_0^o\delta$$

In contrast, the marginal realist's contemporaneous valuation remains unchanged ($\overline{\xi_0^r} - \pi^r\delta$). While a full characterization of the period 1 equilibrium would require us to take a stance on the full evolution of all agent's future price expectations $E_1^r[P_2^{m_2}]$, $E_1^{o,NC_{0,1}}[P_2^{m_2}]$, $E_1^{o,C_{0,1}}[P_2^{m_2}]$, $E_2^{o,NC_{0,2}}$, $[P_3^{m3}]$, $E_2^{o,NC_{0,1};C_{1,2}}[P_3^{m_3}]$, ... including the extent to which each type of agent is aware of ex-post rationalization effects, how it colors their beliefs about others' beliefs, etc., a plausible scenario - in line with the structure of the baseline model - is that optimists' future price expectations at time 1 increase at least weakly more than realists' future price expectations in response to their updated beliefs (20): $E_1^{o,C_{0,1}}[P_2^{m_2}] \geq E_1^{o,NC_{0,1}}[P_2^{m_2}] \geq E_1^r[P_2^{m_2}] \geq E_0^r[P_1^{m_1}]$. In that case, we would expect the period 1 equilibrium to unfold as follows: some measure of non-coastal optimists' valuations to now exceed those of coastal resident realists, leading the former to buy coastal homes from the latter. Importantly, the *marginal buyers* are now the previously non-coastal optimists, whereas the marginal sellers are the realists.[22] The equilibrium coastal home price in period 1 is

[22] In the aftermath of a storm, coastal optimists could become marginal sellers as well, depending on how they

thus determined by the interaction between these groups. More formally:

$$P_1^* = \underbrace{\beta(e^h + \overline{\xi_1^r} - \pi^r\delta + E_1^r[P_2])}_{\text{Newly marginal coastal realists}} = \underbrace{\beta(e^h + \overline{\xi_1^o} - \pi_1^{o,NC_{0,1}}\delta + E_1^{o,NC_{0,1}}[P_2])}_{\text{Marginal new coastal Bayesians}} \quad (21)$$
$$< \underbrace{\beta(e^h + \overline{\xi_0^o} - \pi_1^{o,C_{0,1}}\delta + E_1^{o,C_{0,1}}[P_2])}_{\text{Long-term coastal Bayesians}}$$

With ex-post rationalization (or differential updating), the model thus predicts that long term coastal residents' valuations of their homes may well exceed the market price of coastal homes being sold. However, as long as there are marginal buyers of coastal homes that hold inaccurate flood risk beliefs $\pi_1^{o,NC_{0,1}}$, the potential for mispricing remains robust to ex-post rationalization effects among coastal residents.

Empirically, the key implication of (21) is that optimistic beliefs should be calibrated based on a sample representing marginal buyers, which may not correspond to the full sample. That is, if (long-term) coastal residents are more optimistic about flood risks than the marginal Bayesians whose beliefs pin down prices, we might be concerned that combining survey responses from all residents leads to an overestimate of optimism compared to the relevant population.

While do not observe agents in the home-buying process, we can approximate the beliefs of marginal buyers in several ways. First, Figure 14 compares the flood worry distributions among *new movers*, defined as agents who moved from another town to their survey area within the past 3 years ($n = 26$).

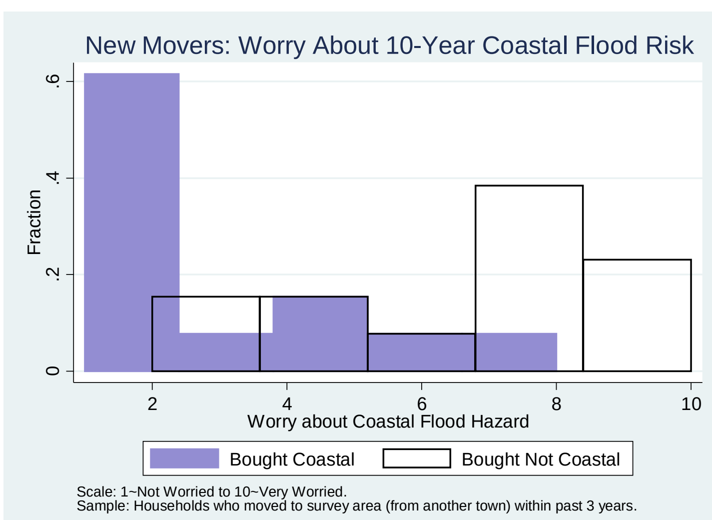

Figure 14

update their beliefs.

