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ABSTRACT

How will climate risk beliefs affect coastal housing market dynamics? This paper provides both theoretical and 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 allowing agents to update their beliefs depending on whether flood events occur. Second, to quantify these elements, we implement a door-to-door survey campaign 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 coastal home price trajectories given a future flood risk increase and policy reform across different belief scenarios. Accounting for heterogeneity increases the projected home price declines due to sea level rise by a factor of four, and increases market volatility by an order of magnitude. Studies assuming homogeneous rational expectations may thus substantially underestimate the home price implications of future climate risks. We conclude by highlighting potential implications for welfare and flood policy.

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1 Introduction

How will climate risks affect coastal housing markets? In a world with homogeneous 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). While heterogeneity appears highly empirically relevant for flood and climate risk perceptions in the United States, standard approaches to modeling the economic impacts of sea level rise have assumed homogeneous beliefs, thus potentially underestimating its broader economic ramifications.

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). 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 are determined by the joint distribution of flood risk beliefs, amenity values, and expectations of future flood risks, beliefs, and policy. In order to calibrate these relationships, we implement a door-to-door survey campaign in Rhode Island.[1] The results confirm significant heterogeneity in flood risk beliefs, and that selection into coastal homes is driven by both lower risk perceptions and higher amenity values for waterfront living. For example, we find that the majority of coastal residents underestimate their homes' flood risks relative to inundation models, and that 40% of *flood zone* respondents say they are "not at all" worried about flooding over the next ten years. In contrast,

[1] Section 4 structurally motivates the use of stated preference methods by highlighting the limitations of hedonic approaches in estimating the desired parameters of interest from housing sales data. However, as a robustness check we also present results from a hedonic analysis in Section 7.

a plurality of respondents living further inland indicate that they would be "very worried" about flooding if they lived on the coast. We confirm that these differences are not driven by differential expectations of damages, government assistance, or insurance reimbursements in case of a flood.

Calibrating the model based on the survey and regional data, we then simulate coastal home price trajectories given future flood risk increases and policy reform across different belief scenarios. The main result is that consideration of belief heterogeneity dramatically increases the projected housing market impacts of future flood risk increases. Compared to the standard setting with homogeneous rational expectations, projected price declines increase by a factor of four, and market volatility increases by an order of magnitude once heterogeneity is taken into account. Our benchmark estimate suggests flood risk change impacts on median coastal home prices of -12.7% over the next 25 years, compared to a -3% effect with homogeneous rational beliefs. Intuitively, the presence of optimistic agents prevents coastal home prices from fully incorporating expected future flood risk changes, causing them to be higher initially, but falling more steeply later on as agents learn of the true risks and/or are eventually forced to internalize them through insurance policy reform. To put this figure in context, the Great Recession median U.S. home price change from peak to trough was approximately -19%.[2]

These findings have important policy and welfare implications. First, they 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.[3] Even updated maps generally provide backwards-looking risk assessments that do not take climate change into account. Our framework demonstrates how the absence of accurate flood risk information can threaten both the efficiency and stability of coastal housing markets. Second, coastal mispricing creates welfare costs. We quantify the allocative inefficiency of agents with high amenity values for waterfront living being priced out of coastal areas by agents with lower amenity values but optimistic flood risk beliefs. While we do not model the mortgage origination process and the use of coastal properties as collateral, we note the potential for significant additional welfare costs through this channel. For example, the devaluation of coastal properties could lead to defaults and adverse credit market impacts (see, e.g., Geanakoplos, 2010), thereby exacerbating market incompleteness. Finally, our results highlight the potential impacts of flood insurance policy reform. The need for changes to the National Flood Insurance Program has become increasingly apparent as the program remains fiscally insolvent. As of March 2016, FEMA already owed $23 billion to the U.S. Treasury (GAO, 2017), a figure unfortunately likely to increase significantly in the aftermath of Hurricanes Harvey and Irma. We model an insurance

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

[3] 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

mandate at actuarially fair rates which would force the internalization of real risk rates and re-align coastal housing prices with market fundamentals. Though efficient, this policy raises fundamental distributional concerns. Our simulations moreover highlight a trade-off in the timing of reform: completing policy changes in 15 rather than 25 years can cut allocative inefficiency in half, but triples market volatility in the process. All together, our results thus highlight the role of policy in shaping future dynamics of housing markets and associated welfare implications.

The remainder of this paper proceeds as follows. Section (2) reviews related literatures and provides institutional background on U.S. flood policy. Section (3) presents the model. Section (4) structurally motivates and describes the survey, and presents its results. Section (5) briefly describes current and future expected flood risks in our empirical setting. The model calibration and simulation results are presented in Section (6). Section (7) presents a sensitivity analysis, discusses model extensions, and provides empirical comparisons to verify the quantitative plausibility of our most sensitive model inputs and outputs. These include a hedonic analysis we perform in our study area to provide alternative measures of, e.g., coastal amenity values. Finally, 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 and 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 "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, 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 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.

Also related in spirit but different in methodology, 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 that counties with greater beliefs in climate change incorporate future expectations to a greater degree than counties with lower beliefs. In addition, Kahn and Zhao (2017) present a theoretical framework to study the impacts of climate change skeptics in a spatial equilibrium between two cities, finding that skeptics lower the price of land in the cooler city less impacted by climate change. Our results thus add to a nascent literature on the impacts of climate skepticism on broader economic outcomes.

Third, a rich empirical literature analyzes the impact of flood risk on home prices, typically using hedonic analysis to decompose house prices into a property's component amenities and dis-amenities in the spirit of Rosen (1974). A meta analysis finds a negative effect across the literature (Daniel, Florax, Rietveld, 2009). Other methods to estimate willingness to pay to avoid flood risk include, e.g., applications of sorting models (Bakkensen and Ma, 2017). 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 factors,[4] we implement a survey to separate these and other confounding factors affecting demand for coastal housing.

Finally, several empirical studies have analyzed the impacts of storms flood events on both housing and insurance markets. Hallstrom and Smith (2005) postulate that storm events convey information about the underlying flood risk, finding that properties nearly missed, and therefore unharmed by Hurricane Andrew, received a 19 percent price drop after the event. Bin and Landry (2013) find a smaller decrease of 5.7% following Hurricane Fran and 8.8% after Hurricane Floyd. However, these price drops last only about 5 to 6 years. Kousky (2010) documents similar

[4] See, e.g., Bin, Crawford, Kruse, and Landry (2008).

results for a 1993 flood in Missouri. A key question is how to model households' flood risk learning. Studying empirical evidence from flood insurance purchases, Gallagher (2014) finds that flood risk learning is consistent with a Bayesian model. 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 impacts how flood risk is internalized by property owners through capitalization into home values (e.g., Shilling, Simans, and Benjamin, 1989) NFIP 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 some financial risks as available policies are subject to various limitations, including a $250,000 property policy limit. Insurance take-up is moreover limited despite some generous 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). This finding is consistent with both limited enforcement of flood insurance requirements and low flood risk perceptions among flood zone home owners.

NFIP also 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 source of public flood risk information. Flood risk is categorized broadly in terms of probability of inundation, where zones having an annual risk exceeding 1 in 100 are designated as the Special Flood Hazard Areas. Maps are based on historical data and may be updated periodically to incorporate 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.

More broadly, NFIP has been subject to many critiques for its failure to charge actuarially fair rates for many of its policies. One in five policies are officially subsidized, charging less than half of full risk levels on average (CBO, 2014). The extent to which even full risk rates are actuarially fair is moreover an open question (CBO, 2014). As discussed in detail below, the Biggert-Waters Act of 2012 was aimed at phasing out subsidies and bringing the program towards fiscal solvency. However, due to concerns over its impacts on homeowners, the law was partially repealed and modified by the 2014 Homeowners Flood Insurance Affordability Act.

In addition to the National Flood Insurance Program, the literature has found that expectations of post-disaster aid may shape the perceived level of flood risk that is internalized by property owners (Lewis and Nickerson, 1989). In reality, FEMA payouts are small, typically 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 nonetheless 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 $k < 1$ where fraction $k_1 < k < 1$ is coastal.[5] 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 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

[5] We thus abstract from (endogenous) housing supply. Empirical estimates find coastal supply to be highly inelastic, driven by topographic constraints (Glaeser, Gyourko, and Saks, 2005; Green, Malpezzi, and Mayo, 2005). Saiz (2010) estimates MSA-level elasticities, finding Miami, Los Angeles, Fort Lauderdale, and San Francisco to have the lowest supply elasticities. We moreover define "coastal" homes as within 400 feet of the waterfront, so that the assumption of fixed supply is empirically well-justified, particularly in our empirical setting in Rhode Island. (In contrast, for a detailed theoretical analysis of how developers of new coastal real estate may respond to climate risks of land and investment destruction, see Bunten and Kahn, 2017).

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

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

where $\pi_t^{m_t}$ is the time t marginal buyer's perception of coastal flood risk at time t, and $E_t^{m_t}[P_{t+1}]$ is m_t's expectation of next period's coastal home price P_{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:

$$P_t = \beta(e^h + \xi^{m_t} - \pi_t^{m_t}\delta + E_t^{m_t}[P_{t+1}]) \quad (2)$$

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, and on the (higher order) expectations of agents' own and others' evolution of flood risk beliefs (through $E_t^{m_t}[P_{t+1}]$). 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:

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

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

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

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

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

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

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

And the market clearing condition becomes:

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

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:

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

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:

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

On the one hand, prices in this case will still be distorted if some optimists with lower amenity values take up coastal real estate that should, from an efficiency perspective, go to realists with higher amenity values. That is, the marginal realist's amenity value $\widehat{\overline{\xi}^r}$ in Case 3 is weakly higher than in the first-best with homogeneously informed beliefs. On the other hand, prices in this case are unlikely to be as volatile as in Cases 1 and 2 as realists are assumed to be informed about true flood risk, so that their perceptions π_t^r should not to change in response to flood events.

