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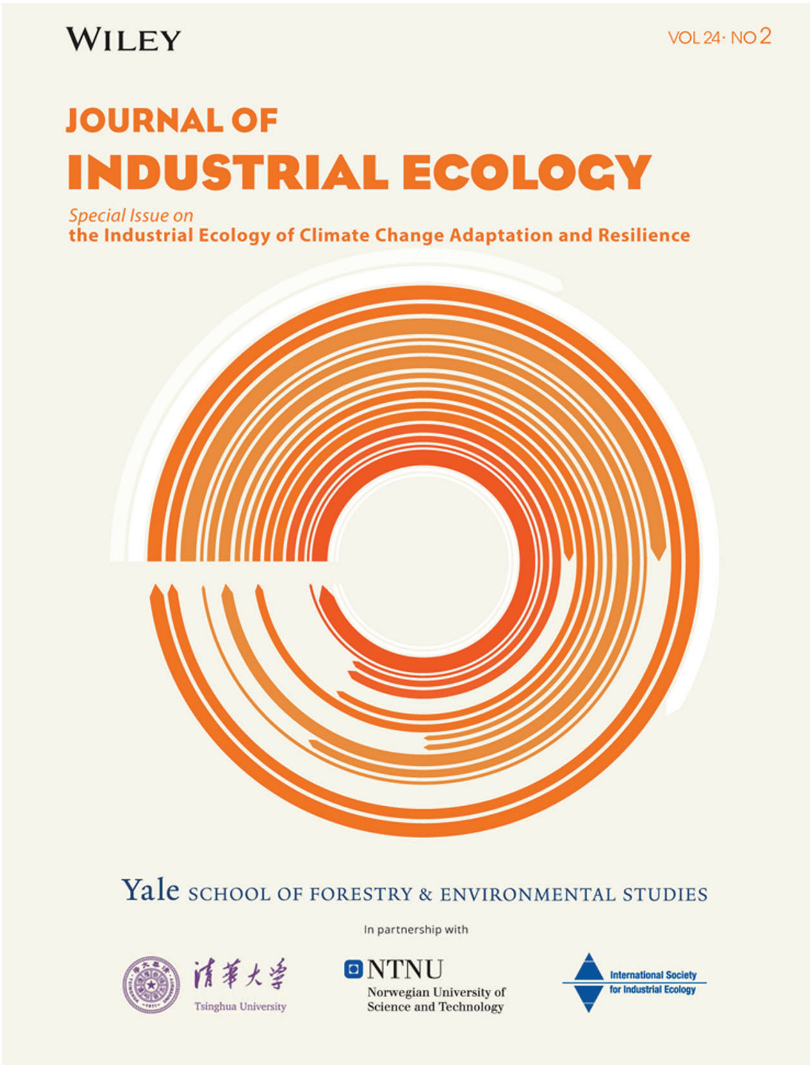

Cover Image

The cover image, designed by Peter Hirsch and Yanin Kramsky, evokes a Sankey diagram, a type of flow chart widely used in industrial ecology in which the width of the arrows is proportional to the magnitude of material and energy flows. For a description of the history and methodology of Sankey diagrams, see the work of Mario Schmidt.

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EDITORIALS

FORUM

RESEARCH AND ANALYSIS

ANCILLARY INFORMATION

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RESEARCH AND ANALYSIS

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An integrated model of real estate market responses to coastal flooding

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Abstract

Understanding and improving how humans adapt to climate change are priorities in our research community, and coastal settlements are good places to study adaptation. Severe storm events and sea-level rise are threatening coastal communities with increasing levels of flood damage. Because ownership of coastal assets is distributed among many private and public actors, both individual property owners and public officials must take adaptive actions. This paper introduces an integrated agent-based and hedonic pricing modeling system to simulate coastal real estate market performance under non-equilibrium conditions that reflect the effects of storm events. The modeling system, which is used for policy analysis, is calibrated to conditions in two towns in Monmouth County, New Jersey, USA, which were badly damaged by Hurricane Sandy in 2012. The key findings are that (a) coastal real estate markets capitalize flood risk into property values but this discount diminishes rapidly as time passes between storm events, and (b) there is a distinct equity versus efficiency tradeoff in designing public policies to reduce the cost to society of coastal flooding. Stringent regulation of building practices reduces flood damage but drives away poorer home buyers and owners, whereas informational and incentive-based policies are fairer but less effective. Hands-off, market-based retreat from risky areas is socially costly but allows less wealthy people to remain at the shore, albeit in vulnerable situations. Managed retreat should emphasize improved recreational access to coastal amenities while discouraging people from living there.