Much like the analogous figures for the full sample, Figure 14 shows that those who select into buying coastal homes are significantly less concerned about flood risks than those who select into inland homes. Importantly, however, there is considerable overlap in the flood belief distributions, suggesting that flood risk misperceptions exist independently of any ex-post rationalization effects that may be occurring among those who selected into coastal homes. That is, flood risk misperceptions seem to exist among potential buyers for coastal homes. Figure 15 further illustrates this fact by showcasing the joint amenity value and flood risk distribution among recent movers:

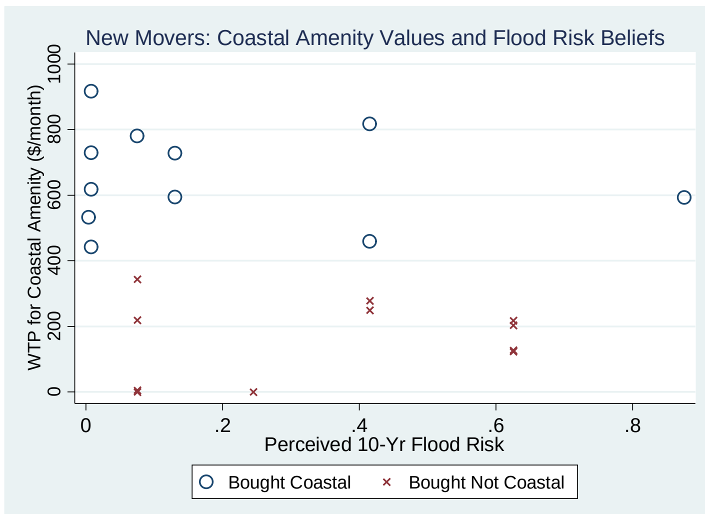

Figure 15

How quantitatively important are misperceptions among potential buyers? Returning to our definition of optimists as those that underestimate 10-year flood risk by at least 50% yields the following estimates of optimist shares $\widehat{\theta}^o$:

Sample	$\widehat{\theta}^o$	n
Full Sample	40%	185
Coastal Residents	49%	96
Non-Coastal Residents	30%	89
New Movers	32%	31
Coastal New Movers	53%	16
Non-Coastal New Movers	13%	15

The results in Table 6 suggests that a considerable fraction of non-coastal agents significantly underestimate flood risks. Consequently, the potential marginal buyers for coastal properties appear likely to misperceive flood risks in our sample and empirical setting, regardless of whether beliefs of established coastal residents are additionally affected by ex-post rationalization.[23]

7.2 Overreactions and Belief Change Myopia

The benchmark model assumes that realists have fully rational expectations about the evolution of optimists' future flood risk perceptions and predictions. This setup creates heterogeneity not only in flood risk perceptions but in agents' beliefs about the evolution of each other's beliefs. This section relaxes the assumption of this level of sophistication and presents results for a model run where both optimists and realists are mostly myopic about each other's future flood risk belief changes. An exception occurs in period $T-1$, when both agents learn that the true flood risk will be announced in period T, with each type expecting the other to revise their beliefs in the next period. In order to facilitate the comparison to the benchmark case, we present two scenarios where flood risk has already changed in the first period (i.e., the world begins at T_1). Figure 16 presents projected price dynamics. The results suggest broadly similar patterns across the two scenarios, although the initial coastal home price overvaluation is larger in the benchmark setting. Intuitively, this is because disagreements about future prices can increase willingness to pay for homes in the benchmark setting, whereas this channel for home price overvaluation is shut down in the myopic case.

[23] It should further be noted that even the 13% estimate among non-coastal new movers (setting aside small sample concerns) could still be consistent with substantial mispricing, in contrast to the benchmark framework. The reason is that, with ex-post rationalization, a fraction of coastal homes is effectively off the market due to the 'entrenched' long-term coastal residents with differentially optimistic beliefs. Consequently, the marginal coastal buyer will be misinformed as long as there are enough misinformed agents relative to the measure of coastal homes available for sale at their willingness to pay in any given period.