3.1 Solving the Model

We solve for pricing dynamics through backwards iteration. At the core of our approach is the notion that flood risk valuation disagreements will not persist indefinitely. Arguably the most likely scenario forcing effective belief convergence will be continued reform efforts of the National Flood Insurance Program. The current NFIP pricing scheme, including subsidized policies offered to many homeowners, is considered fiscally unsustainable (GAO, 2017). Consequently, policy efforts such as the Biggert-Waters Flood Insurance Reform Act of 2012 have sought to push the NFIP towards charging real-risk rates. Flood insurance is moreover already mandatory for homeowners with federally insured mortgages in high-risk areas. In theory, a fully enforced flood insurance requirement at actuarially fair rates would force all agents - regardless of personal beliefs - to internalize the true flood risk. In the context of our model with linear utility, policy reform mandating real risk-rate flood insurance is thus equivalent to a convergence of flood risk beliefs towards their true value π^*.[6] We thus formally assume that, at some future time T, *effective* flood risk beliefs will become homogeneous at the true risk value π_T^*. At time $T-1$, the realists and optimists each hold expectations over the announced value of π_T^*, $E_{T-1}^r[\pi_T^*] = \pi_T^{*,r}$ and $E_{T-1}^o[\pi_T^*] = \pi_T^{*,o}$, respectively. Note, again, that $\pi_T^{*,o}$ need not equal the optimists' actual flood risk beliefs and can reflect their beliefs about the mandated flood insurance risk rates.

Given assumptions about beliefs, it is then straightforward to solve for time $T-1$ prices. Solving for $T-n$ prices with $n \geq 2$ requires characterizing a basic form of higher order beliefs, as described below. First, 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):

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

[6] Alternatively, one might also argue that, in the very long run, flood risk beliefs must converge as sea levels continue to rise to the point of making annual flood risks undeniable (approaching unity as sea levels rise to reach current coastal properties' elevation). While we focus our analysis on medium-run flood risk increases, we note that, in the very long run, beliefs will almost surely converge even in the absence of policy reform.

Optimists reason analogously, but with a potentially different expectation over the flood risk announcement $\pi_T^{*,o}$ defining $E^o_{T-1}[P_T]$. 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:

$$\Xi\frac{k_1}{\theta^o} + \left\{E^r_{T-1}[P_T] - E^o_{T-1}[P_T]\right\} < \delta(\pi^r_{T-1} - \pi^o_{T-1}) \tag{10}$$

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

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

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

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

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 expectation of his own as well as others' expectations about the marginal buyer and flood risk beliefs in the subsequent periods. Intuitively, this is because agents understand that the re-sale value of a coastal home in the next year will depend on the distribution of re-sale price expectations in the subsequent years, which, in turn, depend on the (expected) evolution of flood risk beliefs. For example, the realists' prediction at time $T-2$ of the coastal home price at time $T-1$ depends on his expectation over who the marginal buyer will be next period, informally $\sim E^r_{T-2}(m_{T-1})$. The realist also anticipates that the marginal buyer at time $T-1$ will be determined by condition (10). Consequently, his time $T-2$ expectation of prevailing beliefs at time $T-1$ determines his forecast for the future marginal buyer, which, in turn, determines his price expectation along with his projects of the distribution of future flood risk beliefs, i.e.:

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

Where, again, the expectations of the price at time T are given by (10) and the analogous expression for optimists, but based on time $T-2$ expectations, i.e.:

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

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 follows the same procedure and can be illustrated as follows:

$$\underbrace{\begin{pmatrix} \mathbf{E}^{r,r,\ldots r}_{t:T-1}[\pi^*_T] & \mathbf{E}^{r,r,\ldots,o}_{t:T-1}[\pi^*_T] & \ldots \\ \mathbf{E}^{r,o,..r}_{t:T-1}[\pi^*_T] & \mathbf{E}^{r,o,\ldots,o}_{t:T-1}[\pi^*_T] & \ldots \\ \mathbf{E}^{o,r,\ldots r}_{t:T-1}[\pi^*_T] & \mathbf{E}^{o,r,\ldots,o}_{t:T-1}[\pi^*_T] & \ldots \\ \ldots & \ldots & \ldots \end{pmatrix}}_{2^{(T-t)}\text{ elements}} \rightarrow \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,\ldots r}_{t:T-1}[P_T] & \mathbf{E}^{r,r,\ldots o}_{t:T-1}[P_T] & \ldots \\ \mathbf{E}^{r,o,\ldots,r}_{t:T-1}[P_T] & \mathbf{E}^{r,o,\ldots,o}_{t:T-1}[P_T] & \ldots \\ \mathbf{E}^{o,r,\ldots,r}_{t:T-1}[P_T] & \mathbf{E}^{o,r,\ldots,o}_{t:T-1}[P_T] & \ldots \\ \ldots & \ldots & \ldots \end{pmatrix}}_{2^{(T-t)}\text{ elements}} \quad (14)$$

$$\& \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,\ldots}_{t:T-2}[\pi^r_{T-1}] & \mathbf{E}^{r,r,\ldots}_{t:T-2}[\pi^o_{T-1}] & \ldots \\ \mathbf{E}^{r,o,\ldots}_{t:T-2}[\pi^r_{T-1}] & \mathbf{E}^{r,o,\ldots}_{t:T-2}[\pi^o_{T-1}] & \ldots \\ \mathbf{E}^{o,r,\ldots}_{t:T-2}[\pi^r_{T-1}] & \mathbf{E}^{o,r,\ldots}_{t:T-2}[\pi^o_{T-1}] & \ldots \\ \ldots & \ldots & \ldots \end{pmatrix}}_{2^{(T-t)-1}\text{ elements}} \rightarrow \underbrace{\begin{pmatrix} \mathbf{E}^{r,r,\ldots r}_{t:T-2}[P_{T-1}] & \mathbf{E}^{r,r,\ldots o}_{t:T-2}[P_{T-1}] & \ldots \\ \mathbf{E}^{r,o,\ldots,r}_{t:T-2}[P_{T-1}] & \mathbf{E}^{r,o,\ldots,o}_{t:T-2}[P_{T-1}] & \ldots \\ \mathbf{E}^{o,r,\ldots,r}_{t:T-2}[P_{T-1}] & \mathbf{E}^{o,r,\ldots,o}_{t:T-2}[P_{T-1}] & \ldots \\ \ldots & \ldots & \ldots \end{pmatrix}}_{2^{(T-t)-1}\text{ elements}}$$

$$\& \ldots \rightarrow \quad (15)$$

$$\& \ldots \rightarrow \begin{pmatrix} E^r_t[E^r_{t+1}[P_{t+2}]] & E^r_t[E^o_{t+1}[P_{t+2}]] \\ E^o_t[E^r_{t+1}[P_{t+2}]] & E^o_t[E^o_{t+1}[P_{t+2}]] \end{pmatrix} \quad (16)$$

$$\& \begin{pmatrix} E^r_t[\pi^r_{t+1}] & E^r_t[\pi^o_{t+1}] \\ E^o_t[\pi^r_{t+1}] & E^o_t[\pi^o_{t+1}] \end{pmatrix} \rightarrow \begin{pmatrix} E^r_t[P_{t+1}] \\ E^o_t[P_{t+1}] \end{pmatrix} \& \begin{pmatrix} \pi^r_t \\ \pi^o_t \end{pmatrix} \Rightarrow P_t \quad (17)$$

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. 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 order sophistication for agents who are misinformed about the first order issue of flood risks they face. Our benchmark model adopts a mixed approach, 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, 2014). Our updating framework is an adaptation from Dieckmann (2011) for the present setting. Optimists have a prior belief about the probability q_t^o 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:

$$\begin{aligned} q_{t+1}^o|_{\text{Flood}=1} &= \Pr(\pi^H|_{\text{Flood}=1}) = \frac{\pi^H \cdot q_t^o}{\pi^H q_t^o + (1 - q_t^o)\pi^L} \\ q_{t+1}^o|_{\text{Flood}=0} &= \Pr(\pi^H|_{\text{Flood}=0}) = \frac{(1 - \pi^H) \cdot q_t^o}{(1 - \pi^H)q_t^o + (1 - q_t^o)(1 - \pi^L)} \end{aligned} \tag{18}$$

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

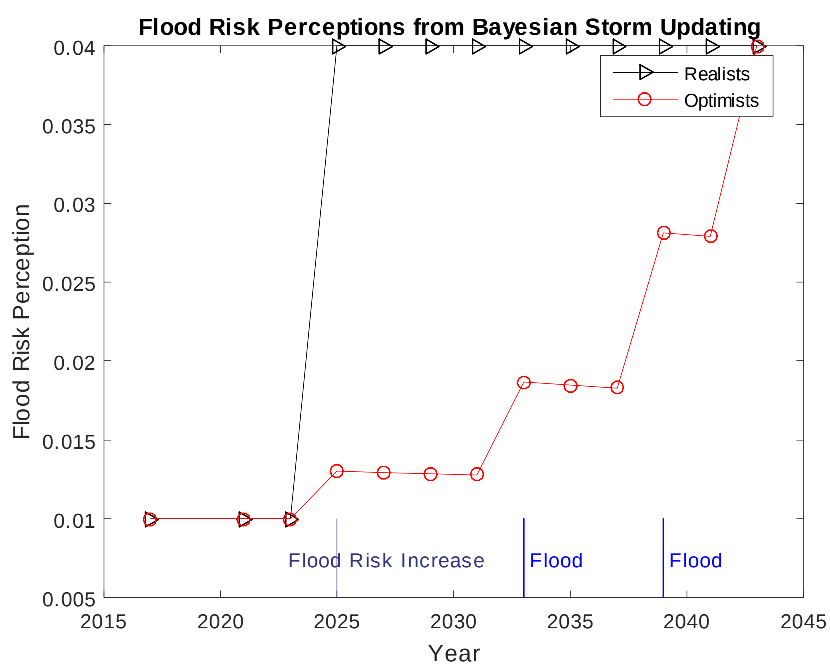


Figure 1

Next, with regards to higher order beliefs, we assume that realists have rational higher order expectations of optimists' belief changes, meaning they take into account that, in each future period $t + j$ a flood will occur with probability π_{t+j}^r and change optimists' beliefs according to (18). In contrast, optimists do not anticipate the possibility of future changes in their own beliefs after T_1, 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:

$$\begin{aligned} E_t^o[\pi_{t+1}^o] &= \pi_t^o \\ E_t^r[\pi_{t+1}^o] &= \pi_t^r \left[(q_{t+1}^o|_{\text{Flood}=1})(\pi^H) + (1 - q_{t+1}^o|_{\text{Flood}=1})(\pi^L)\right] \\ &\quad +(1-\pi_t^r)\left[(q_{t+1}^o|_{\text{Flood}=0})(\pi^H) + (1 - q_{t+1}^o|_{\text{Flood}=0})(\pi^L)\right] \end{aligned} \tag{19}$$

Finally, we need to specify agents' beliefs about enforced policy rates (or commonly held long-run beliefs) after time T. Realists correctly anticipate long-run rates/beliefs:

$$E_t^r[\pi_T^*] = E_t^r[\pi_T^r] = \pi^*$$

For optimists, we consider beliefs in the range of:

$$E_t^o[\pi_T^*] \in [E_t^o[\pi_T^o], E_t^o[\pi_T^r]] \tag{20}$$

with a benchmark assumption that optimists believe that enforced rates after time T will correspond to the population-weighted average of beliefs at the time:

$$E_t^o[\pi_T^*] = (\theta^o)E_t^o[\pi_T^o] + (1-\theta^o)E_t^o[\pi_T^r] \tag{21}$$

Intuitively, the two extremes nested by (20) can be thought of as follows. On the one hand, if $E_t^o[\pi_T^*] = E_t^o[\pi_T^o]$, this means that optimists believe that everyone will eventually agree with them, or, equivalently, that the government will offer and require cheap flood insurance at a risk rate corresponding to optimists' beliefs. Naturally, these beliefs boost optimists' valuation of coastal properties. In contrast, if $E_t^o[\pi_T^*] = E_t^o[\pi_T^r]$ this means that optimists anticipate that they will eventually be forced to purchase flood insurance at risk rates corresponding to realists' beliefs. However, the implications of this assumption are arguably at odds with the empirical evidence on the impacts of changes in flood insurance requirements, as discussed in Section 7. Consequently, our benchmark scenario assumes that optimists' beliefs about long-run rates/beliefs reflect the population average belief (21), though we assess robustness to other assumptions in (20).

Section (7) further considers a behavioral extension of (18) with faster belief changes to better match the empirical literature, and discusses the implications of agents engaging 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 in coastal property markets, it is necessary to estimate the joint distribution of amenity values and flood risk beliefs. While a 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, flood risk beliefs, and future expectations. Through the lens of the model, the coastal home premium at any point in time t is given by:

$$PREM_t^{\text{Coast}} \equiv (P_t - P_t^{NC}) = \beta \left(\xi^{m_t} - \pi_t^{m_t}\delta + E_t^m[P_{t+1} - P_{t+1}^{NC}]\right) \tag{22}$$

In words, (22) 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 (iii) 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 the empirically observed coastal home premium. Indeed, Bayer, McMillan, Murphy, and Timmins (2016) demonstrate the potential importance of dynamic considerations in hedonic estimation in sorting models.

In our framework, 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 (see, e.g., (18) and (19)). 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:

$$\frac{\Delta PREM_t^{\text{Coast}}}{\Delta \text{Flood}_{t-1}} \sim \beta \left(\frac{\Delta \xi^{\Delta m_t}}{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}} \frac{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}}{\Delta \text{Flood}_{t-1}} - \frac{\Delta \pi_t^{\Delta m_t}}{\Delta \text{Flood}_{t-1}} \delta + \frac{\Delta E_t^{\Delta m_t}[P_{t+1} - P_{t+1}^{NC}]}{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}} \frac{\Delta \mathbf{E}[\mathbf{\Pi}]_{t:T}}{\Delta \text{Flood}_{t-1}} \right) \tag{23}$$

In words, observed changes in coastal home prices after a flood event would 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 expectations (through changes in the identity and/or value for the marginal buyer $\Delta\pi_t^{\Delta m_t}$), and (iii) changes in (higher and first order) expectations about future prices and beliefs $\Delta E_t^{\Delta m_t}[P_{t+1} - P_{t+1}^{NC}]$. 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. For robustness, however, we also present a hedonic analysis for our empirical setting in Section 7.2.

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).[7] 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 a hedonic estimation of the annualized waterfront living premium using 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 (Cameron and James, 1987; Arrow et al., 1993; Hanemann, 1994; 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 quantitative 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

[7] For sensitivity, we also estimate WTP using a single-bounded dichotomous choice with the first bid and find the mean WTP to be similar (11% lower).

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 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 2:

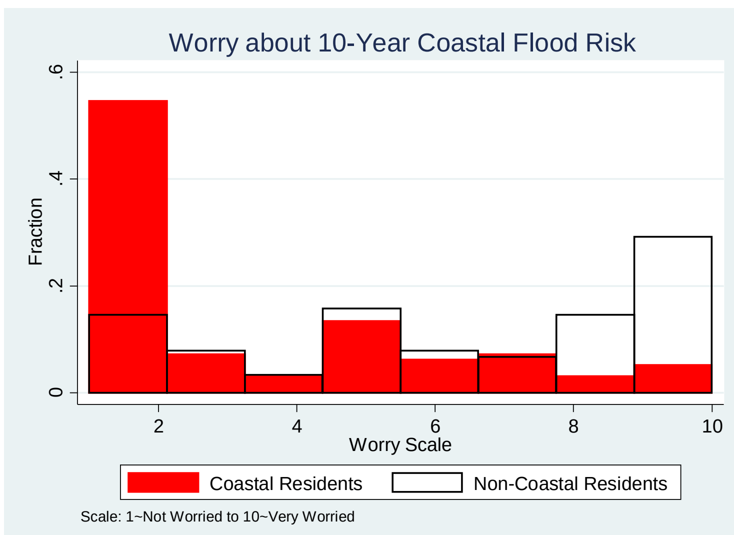


Figure 2

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 3:

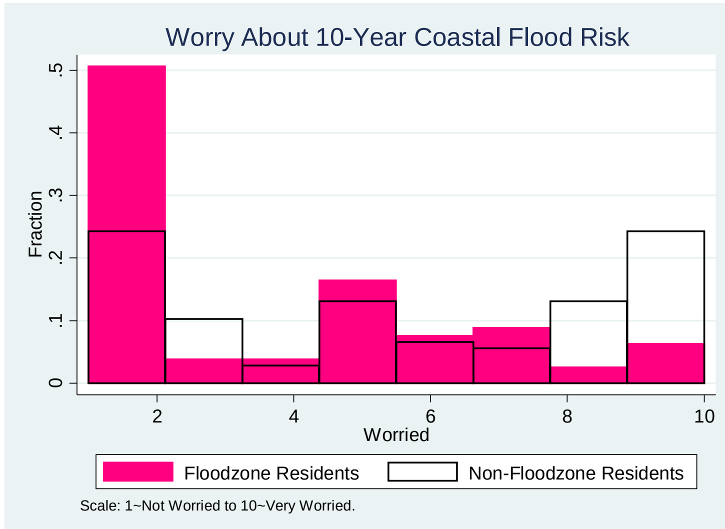


Figure 3

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 4 showcases the distribution of expected flood damages (as percentage of home value) net of expected insurance reimbursements and government assistance.[8] While flood zone 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 differences in flood worries are not driven by differential expectations of damages or ex-post flood assistance.

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

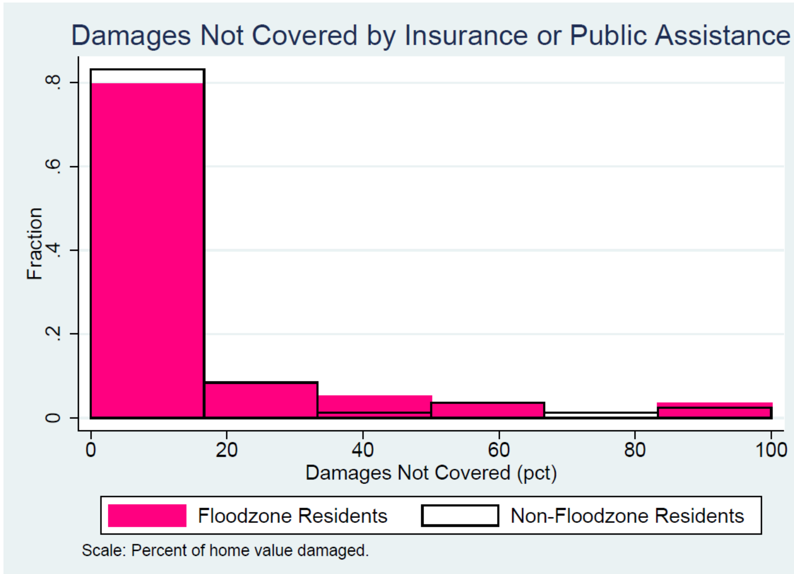


Figure 4

In order to evaluate these differences 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 flood zone and non-flood zone residents. Beyond exhibiting highly significantly *lower* flood risk concerns, flood zone residents differ from non-flood zone residents mainly in having smaller households and homes. 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: Flood Zone Residents

Variable	Non-Flood Zone	Flood Zone	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. However, we also elicit numerical flood risk beliefs. Figure 5 compares these perceptions with respondents' homes' 10-year flood risk estimates derived from storm surge elevation risk models (described in Section 5). Importantly, this estimation takes into account each property's elevation. The sample is restricted to coastal homes so that responses 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, 70% of answers lie beneath the 45° line, again suggesting that many coastal residents underestimate the flood risks they face as per inundation models.

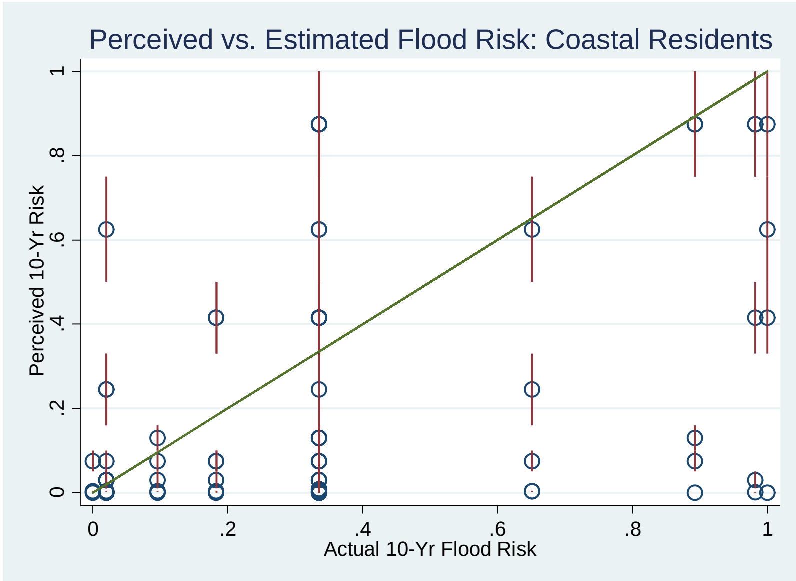


Figure 5. Note: Red lines span range of 10-year flood risk probability in respondent's answer (e.g., 5-10%) on the y-axis, with blue circles marking the mid-points of each range.