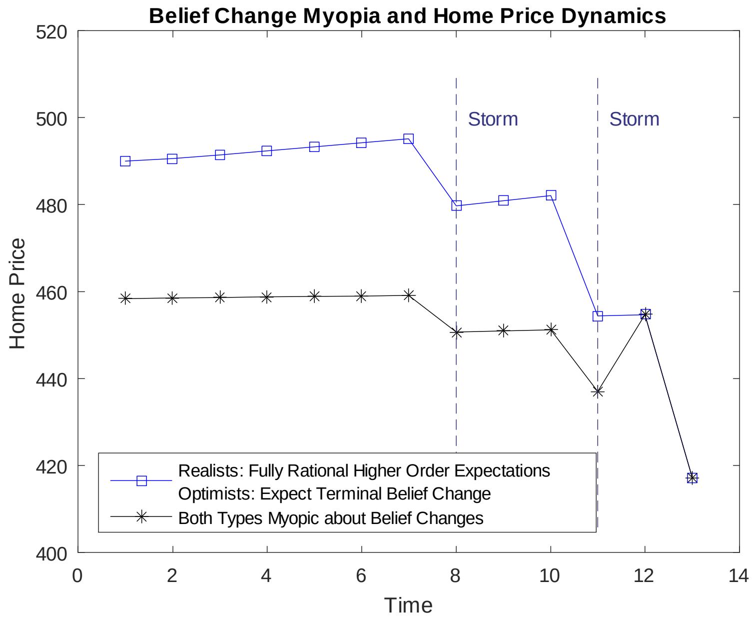

Figure 16

The second extension considers the possibility that optimistic agents "overreact" to flood events as per (16). The motivation for this extension is that several empirical studies have found that, in the aftermath of flood events, both home prices and flood insurance demand revert to baseline within only 5-10 years (Bin and Landry, 2013; Gallagher, 2014; Atreya and Ferreira, 2015). As shown in Figure 2, a modest degree of overreaction compared to the benchmark Bayesian learning scenario is sufficient for beliefs to revert to baseline at this pace. Figure 17 presents simulated coastal home price dynamics across standard Bayesian learning and two overreaction scenarios. It should be noted that these are all still 'myopic' scenarios with regards to realists' failure to anticipate changes in optimists' beliefs.[24]

[24] The 'myopic' scenario can readily be simulated for long time horizons where the overreaction parameters are more likely to be important, compared to the benchmark scenario where the curse of dimensionality hampers consideration of long time horizons.

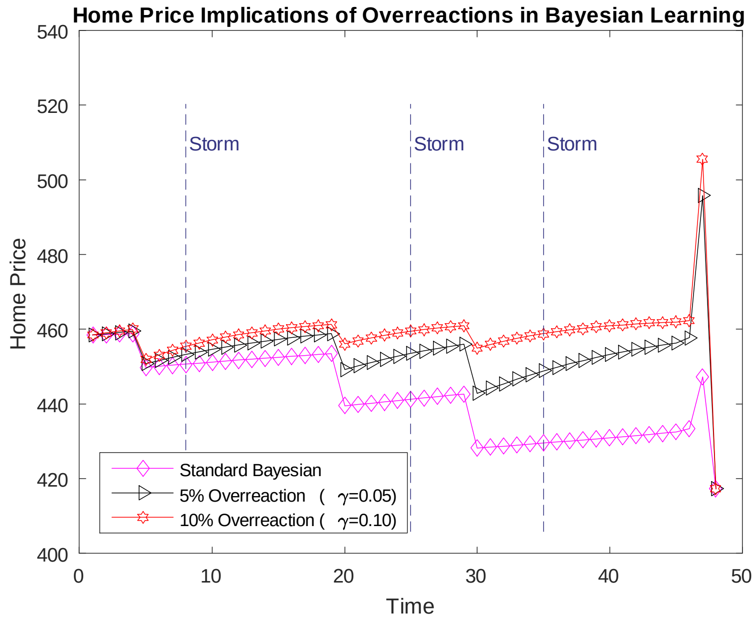

Figure 17

As one might expect, we find that even a modest degree of "overreaction" in optimists' inference from flood events can significantly hamper learning of true flood risks, and thus the correction of coastal home prices to their fundamental value. This overvaluation ultimately leads to larger coastal home price devaluations as the market adjusts to the true new flood risk. In sum, consideration of overreaction in optimists' Bayesian updating thus further enhances the potential of belief heterogeneity to exacerbate the economic risks associated with sea-level rise.