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 are significantly more likely to be concerned about flooding (see Appendix Figure A1). Second, coastal residents who are very worried about flooding are significantly more likely to plan on selling their homes within the next five years, as shown in Figure 6:[9]

[9] Defining "very worried" households as those rating their flood worry at a 9 or 10 out of 10, the difference in intent to move is significant with a p-value of 0.0375 for one-sided and 0.075 for two-sided t-test, respectively.

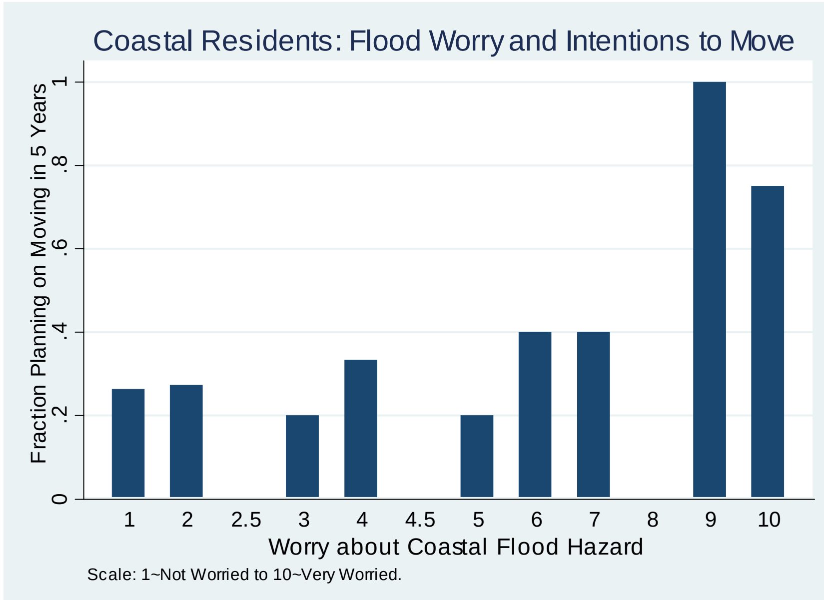


Figure 6

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 out 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 homes is driven by a combination of higher amenity values and lower flood risk concerns, in line with the core mechanisms of the model.

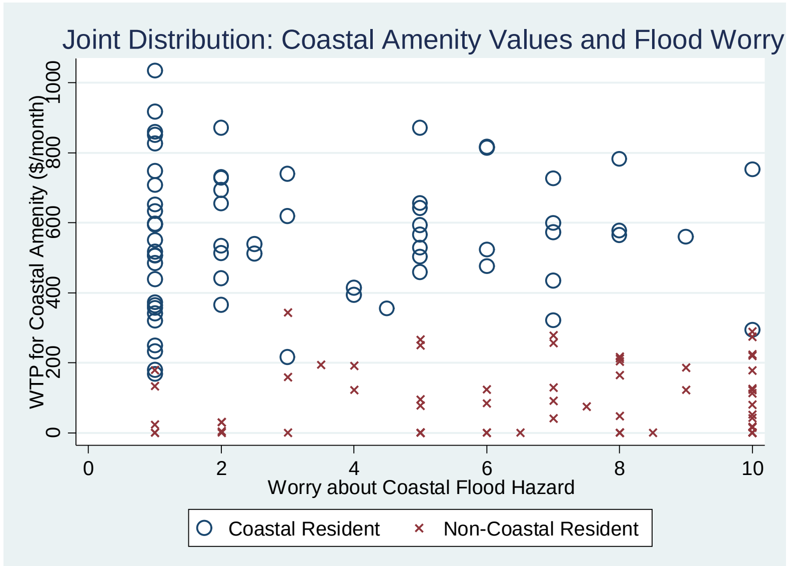


Figure 7

With regards to 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 in our study area is between $0 - 5\%$. In fact, 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%.[10] While the mean of amenity values is slightly 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. Finally, the results indicate that the majority of respondents expect future flood risks to be at least "somewhat greater" than current risks. Figure 8 plots the distribution of these beliefs across types. As expected, realists are more likely to assume higher future flood risk increases than optimists. However, even the majority of optimists anticipates some 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 positive prior belief on the probability that flood risks have indeed risen.

[10] While not all coastal homes in our sample are 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.

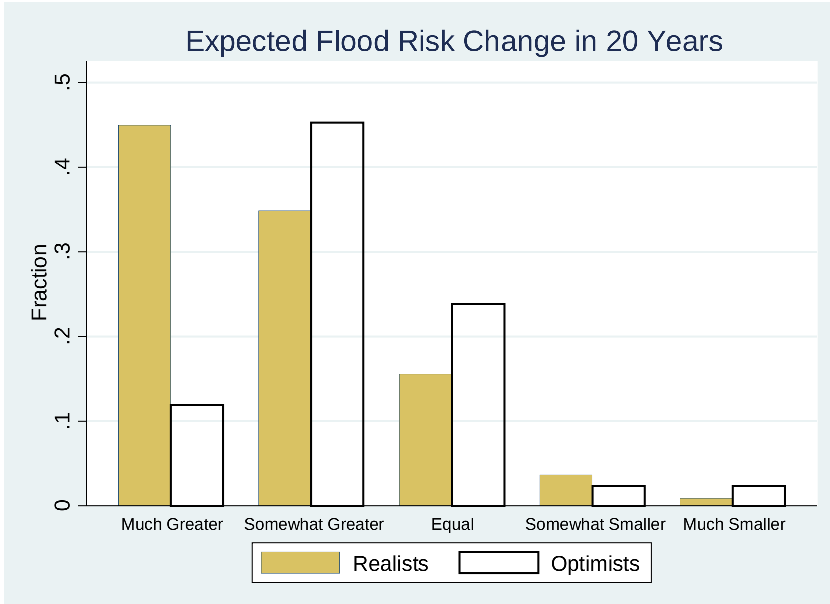


Figure 8

5 Flood Risk

Coastal flood risk is broadly determined by two main channels: (1) by the sea level, which is projected to increase in the coming decades, thereby increasing flood risk through high tide impacts (Rahmstorf, 2007), and (2) by extreme event surges such as tropical cyclones and other storms (Emanuel, Sundararajan, and Williams, 2008; Knutson et al, 2010). We utilize future sea level rise projections for Newport, RI, from the U.S. Army Corps of Engineers (USACE, 2017) and NOAA (Blank, Lubchenco, and Dietrick, 2012). In order to translate sea level rise to coastal inundation probabilities, we further utilize STORMTOOLS, a set of Rhode Island inundation maps and flood return rates under various projections of sea level rise developed by partners including the University of Rhode Island and NOAA (SAMP, 2017).[11] 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 assumes additive inundation increases from sea level rise and does it account for local flood mitigations strategies that may change over time. Figure 9 compares the 1 in 100 year inundation risks under zero and three feet of sea level rise for the upper Narragansett Bay, highlighting the quantitative importance of increasing flood risks in this area:

[11] A full explanation of the methodology can be found at *http://www.rigis.org/data/stormtools*.

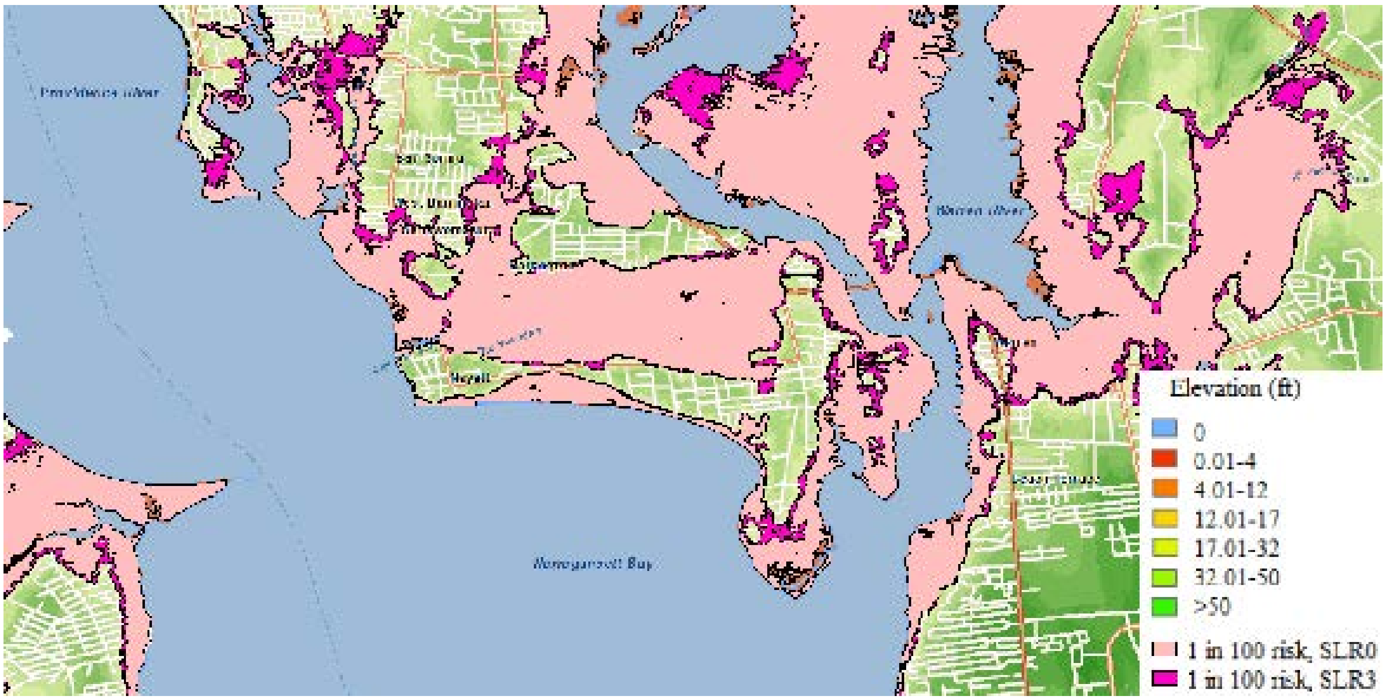


Figure 9

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 across scenarios of sea level rise. We note that as sea levels increase, the distribution of homes will shift right, reflecting the increased probability of inundation across the sample. The average property in our sample faces a baseline annual flood risk of over 7%, increasing to 15% with 1 foot of sea level rise. 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 use more conservative flood risk probabilities in the calibration below.