8 Conclusion

This paper examines how climate risk belief heterogeneity impacts coastal housing markets and the costs of sea level rise through both theoretical and empirical evidence. We develop a dynamic housing market model incorporating heterogeneity in home types, consumer preferences, and flood risk beliefs. A subset of agents is not immediately informed about sea-level rise and learns about the new flood risk level from storm events in a Bayesian framework. We also extend the model to account for potential overreaction to flood events, consistent with empirical findings in the flood impact valuation literature.

The central insight from the model is that coastal home price dynamics depend critically on the joint distribution flood risk beliefs and coastal amenity values, and on the evolution of climate beliefs, and that even a modest fraction of misinformed agents can lead to significant overvaluation and subsequent price collapses in coastal housing markets. Thus, we conduct a door-to-door survey in Rhode Island to elicit these joint distributions empirically, controlling for critical other factors such as expectations of flood damages, insurance payouts, and post disaster public aid. Consistent with the theoretical model, we find coastal residents to have on average higher amenity values for coastal living and a lower perception of the true risk of flooding, relative to inland counterparts, while other observables are not statistically different.

Lastly, we utilize our survey data to calibrate the model and project home price dynamics under a flood risk increase. In the scenario with fully informed agents, home prices decrease only modestly (-3.4%) as the disamenity has already been smoothly capitalized into the home prices. However, increasing the fraction of optimistic agents to our benchmark estimate of 35% leads to a future price change of -24% for coastal homes, reflecting the previous overvaluation and leading to greatly increased volatility in the market.

Two fundamental policy-relevant variables that play a key role in the model are (1) the fraction of optimistic agents in the market and (2) the availability of high quality information concerning current and projected future flood risk. The fraction of optimistic agents directly impacts the degree of overvaluation and volatility in the housing market. Thus, education and information campaigns, such as FEMA's Risk Mapping and Assessment Program (Risk MAP), aimed at providing high quality information surrounding current flood risk may be able to contribute to broader stability in housing markets. Another important but missing element of FEMA's current flood map system are projections of future flood risks. Without information on the likelihood of future changes to coastal flood risk, even rational buyers may be unable to forecast future home values, leading to additional overvaluation and volatility. To date, projections of future flood risks have been few and piecemeal. Given recent state and federal budget proposals to deprioritize the production of flood risk information, public policy thus has the potential to exacerbate - or mitigate - U.S. housing market volatility in the coming years.