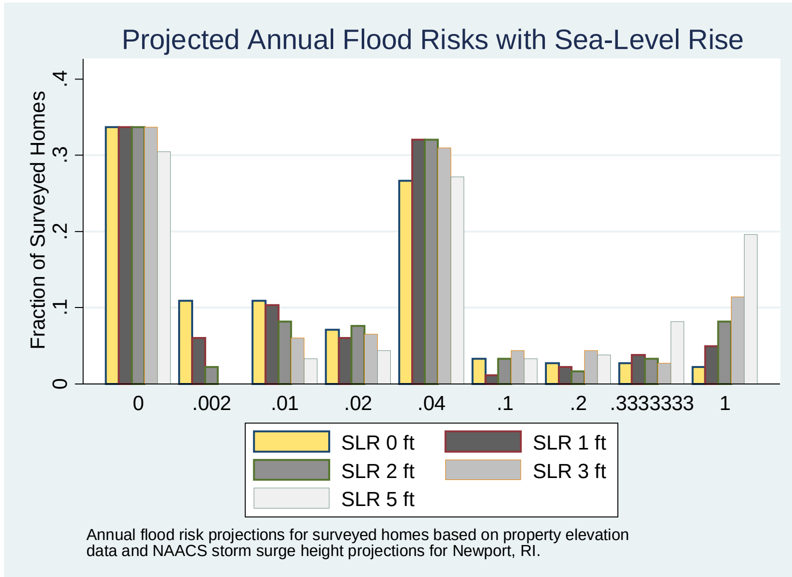


Figure 10

6 Model Simulations

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

Table 3: Benchmark Model Calibration

Parameter		Value	Source
k_1	Share of coastal homes	0.134	Authors' calculation from RIGIS properties and coastline
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 $\times$ Med. price
e^h	Net value of living in own home	2.98	Match initial med. coastal home price \$410k
β	Annual discount factor	0.98	
π_L	Initial annual flood risk	1%	FEMA
π^H	New higher flood risk	4%	STORMTOOLS; elevation mapping
T_1	Flood risk increase	2023	
T	Policy reform period	2043	
$q_{T_1}^o$	Optimists' prior $\Pr(\pi = \pi^H)$ at T_1	0.1	
Flood events: 2031, 2037			

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.[12] Second, for reasons described above, we adopt the FEMA lower bound on flood event risk of 1% as a conservative measure of baseline flood risk. As for the future high risk, we focus on a 1 foot of sea level rise scenario based on USACE projections over the time horizon of our simulation. Again, however, we select a more conservative annual probability of 4% in order to represent the probability of a serious event. The sensitivity analysis below also consider 2% and 6%. Finally, the benchmark share of optimists represents a re-weighted average of the survey population to correct for over-sampling of coastal homes.

Figure 12 presents the main results. We run the model varying the percentage of optimistic agents in the population from 0% to our benchmark population 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.

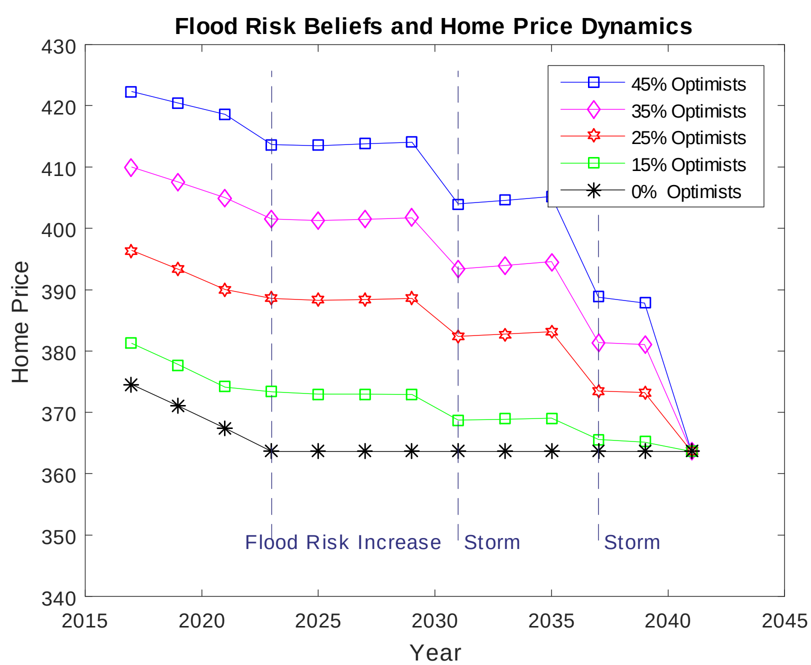


Figure 12

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

First, if all agents are perfectly informed about future flood risks (0% optimists), home prices are projected to decline only modestly (-3%) 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. In contrast, if even just 25% of the population are optimistic Bayesian learners, the projected future home price decline due to flood risk changes triples to -9%, and more than quadruples to -12.7% for our benchmark value of 35% optimists. 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%. The volatility of coastal housing prices is moreover projected to increase under belief heterogeneity as well, by more than an order of magnitude in our benchmark scenario. Table 4 summarizes these results.

Table 4: Benchmark Simulation Results

Scenario	Future $\%\Delta P$	Var($\%\Delta P$)
0% Optimists	-3.0%	0.19
15% Optimists	-4.8%	0.21
25% Optimists	-9.0%	0.99
35% Optimists	-12.7%	2.38
45% Optimists	-16.1%	4.11

Flood risk increase from 1% to 4% in 2023.

Risk internalization policy / belief change at T=2043.

Figure 13 plots the projected evolution of coastal home prices for alternative flood risk scenarios, comparing the homogeneous 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 approximately quadruples the projected impacts in each scenario.

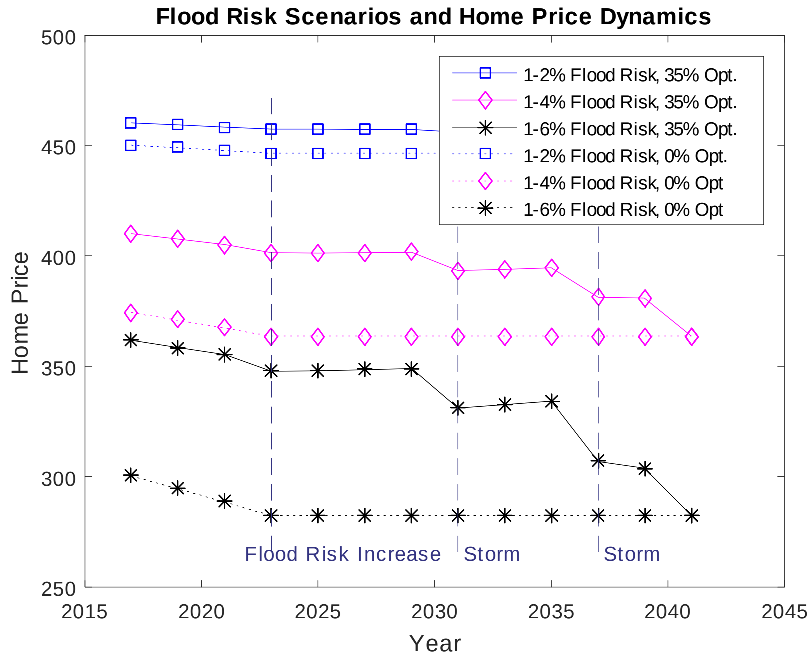


Figure 13

Table 5: Flood Risk Sensitivity

	Future $\%\Delta P$	
Scenario	$\pi_H = 2\%$	$\pi_H = 6\%$
0% Optimists	-0.8%	-6.3%
35% Optimists	-3.1%	-28.0%

Next, Table 6 presents results for alternative assumptions on optimists' beliefs about the long-run risk rates enforced by policy (or, alternatively, convergence of population beliefs). The benchmark scenario assumes optimists expect a population-weighted average of beliefs to become enforced at time T; Table 6 presents results for the alternative values assumed in (20).

Table 6: Optimists' Long-Run Policy Expectations

Scenario	Future $\%\Delta P$	Var($\%\Delta P$)
$E_t^o[\pi_T^*] = E_t^o[\pi_T^o]$	- 28.3%	18.11
$E_t^o[\pi_T^*] = (\theta^o)E_t^o[\pi_T^o] + (1-\theta^o)E_t^o[\pi_T^r]$	- 12.7%	2.38
$E_t^o[\pi_T^*] = E_t^o[\pi_T^r]$	- 4.7%	0.06

The results indicate that even optimists' beliefs about very long-run flood insurance policy changes can significantly affect coastal housing prices in the present. Expectations of long-run availability of cheap insurance can greatly increase property prices relative to their long-term fundamental value, with projected housing price declines exceeding the homogeneous, rational beliefs case by an order of magnitude (-28.3% versus -3%). In contrast, if optimists expect to be forced to pay real-risk rates eventually, overvaluation is significantly mitigated.

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 an order of magnitude once heterogeneity in flood risk beliefs is taken into account.

6.1 Allocative Inefficiency Costs

Within the context of our framework, the only efficiency cost associated with coastal home mispricings is the allocative inefficiency of realists with high amenity values being priced out of coastal markets. In reality, coastal mispricing is likely to create welfare costs through a number of important additional channels. For example, if we modeled the mortgage process whereby optimists obtain loans using coastal properties as collateral, then the devaluation of those properties due to flood events or policy changes could lead to defaults, further asset value losses, and adverse effects on credit markets (see, e.g., Geanakoplos, 2010), thereby exacerbating market incompleteness. When coastal properties constitute an important source of local tax revenues, both fluctuations and permanent reductions in their value could create additional efficiency costs depending on the fiscal policy response. As our model does not incorporate these effects, the efficiency cost estimates represent a strictly lower bound.[13]

A social planner would allocate coastal homes to the optimists and realists with the k_1 highest valuations, equating the marginal buyers' valuations at the optimum:

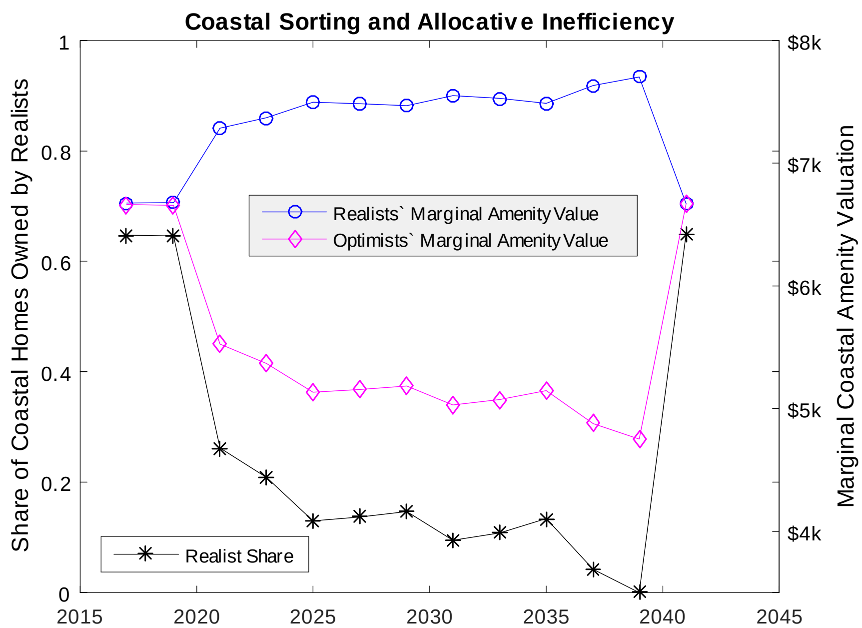
$$\overline{\xi}^{o,*} = \overline{\xi}^{r,*} = \Xi(1 - k_1)$$

In contrast, allocative inefficiency from belief heterogeneity occurs whenever the marginal realist's valuation exceeds that of the marginal optimist (i.e., $\overline{\xi}_t^r > \overline{\xi}^{r,*}$ and $\overline{\xi}_t^o < \overline{\xi}^{o,*}$). Let q_t^i denote the quantity of coastal housing consumed by group i in period t, which equals $q_t^o = \frac{\theta^o}{\Xi}(\Xi - \overline{\xi}_t^o)$ for optimists and $q_t^r = \frac{(1-\theta^o)}{\Xi}(\Xi - \overline{\xi}_t^r)$ for realists. The net loss in consumer surplus CS_t from coastal housing in period t due to belief heterogeneity is then given by:

[13] We also acknowledge existing literature on welfare implications of belief structure. For example, Brunnermeier, Simsek, and Xiong (2014) develop a welfare criterion, belief-neutral efficiency, in cases where beliefs are distorted and heterogeneous. However, a key difference from our work is that the future probabilities across the flood outcome are scientifically estimable rather than unknown.

$$\Delta W_t \equiv CS_t^* - CS_t = \int_{q^{*,o}}^{q_t^o} \left[\Xi - \frac{\Xi}{\theta^o} q\right] dq - \int_{q_t^r}^{q^{*,r}} \left[\Xi - \frac{\Xi}{(1-\theta^o)} q\right] dq \tag{24}$$

Figure 14 illustrates the evolution of the marginal coastal optimist's and realist's respective amenity values ($\overline{\xi}_t^o$ and $\overline{\xi}_t^r$) over time (right axis), as realists increasingly move out of coastal property markets (left axis).



Figure

As the flood risk increases and beliefs start to diverge, an increasing number of realists are projected to move out of coastal markets. This prediction is in line with our survey finding that coastal residents who are more concerned about flooding are also significantly more likely to intend to sell their homes within the next five years (Figure 6). The first realists to move are the ones with relatively lower amenity values for coastal living, so that the remaining coastal realists' amenity values increase (blue line with circles). In turn, the departing realists are replaced by optimists with lower amenity values (pink line with diamonds) but also flood risk expectations. Only once the policy reform at time T enforces the internalization of real risk rates do prices adjust so that realists return to coastal housing markets, restoring allocative efficiency.

Table 7 summarizes the allocative inefficiency costs in our target housing market on a per household basis, computed specifically as the present value of the flow costs (24) across the study period until policy reform ($\mathbf{\Delta W} = \sum_{j=0}^{T} \beta^j \Delta w_j$). The benchmark costs are estimated at

\$685 per household - a modest amount, although it should be noted that this is the average net cost across *all* households, not just those relocated due to belief heterogeneity. Alternative assumptions for the maximum coastal amenity value (Ξ) - set at either our hedonic regression estimate (\$4.9k/yr), or at the 75th percentile of coastal residents in our survey (\$8.5k/yr) - do not materially affect this estimate due to the fact that higher losses for realists are partly offset by higher gains for optimists. In contrast, the share of coastal homes (k_1) naturally has a large effect on the allocative inefficiency. Finally, enacting flood insurance reform sooner than in the benchmark (2033 vs. 2043) naturally reduces the allocative inefficiency as well.

Table 7: Allocative Inefficiency Costs

Scenario	Per Household Net Costs	Scenario	Per Household Net Costs
Benchmark	\$685	k_1= 0.05	\$137
$\Xi = \$4.9k$	\$609	k_1= 0.20	\$862
$\Xi = \$8.5k$	\$648	$T = 2035$	\$374

7 Robustness and Empirical Validity

7.1 Robustness

This section presents results from both additional sensitivity analysis and an alternative specification allowing optimistic agents to "overreact" to flood events or the lack thereof. The motivation for this extension is that several empirical studies have found home prices and flood insurance demand to revert to baseline within only 5-10 years (Bin and Landry, 2013; Gallagher, 2014), a pace not matched by our baseline Bayesian framework. We thus incorporate an ‘overreaction’ parameter γ into agents’ updating rules as follows:

$$\begin{aligned} \widetilde{q}^o_{t+1}|_{\text{Flood}=1} &= \Pr(\pi^H|_{\text{Flood}=1}) = \frac{(\pi^H \cdot q^o_t)\cdot(1+\gamma)}{\pi^H q^o_t + (1-q^o_t)\pi^L} \\ \widetilde{q}^o_{t+1}|_{\text{Flood}=0} &= \Pr(\pi^H|_{\text{Flood}=0}) = \frac{((1-\pi^H)\cdot q^o_t)\cdot(1-\gamma)}{(1-\pi^H)q^o_t + (1-q^o_t)(1-\pi^L)} \end{aligned} \quad (25)$$

Even a modest degree of overreaction ($\gamma = 10\%$) turns out to be sufficient for beliefs to revert back to baseline at a rate in line with these empirical studies (see Appendix Figure A2). As shown in Table 8, this extension does not change the projected cumulative price decline (-12.7%), but does increase the projected volatility of coastal housing growth rates.

Table 8: Further Sensitivity Analysis			
Scenario	Future $\%\Delta P$	Var($\%\Delta P$)	Re-scaled
Benchmark	-12.7%	2.38	n/a
Overreaction $\gamma = 10\%$	-12.7%	3.72	n/a
Max WTP $\Xi = \$4.9k$	-23.2%	7.14	
Max WTP $\Xi = \$4.9k$	-13.2%	2.51	✓
Max WTP $\Xi = \$8.5k$	-11.23%	1.86	
Max WTP $\Xi = \$8.5k$	-12.6%	2.31	✓
Share coastal $k_1 = 0.05$	-15.3%	2.81	✓
Share coastal $k_1 = 0.20$	-12.2%	2.08	✓
Flood events: 2030 only	-12.7%	5.57	n/a
Flood events: 2040 only	-12.7%	5.40	n/a
Flood events: none	-12.7%	7.87	n/a
Policy Reform $T = 2033$	-12.8%	6.73	

Re-scaling of general own-home utility value e^h holds initial coastal home price constant at benchmark/empirical value ($410k).

The remaining sensitivity analysis generally finds price level impacts of similar magnitude as in the benchmark.[14] For example, the number of flood events affects the projected trajectory and volatility of coastal home prices, but not the level of the price decline. Intuitively, this is because both the long-term fundamental value and the initial price depend only on expectations over flood event risks. In contrast, the realization of flood events determines accumulated learning by the time policy reform is enacted; consequently, realizations with more storms mitigate the additional price impacts of policy reform, thus reducing overall price volatility.

The results also highlight an intuitive trade off in the timing of flood policy reform: while faster reform could decrease allocative inefficiency costs (Table 7), it is also projected to increase market volatility. Finally, Table 9 presents results for alternative values of the utility discount factor (not re-scaled). It is important to note that these changes affect projected price declines under both homogeneous rational and heterogeneous beliefs, as β determines the extent to which today's housing prices reflect expected future climate change even if agents are fully informed. The results are nonetheless consistent with the benchmark.

[14] Consideration of an alternative maximum coastal amenity value Ξ based on our hedonic regression results ($\$4.9k/yr$) appears to increase the percentage future price decline considerably, but this is a scaling effect: Decreasing Ξ lowers the predicted initial period coastal home price from $410k to $206k, so that a given devaluation amount appears as a larger percentage of the initial price. Re-scaling the flow general home ownership value e^h to match the benchmark initial coastal home price of $410 in this scenario, the model predicts an equal *level* price decline ($48k), corresponding to a comparable percentage as in the benchmark.

Table 9: Utility Discount Factor		
	Future $\%\Delta P$	
Scenario	$\beta = .97$	$\beta = .99$
0% Optimists	-4.0%	-1.8%
35% Optimists	-12.1%	-13.5%

Finally, we consider an additional extension of the model to account for the possibility that coastal residents change their flood risk beliefs *differentially* after moving to the coast in order to rationalize their sorting choice *ex-post*. Details are presented in the Appendix. We argue that ex-post rationalization should not fundamentally alter the main results as long as there are optimistic agents among the potential marginal buyers of coastal homes, as is consistent with the survey results. That is, while ex-post rationalization may create a class of 'entrenched' coastal residents (who are less likely to become marginal *sellers*), mispricing of coastal homes that are being sold (e.g., by fully informed agents) will continue as long as there are optimists among the marginal buyers. The survey results suggest this to be the case: 30% of (currently) non-coastal residents in our sample are optimistic about coastal flood risks. In addition, Figure 6 compares flood worry distributions among *new movers*, defined as agents who moved from another town to their survey area within the past 3 years ($n = 26$).