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9 Appendix

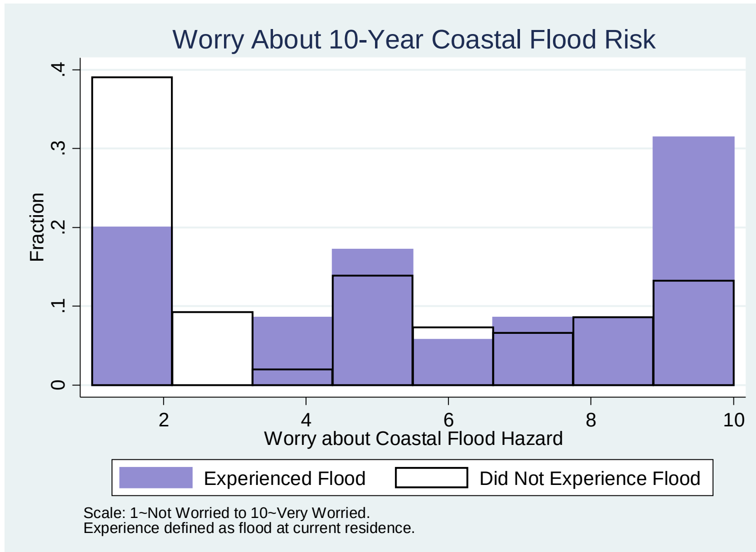

Figure A1

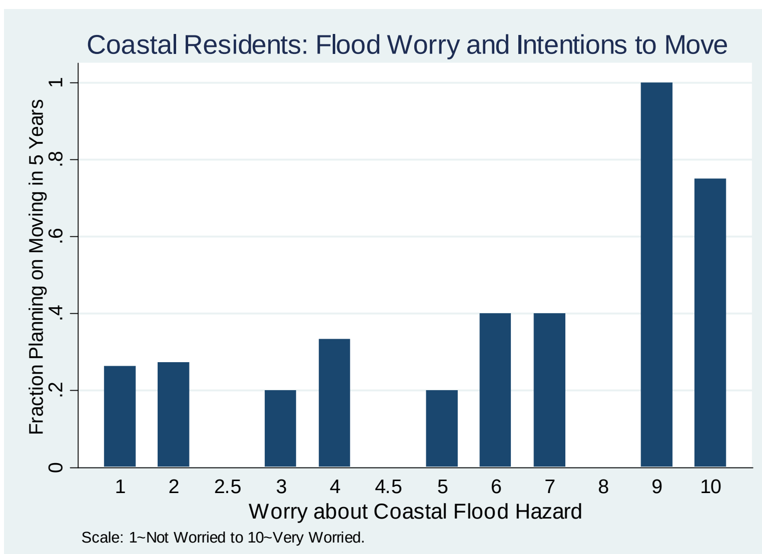

Figure A2

Table A1: Coastal Amenity Willingness-to-Pay

DBDC Estimation on WTP for Coastal Amenity

	Beta	Sigma
ln(Est. Home Market Value)	410.3***	
	(150.5)	
Coastal	339.5***	
	(96.34)	
Income	-0.000322	
	(0.766)	
Age	-3.412	
	(2.812)	
Number in Household	-27.72	
	(29.79)	
Education Index (1-9)	20.90	
	(19.89)	
Caucasian	207.4*	
	(125.7)	
Property Square Footage	-0.0149**	
	(0.00726)	
House # Rooms	24.50	
	(30.95)	
Constant	-2,358***	277.4***
	(857.9)	(59.82)
Observations	126	126

Reports results of double-bounded dichotomous choice estimation of WTP (non-coastal) or willingness to accept (coastal) for living within 400 feet of the waterfront. Starting bids randomized from $150, $250, and $350. Follow-up bids add/subtract $75. Standard errors in parentheses. (*** p<0.01, ** p<0.05, * p<0.1).

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2000	0	0	0	0	0
2005	0	0	0	0.1	0.1
2010	0	0.1	0.1	0.2	0.2
2015	0.1	0.1	0.2	0.3	0.4
2020	0.1	0.2	0.4	0.4	0.5
2025	0.2	0.3	0.5	0.6	0.7
2030	0.2	0.3	0.6	0.7	0.9
2035	0.3	0.4	0.8	0.9	1.2
2040	0.3	0.5	1	1.2	1.5
2045	0.3	0.6	1.1	1.4	1.8
2050	0.4	0.7	1.3	1.6	2.1
2055	0.4	0.8	1.6	1.9	2.5
2060	0.5	0.9	1.8	2.2	2.8
2065	0.5	1	2	2.5	3.2
2070	0.6	1.1	2.3	2.8	3.7
2075	0.6	1.2	2.6	3.1	4.1
2080	0.6	1.3	2.8	3.5	4.6
2085	0.7	1.4	3.1	3.9	5.1
2090	0.7	1.6	3.5	4.3	5.6
2095	0.8	1.7	3.8	4.7	6.2
2100	0.8	1.8	4.1	5.1	6.8

Note: All values are in feet relative to NAVD88 plus 0.3 feet to equal zero in the year 2000. Source: USACE, 2017

Table 1: USACE and NOAA Sea Level Rise Projections (in feet) for Newport, RI

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Survey #__________________ **[C]**   Surveyor: _____________

Rhode Island Housing Choice and Risk Perceptions Survey

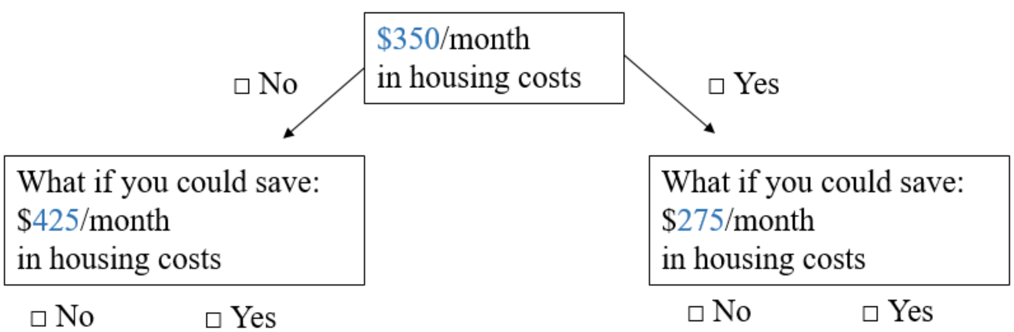
Thank you for your time. We would like to start by asking you some questions about your home.