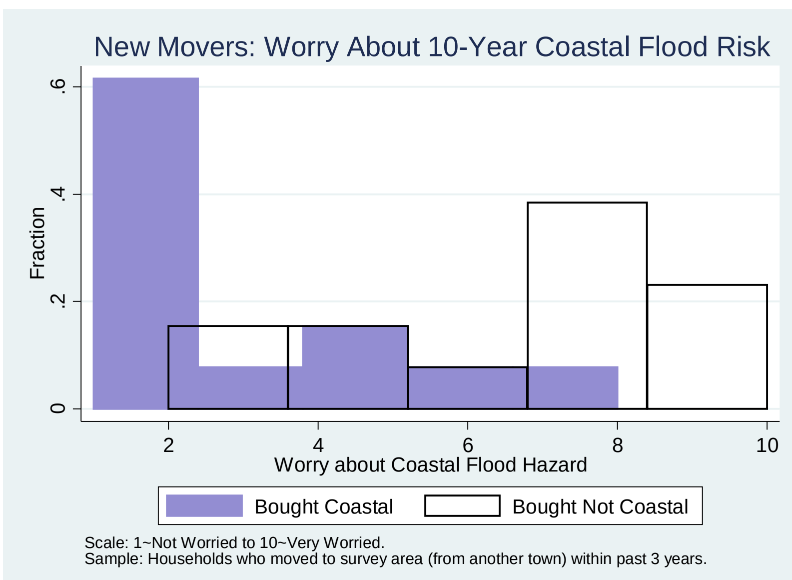


Figure 14

Much like the analogous figures for the full sample, Figure 14 shows that new movers 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. Consequently, the potential marginal buyers for coastal properties appear likely to misperceive flood risks in our empirical setting.

7.2 Empirical Comparisons

Our model delivers predictions for the potential negative home price impacts of future flood risk increases under belief heterogeneity. In order to address concerns that these results may be driven by our research design, this section provides some additional empirical comparisons for potentially sensitive model inputs and outputs.

First, this study elicits coastal amenity values using contingent valuation, a stated preference elicitation method with known shortcomings. We chose this method because it enables us to ask respondents specifically about their valuation of the coastal amenity holding flood risk and other confounders constant. An important alternative methodology, hedonic regression, can provide revealed preference estimates, but typically cannot cleanly disentangle the different components entering the observed coastal home price premium. As a comparison, we nonetheless present results for a hedonic analysis in our empirical setting. We collect home sales transactions and characteristics data for Bristol County and North Smithfield, RI, from Tax Assessor records and merge these with a spatial layer to identify homes that are within 400 feet of the waterfront as well as in official NFIP-designated flood zones. (The Appendix provides details on the data and estimation.) The estimated coastal home premium is around +23% and generally precisely estimated, as shown in Table A2. Given the median coastal home price in the data ($424k), at a real interest rate of 5%, this estimate corresponds to an annual coastal value of $4,876. For comparison, the survey results imply an annualized coastal value of $6,720 for the median coastal home price in our sample ($410). As shown in equation (22), the overall coastal home premium should reflect a combination of the marginal buyer's coastal amenity value, flood risk perceptions, and future housing market expectations. Consequently, it should not come as a surprise that the estimated net coastal premium is lower than the coastal amenity value elicited from the survey, particularly as true flood risks and expectations are difficult to control for empirically, and strongly correlated with being on the coast. At the same time, we cannot disentangle how much of the gap between the survey results and hedonic estimate is due to these structural differences versus methodological biases in stated preference elicitation (e.g., hypothetical bias). We address this concern by adopting the hedonic regression estimate as a value of Ξ in the sensitivity analysis.

Next, this study also uses stated preference methods to elicits households' flood risk perceptions. This methodological choice again reflects the difficulty of cleanly isolating flood risk belief levels from other confounders feeding into empirically observed home prices. Once heterogeneity and dynamics are formally taken into account, changes in housing prices after flood events do not cleanly isolate contemporaneous belief changes, as demonstrated in (23). However, empirically observed home price responses to non-direct impacts of flood events are difficult to reconcile with the notion that events were rationally anticipated by the market. Evidence from insurance uptake further supports the notion that many households underperceive flood risks. First, by some estimates only about half of homeowners in high risk areas are insured, despite generous subsidies of some policies below actuarially fair rates (Harrison, Smersh, and Schwartz, 2001). Second, the dynamics of flood insurance demand in response to flood events have been shown to follow a pattern consistent with Bayesian learning with forgetting (Gallagher, 2014).

Third, our model assumes a convergence of effective flood risk beliefs at some time T which is formally equivalent to a policy change to an enforced flood insurance mandate at actuarially fair premiums. This assumption is empirically motivated in part through recent legislative efforts. The National Flood Insurance Program (NFIP) has long been out of actuarial balance, with payouts exceeding premiums, FEMA owing the U.S. Treasury $23 billion as of March 2016 (GAO, 2017). The Biggert-Waters Flood Insurance Reform Act of 2012 sought to bring the program closer into fiscal balance through insurance subsidy phase-outs and immediate price increases for lapsed or new policies, including those for newly sold properties which would be charged official full risk rates (FEMA, 2013). The policy shift was short-lived as the Homeowner Flood Insurance Affordability Act of 2014 partially repealed and modified Biggert-Waters.[15] Looking toward the future, however, an eventual move towards real risk rates and more strictly enforced insurance mandates is highly likely, especially in light of increasing NFIP payout costs yet to come, such as from the extraordinarily destructive 2017 Hurricanes Harvey and Irma.

Finally, our model predicts coastal home prices declines due to belief changes after flood events, risk changes, and insurance policy reform. In order to gauge whether our predictions are quantitatively reasonable, we conclude by highlighting related evidence from the empirical literature. First, the literature has repeatedly found significant negative short-run price impacts from flood events' informational signal (i.e., excluding direct damage effects). Bin and Landry (2013) estimate price declines of -5.7% to -13% from 1999 floods in North Carolina; Kousky (2010) finds impacts of -6% to -10% from 1993 floods in Missouri and Mississippi, and Hallstrom and Smith (2005) find a -19% short-run impact of a 1992 flood event in Florida.

Second, while there is no past empirical experience with the future climate and policy change whose impacts we study - this is, after all, a raison d'être of the model - we can look at FEMA

[15] Specifically, the HFIAA impacts policyholders heterogeneously, by lowering the rate of future premium increases for some, eliminating rate increases for others, and providing premium refunds to a subset who paid the full risk rate on new insurance purchases (FEMA, 2014).

flood map updates and the Biggert-Waters Act as partial policy proxies.[16] Gibson, Mullins, and Hill (2017) study New York City property prices and estimate that 2012 FEMA flood map updates (i.e., new insurance requirements) lowered some property prices by as much as -12% to -23%. They further estimate a Biggert-Waters impact of -3% to -6%. Lastly, we also utilize our dataset to estimate Biggert-Waters impacts on newly sold flood zone properties in our sample. The point estimates suggest an effect between -1% and -7%, though these are not precisely estimated (see Appendix Table A2). Identification of the impacts of Biggert-Waters is generally challenging due to the short time period for which it was in place and because Superstorm Sandy hit the Northeastern U.S. just three months after its enactment, depressing the number of flood zone home sales and complicating causal inference. Overall, however, we conclude that the orders of magnitude of our projections compare favorably with the available empirical evidence on past related events and policy changes.

8 Conclusion

This paper examines how climate risk belief heterogeneity impacts coastal home price dynamics. 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 risk level from storm events in a Bayesian framework, 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, coastal amenity values, and expectations of future risks, beliefs, and policy. Even a modest fraction of misinformed agents can lead to overvaluation, excess volatility, and eventual price declines in coastal housing markets as flood risks rise. The model also highlights structural challenges inherent in inferring flood risk belief levels from home price data. We thus conduct a door-to-door survey campaign 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 both higher amenity values for coastal living and lower flood risk perceptions, compared to their inland counterparts.

We utilize the survey results to calibrate the model and project coastal home price dynamics over 25 years. In the scenario with fully informed agents, home prices decrease only modestly (-3%) as the expected costs of future flood risk increases have already been smoothly capitalized into the home prices. In contrast, at our benchmark estimate that 35% of the population are

[16] Neither policy corresponds to our time T policy reform as both entail heterogeneous treatment of different homeowners, partly subsidized rates, imperfect enforcement, and limited flood risk increases.

optimistic Bayesian learners, the projected price decline increases by a factor of four (to -12.7%), reflecting the previous overvaluation and leading to greatly increased price volatility.

These results motivate several policy implications. While our model can only capture welfare effects in the form of allocative inefficiency, in reality devaluations and volatility in housing markets are a significant policy concern for several additional reasons, such as their potential effects on mortgage and credit markets. A formalizations and quantification of these impact mechanism would arguably be a highly interesting topic for future work.

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 1.6 feet of sea level rise - a plausible scenario by the middle of the century (USACE, 2017) - would result in substantial inundations plus a 7,000 square mile (38%) increase in U.S. flood zones. At the same time, household beliefs about these changes remain strongly heterogeneous, with 60% of respondents in a recent national survey indicating that they do not believe rising sea levels to be a 'very likely' consequence of climate change (Pew, 2016). This paper has argued that this heterogeneity can directly affect the price impacts of sea level rise in coastal hosing markets. More broadly, at this time the United States faces a critical policy juncture in flood risk management. As recovery efforts for Hurricanes Harvey and Irma are ongoing, the National Flood Insurance Program is up for re-authorization, and recent federal budget proposals seek to cut funding for FEMA flood map updates. The results of this paper highlight the importance of flood risk information, beliefs, and long-run policy expectations in ensuring the efficiency and stability of coastal housing markets moving forward.

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9 Appendix

9.1 Tables and Figures

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. (*** $p<0.01$, ** $p<0.05$, * $p<0.1$).