1) Is your home:
[] Owned by someone in your household   [] Rented   [] Other: ______________________________

2) We are interested in what you think will happen to the prices of homes [*if owned:* like yours] in this part of Portsmouth in the future. By about what percent do you expect prices of homes [*if owned:* like yours] to go (up or down), on average, over the next year?
[] Increase   [] Decrease   []Unsure
+%____________   -%____________

IF OWN:
2.1) Do you have any plans to sell this home in the next 5 years?
[] Yes   [] No   [] Unsure

Great! Next we'd like to ask you about living near the water.
3.1) Imagine that you had the option to instantly move to another house in Portsmouth that was about 400 feet further inland, but that was otherwise identical to your home: Same house, same school district, same environmental risks, etc. – everything the same except being about 400 feet further inland. Would you be willing to move to such a house if you could save:



[NOTE: IF IN QUESTION, CLARIFY THAT THIS IS HOLDING FLOOD RISK CONSTANT.]
Great! We'd now like to ask you about flooding.

4) At your current residence, have you experienced a flood in the past?
[] Yes   [] No   [] Don't know

We'd like to understand your perceptions on the risk that, over the next 10 years, your home will be flooded at least once.

Survey #__________________ **[C]** Surveyor: _____________

5) How worried are you about the risk of a flood to your home over the next 10 years, on a scale of 1 to 10 where "1" means "not worried at all" and "10" means "very worried"?

____

5.1) And what do you think the probability is that such a flood will occur? [SHOW THEM SCALE]. Here is a list of probability ranges from 0% or no chance to close to 100% chance. Which of these comes closest to your view?
[] 0 [] 0-0.2% [] 0.2-0.5% [] 0.5-1% [] 1-5% [] 5-10% [] 10-16%
[] 16-33% [] 33-50% [] 50-75% [] 75-100%

5.2) Have you taken any precautionary steps to reduce your risk of flooding? [E.g.: install water pump, elevate water heater, etc.] If yes, what steps have you taken?
[] No / None
[] Yes (please list all stated):____

____

6) If a major flood event did occur here in Portsmouth, how much total damage would you expect it to cause to your home and its contents, including both insured and uninsured losses?
$_______________________________

6) Of these damages, about what fraction would you expect to be repaid by insurance?
[] Nothing [] 0-20% [] 20-40% [] 40-60% [] 60-80% [] 80-100%

7) Would you also expect any financial assistance with these flood damages from the government?
[] Yes [] No [] Not sure

IF YES: Of the total flood damages, about what fraction would you expect to be paid back through public assistance?
[] Nothing [] 0-20% [] 20-40% [] 40-60% [] 60-80% [] 80-100%

9) Last flood-related question: Do you think the risk of flooding to homes like yours will change in the future? 20 years from now, do you think the risk of flooding will be:
[] Much Greater [] Somewhat greater [] Equal [] Somewhat smaller [] Much smaller

10) Why do you think flood risk will change this way? [*DO NOT READ EXAMPLES*]
[] Construction/land use change [] Sea-level rise [] Climate change

Other: ____

11) At this point we'd also like to ask you about your opinions on climate change. Do you believe that the global climate is changing? [] Yes [] No [] Unsure

Survey #_________________ **[C]** Surveyor: _____________

IF YES:
11.1) Do you believe that climate change will increase the flood risk to your home?
[] Yes [] Maybe [] No [] Unsure

Great, thank you! We are close to done but first have just a couple more risk-related questions:

11) How worried are you about the risk of a fire to your home over the next 10 years, again on a scale of 1 to 10 where "1" means "not worried at all" and "10" means "very worried"?

____

11.1) And what do you think the probability is that a fire will occur? [SHOW THEM SCALE]
[] 0 [] 0-0.2% [] 0.2-0.5% [] 0.5-1% [] 1-5% [] 5-10% []10-16%
[] 16-33% [] 33-50% [] 50-75% [] 75-100%

11.2) Have you taken any precautionary steps to reduce your risk of fire? [E.g.: fire alarm, fire extinguisher, fire ladder, etc.] If yes, what steps have you taken?
[] No / None
[] Yes (please list all stated):____

____

Great! Thank you Now just a few more questions:

IF OWNED:
You said you owned this home:
12.1) Approximately much do you think your home would sell for on today's market?

$_______________________________

12.2) When did you purchase this home? Year: ________________ [] Check if unsure

12.3) Prior to moving to this house, what town did you live in? ____________________

12.4) And was your prior home also very close (within 400 feet) of coastal water? [] Yes [] No

IF RENTED:
12.1) You said you rent this home. May I ask what is your monthly rent payment?
$_________________ [] Check if unsure

Great! Thank you. To wrap up, we would really appreciate if you could fill out a very quick confidential demographic questionnaire.

[Hand over questionnaire]

Survey #__________________ **[C]** Surveyor: _____________

Confidential Demographic Questionnaire

1) Number of people who live in your household: _____________

2) What is your age? ______________

3) What is your total annual household income?

[] Less than $15,000 [] $15,000-$29,999 [] $30,000-$44,999 [] $45,000-$59,999
[] $60,000-$74,999 [] $75,000-$99,999 [] $100,000-$149,999 [] $150,000-$199,999
[] >$200,000

4) What is your ethnicity (or race)?

[] Caucasian/White [] Hispanic/Latino [] African American [] Asian/Pacific Islander
[] Native American/American Indian [] Other

5) What is the highest degree or level of schooling you have completed?

[] 8th Grade or Less [] Some High School [] High School Graduate or equivalent (GED)
[] Some College [] Trade/Technical/Vocational Training [] Associate Degree
[] Bachelor's Degree [] Some Graduate School [] Graduate Degree

6) What is your political affiliation?
[] Democrat [] Independent [] Republican [] None
[]Other ____

Thank you very much for your time and participation!

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10-Year Flood Probability Range	
0% - No chance	
0-0.2% chance	0 to 1 in 500
0.2-0.5% chance	1 in 500 to 1 in 200
0.5-1% chance	1 in 200 to 1 in 100
1-5% chance	1 in 100 to 1 in 20
5-10% chance	1 in 20 to 1 in 10
10-16% chance	1 in 10 to 1 in 6
16-33% chance	1 in 6 to 1 in 3
33-50% chance	1 in 3 to 1 in 2
50-75% chance	1 in 2 to 3 in 4
75-100% chance	3 in 4 to 1 in 1

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Survey #_________________ **[NC]** Surveyor: _____________

Rhode Island Housing Choice and Risk Perceptions Survey

Thank you for your time. We would like to start by asking you some questions about your home.

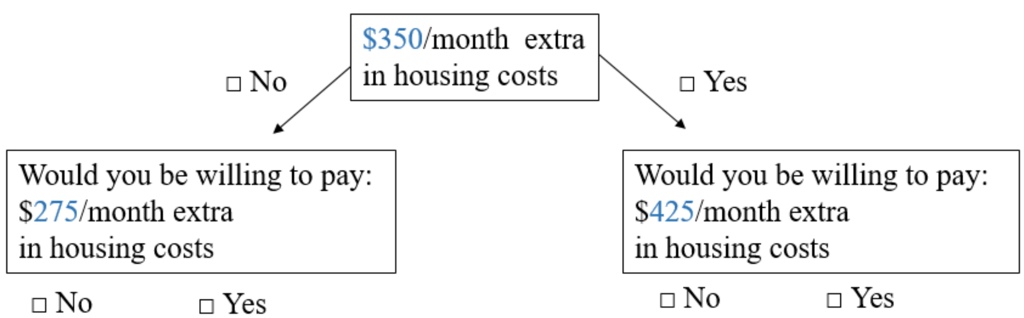
1) Is your home:
[] Owned by someone in your household [] Rented [] Other: ____________________________

2) We are interested in what you think will happen to the prices of homes [*if owned:* like yours] in this part of Portsmouth in the future. By about what percent do you expect prices of homes [*if owned:* like yours] to go (up or down), on average, over the next year?
[] Increase [] Decrease []Unsure
+%___________ -%___________

IF OWN:
2.1) Do you have any plans to sell this home in the next 5 years?
[] Yes [] No [] Unsure

Great! Next we'd like to ask you about living closer to the water.