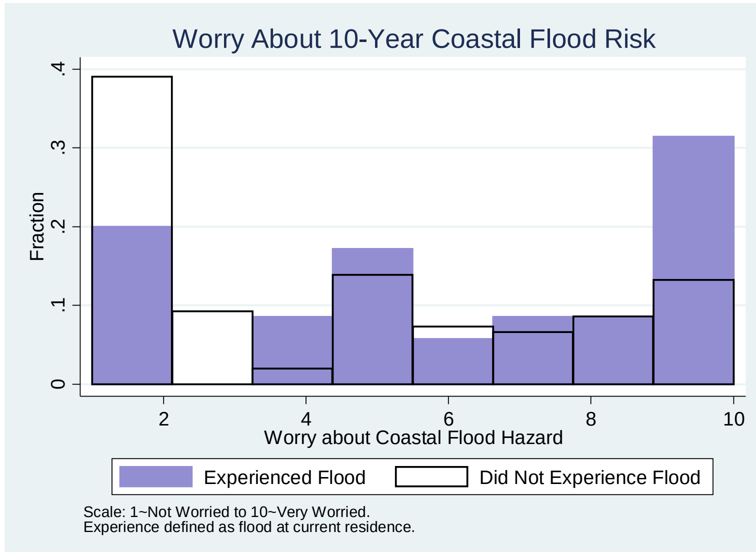

Figure A1

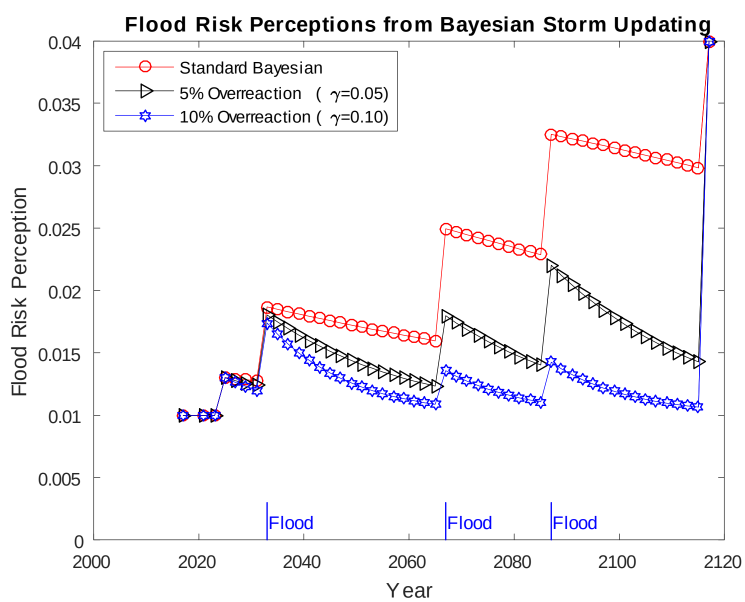

Figure A2

9.2 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. This section presents an illustrative extension of the model to showcase the potential effects of ex-post rationalization. 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 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:

$$P_0^* = \beta(e^h + \overline{\xi_0^r} - \pi^r\delta + E_0^r[P_1]) = \beta(e^h + \overline{\xi_0^o} - \pi_0^o\delta + E_0^o[P_1]) \tag{26}$$

If no storm occurs in period 0, both coastal and non-coastal Bayesian learners update their flood risk beliefs 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:

$$\pi^r > \underbrace{\pi_0^o > \pi_1^{o,NC_{0,1}}}_{\substack{\text{Bayesian}\\ \text{Updating}}} \underbrace{> \pi_1^{o,C_{0,1}}}_{\text{Rationalization}} \tag{27}$$

Beliefs (27) 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 (27): $E_1^{o,C_{0,1}}[P_2^{m_2}] \geq E_1^{o,NC_{0,1}}[P_2^{m_2}] \geq E_1^r[P_2^{m_2}] \geq E_0^r[P_1^{m_1}]$. 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.[17] The equilibrium coastal home price in period 1 is thus determined by the interaction between these groups. More formally:

$$\begin{aligned} P_1^* &= \underbrace{\beta(e^h + \overline{\xi_1^r} - \pi^r\delta + E_1^r[P_2])}_{\text{Newly marginal coastal realists}} = \underbrace{\beta(e^h + \overline{\xi_1^o} - \pi_1^{o,NC_{0,1}}\delta + E_1^{o,NC_{0,1}}[P_2])}_{\text{Marginal new coastal Bayesians}} \\ &< \underbrace{\beta(e^h + \overline{\xi_0^o} - \pi_1^{o,C_{0,1}}\delta + E_1^{o,C_{0,1}}[P_2])}_{\text{Long-term coastal Bayesians}} \end{aligned} \tag{28}$$

With ex-post rationalization (or differential updating), the model thus predicts that long term coastal residents' valuations of their homes will 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.

Empirically, the key implication of (28) 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. As noted in the main text, our survey results suggest that 30% of currently non-coastal residents are optimistic about coastal flood risks, and that new movers from other towns also exhibit flood risk optimism. Consequently, the potential marginal buyers for coastal properties appear likely to underestimate flood risks in our sample and empirical setting, regardless of whether beliefs of established coastal residents are additionally affected by ex-post rationalization.

9.3 Empirical Comparison: Hedonic Estimation

This section describes the dataset and estimation for Section 7. We scrape property data for the Rhode Island Bristol County towns of Barrington, Warren, and Bristol from Tax Assessor's records, including transactions histories and property characteristics from 2017. In addition, to allay concerns that potential homebuyers view Bristol County as a housing market, and therefore our "control" group of non-floodzone homes could also be impacted by the Biggert-Waters Act through housing market interactions, we also collect data for all of North Smithfield, Rhode Island, given that it has similar sociodemographic characteristics and proximity to Providence as Bristol Country. We locate buildings within a property using a GIS layer of all structures in Rhode Island originally compiled by the Rhode Island E-911 Uniform Emergency Telephone

[17] In the aftermath of a storm, coastal optimists could become marginal sellers as well, depending on how they update their beliefs.

System and redistributed by the Rhode Island Geographic Information System (RIGIS, 2017). This layer geo-locates all known structures in Rhode Island to the latitude and longitude of the center of the building. We obtain official flood map information from FEMA's Map Services Center and historical flood maps from RIGIS. Finally, to map shorelines, we obtain the Rhode Island Continually Updated Shoreline Product from RIGIS (RIGIS, 2016). We add a 400 foot buffer to the shoreline in order to select coastal properties. In addition, we obtain the spatial extent of Superstorm Sandy surge inundation from STORMTOOLS (SAMP, 2017). We match individual property structures to their flood zone, coastal/non-coastal designation, and Sandy inundation status. We then match properties with Tax Assessor data including building structure information and the history of property transactions including sales price (which we inflation-adjust to 2015 $USD using the BLS Consumer Price Index) and deed type. Based on the sale date, we categorize property sales as before or after: the Biggert-Waters Act passage (July 6, 2012), the Homeowner Flood Insurance Affordability Act passage (March 21, 2014) and introduction (October 29, 2013).

We trim our transactions data to exclude the bottom and top 1% of annualized price changes between sales, as well as observations for which the sales price is more than 50% below the current tax assessor value, in order to remove non-arm's length deals. We also trim non-standard properties in terms of bedrooms (those with more than 10 bedrooms) and bathrooms, and generally seek to exclude apartment buildings, nursing homes, etc. For robustness we also consider a restriction to standard "Warranty" deed types, omitting deeds such as Quit Claims more likely to be associated with non-market sales.

Focusing on the post-crisis years of 2010-2014, we estimate the following specification:

$$lnP_{it} = \beta_0 + \gamma_i X_i + \delta c_i + \beta_1 f_i + \beta_2 BW_{it} + \beta_3 f_i * BW_{it} + \alpha_c + \theta_t d_{Yt} + \varepsilon_{it}$$

In it, we regress the log of house sales price (2015 $USD) on a vector of home characteristics (X_i), an indicator for a coastal home (within 400 feet of the coastline; c_i), an indicator for being in a flood zone (f_i), an indicator for a house sold after the passage of the Biggert-Waters Act (and before its partial repeal in 2014; BW_{it}), the interaction between the flood zone and Biggert-Waters status ($f_i * BW_{it}$), as well as Census tract fixed effects (α_c) and year fixed effects (d_{Yt}). The first column presents results including property sales between 2010 and 2017 that were not directly impacted by Sandy and whose flood designation did not change over the time period. Columns (3)-(4) and (5) further restrict the sample to the time before the HFIAA was passed and introduced, respectively.

Table A2: Hedonic Home Price Estimation

Dependent Variable: Log(Real Sales Price) ($2015)					
	(1)	(2)	(3)	(4)	(5)
Land Area (Acres)	0.220***	0.256***	0.164**	0.254***	0.184**
	(0.0607)	(0.0400)	(0.0607)	(0.0648)	(0.0696)
Age	-0.00428***	-0.00371***	-0.00526***	-0.00336**	-0.00557***
	(0.000838)	(0.00101)	(0.00139)	(0.00106)	(0.00133)
Age^2	1.61e-05***	1.48e-05**	2.25e-05**	1.19e-05*	2.43e-05**
	(4.39e-06)	(6.06e-06)	(7.74e-06)	(5.72e-06)	(7.87e-06)
#Bathrooms	0.224***	0.239***	0.226***	0.243***	0.230***
	(0.0224)	(0.0175)	(0.0297)	(0.0232)	(0.0265)
#Bedrooms	-0.00219	0.0115	-0.0199	-0.00101	-0.0310
	(0.0265)	(0.0241)	(0.0331)	(0.0285)	(0.0360)
Coastal (w/in 400 feet)	0.229***	0.176***	0.242***	0.169**	0.229***
	(0.0672)	(0.0554)	(0.0681)	(0.0624)	(0.0602)
FEMA Floodzone	-0.0413	-0.0127	-0.0409	0.0152	-0.0346
	(0.0723)	(0.0742)	(0.0909)	(0.0965)	(0.0927)
During Biggert-Waters Act	0.104*	0.0683	0.0794**	0.0561	0.0782**
	(0.0538)	(0.0552)	(0.0312)	(0.0351)	(0.0299)
Floodzone*Biggert-Waters	-0.00924	-0.0500	-0.0582	-0.0728	-0.0378
	(0.0723)	(0.0638)	(0.0583)	(0.0871)	(0.0749)
Constant	12.36***	12.29***	12.36***	12.20***	12.48***
	(0.131)	(0.110)	(0.156)	(0.116)	(0.214)
Observations	2,328	1,838	955	686	1,040
R-squared	0.626	0.661	0.615	0.662	0.604
Adj.R-sq.	0.621	0.656	0.606	0.650	0.595
"Warranty" Deeds only		✓		✓	

Reports results of OLS regression of log(Real Sales Price) on indicated variables plus Census tract- and year fixed effects. Standard errors clustered at the census tract level and in parentheses.

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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:

$350/month
in housing costs

□ No → What if you could save:
$425/month
in housing costs
□ No □ Yes

□ Yes → What if you could save:
$275/month
in housing costs
□ No □ Yes

[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]

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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!

BROWN

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