3.1) Imagine that you had the option to instantly move to another house in Portsmouth that was within 400 feet of the waterfront, but that was otherwise identical to your home: Same house, same school district, same environmental risks, etc. – everything the same except being within 400 feet of the waterfront. Would you be willing to move to such a house if you had to pay:



[NOTE: IF IN QUESTION, CLARIFY THAT THIS IS HOLDING FLOOD RISK CONSTANT.]
Great! We'd now like to ask you about flooding.

4) At your current residence, have you experienced a flood in the past?
[] Yes [] No [] Don't know

We'd like to understand your perceptions on the risk of flooding for a home like yours but that is located within 400 feet of the waterfront in this part of Portsmouth. Please imagine that you lived in such a home.

Survey #__________________ **[NC]** Surveyor: _____________

5) How worried would you be about the risk of a flood to a coastal Portsmouth home over the next 10 years, on a scale of 1 to 10 where "1" means "not worried at all" and "10" means "very worried"?
____

And what do you think the probability is that such a flood would occur? [SHOW THEM SCALE]. Here is a list of probability ranges from 0% or no chance to close to 100% chance. Which of these comes closest to your view?
[] 0 [] 0-0.2% [] 0.2-0.5% [] 0.5-1% [] 1-5% [] 5-10% []10-16%
[] 16-33% [] 33-50% [] 50-75% [] 75-100%

6) If a major flood event did occur here in Portsmouth, and if your home was located near the coast, how much total damage would you expect it to cause to your home and its contents, including both insured and uninsured losses?
$________________________________

6) Of these damages, about what fraction would you expect to be repaid by insurance?
[] Nothing [] 0-20% [] 20-40% [] 40-60% [] 60-80% [] 80-100%

7) Would you also expect any financial assistance with these flood damages from the government?
[] Yes [] No [] Not sure

IF YES: Of the total flood damages, about what fraction would you expect to be paid back through public assistance?
[] Nothing [] 0-20% [] 20-40% [] 40-60% [] 60-80% [] 80-100%

9) Last flood-related question: Do you think the risk of flooding to coastal homes here in Portsmouth will change in the future? 20 years from now, do you think the risk of flooding will be:
[] Much Greater [] Somewhat greater [] Equal [] Somewhat smaller [] Much smaller

10) Why do you think flood risk will change this way? [*DO NOT READ EXAMPLES*]
[] Construction/land use change [] Sea-level rise [] Climate change

Other: ____

11) At this point we'd also like to ask you about your opinions on climate change. Do you believe that the global climate is changing? [] Yes [] No [] Unsure

IF YES:
11.1) Do you believe that climate change will increase the flood risk to your home?
[] Yes [] Maybe [] No [] Unsure

Great, thank you! We are close to done but first have just a couple more risk-related questions:

Survey #_________________ **[NC]** Surveyor: _____________

11) How worried are you about the risk of a fire to your home over the next 10 years, again on a scale of 1 to 10 where "1" means "not worried at all" and "10" means "very worried"?

____

11.1) And what do you think the probability is that a fire will occur? [SHOW THEM SCALE]
[] 0 [] 0-0.2% [] 0.2-0.5% [] 0.5-1% [] 1-5% [] 5-10% []10-16%
[] 16-33% [] 33-50% [] 50-75% [] 75-100%

11.2) Have you taken any precautionary steps to reduce your risk of fire? [E.g.: fire alarm, fire extinguisher, fire ladder, etc.] If yes, what steps have you taken?
[] No / None
[] Yes (please list all stated):____

____

Great, thank you for answering these questions. Now:
IF OWNED:
You said you owned this home:
12.1) Approximately much do you think your home would sell for on today's market?

$________________________________

12.2) When did you purchase this home? Year: ________________ [] Check if unsure

12.3) Prior to moving to this house, what town did you live in? ____________________

12.4) And was your prior home also more than 400 feet away from any coastal water? [] Yes [] No

IF RENTED:
12.1) You said you rent this home. May I ask what is your monthly rent payment?
$_________________ [] Check if unsure

Great! Thank you. To wrap up, we would really appreciate if you could fill out a very quick confidential demographic questionnaire.

[Hand over questionnaire]