KEYWORDS

adaptation, agent-based modeling, coastal flooding, housing market, resilience, spatial hedonic

1 | INTRODUCTION

Coastal communities are adapting to intensified storms and sea-level rise, but the process is often emotionally painful for households, politically difficult for public officials, and economically wasteful for insurers and other market actors. People and ecosystems are at risk, and so are the large stocks of materials and embodied energy forming the built environment in coastal settlements. Developing sound public policies to steer coastal adaptation can be difficult because decision-making is distributed, with private individuals often controlling most land and buildings, public actors controlling many infrastructure systems and regulating private activities, and private enablers making the markets work. There is a need to ask lots of "what-if" questions when designing policies, and one way to explore these questions prior to implementation in real communities is with policy simulation models.

Policy simulation tools in the coastal adaptation domain have specific requirements. They need to be able to model distributed, behaviorally plausible human interactions with the natural environment and their associated marketplace transactions under different policy scenarios. Unpacking that sentence, we encounter methodological heterodoxy: distributed agency implies complexity (Andrews, 2000; Broto, Allen, & Rapoport, 2012; Dijkema & Basson, 2009; Dijkema, Xu, Derrible, & Lifset, 2015), behavioral realism suggests agent-based modeling (Axtell, Andrews, & Small, 2002; Baynes, 2009; Wu et al., 2017), human–environment interactions suggests systems analysis (Edwards, 2002; Godschalk, 2003; Holling, 1973; Peterson, 2014; Webster, 2002), and marketplace transactions suggest econometric analysis (Palmquist & Smith, 2001). These various traditions have addressed coastal flood risk but now there is some convergence and integration. Integration raises interesting challenges of providing

feedback between coupled systems, identifying sources of dramatic change, linking multi-scale phenomena, and detecting thresholds (Filatova, Polhill, & van Ewijk, 2016).

The econometric tradition offers the hedonic pricing model, an established method in real property studies that sticks close to the empirical data and is useful for estimating the typical tradeoffs that economic actors make among quality attributes of goods and environmental qualities at a given point in time, including the loss of value due to flood risk (Atreya, Ferreira, & Kriesel, 2013; Bin & Polasky, 2004), the extent to which flood risk is capitalized into property values (Beltrán, Maddison, & Elliott, 2018), how this evolves over time (Beltrán, Maddison, & Elliott, 2019), and the presence of neighborhood effects (de Koning, Filatova, & Bin, 2016). However, the hedonic model does not adequately detect the non-marginal changes present within the dynamics of the real property market. Coastal flooding is an example of an extreme climate event that may dramatically disrupt the market dynamics. The resulting hedonic function before flooding may be different from the hedonic function re-estimated after flooding.

The agent-based modeling tradition offers rule-based methods for simulating non-deterministic interactions among heterogeneous system components, making them useful in exploring non-marginal changes such as adaptation to coastal flooding. Such models are used for studying land use (An, 2012; Levy, Martens, & van der Heijden, 2016; Matthews, Gilbert, Roach, Polhill, & Gotts, 2007; Parker, Manson, Janssen, Hoffmann, & Deadman, 2003), the individual and social behaviors affecting coastal flood risk (Haer et al. 2016; Jenkins, Surminski, Hall, & Crick, 2017), the competing influences of storm risks and coastal amenities (Walls, Magliocca, & McConnell, 2018), individual adaptations (Erdlenbruch & Bonté, 2018), the operation of real estate markets in the coastal zone (Chandra-Putra, Zhang, & Andrews, 2015), effects of flood insurance schemes (Dubbelboer, Nikolic, Jenkins, & Hall, 2017; Han & Peng, 2019), and interactions between insurance schemes and local government actions (Crick, Jenkins, & Surminski, 2018).

Filatova (2015a) innovates by embedding a highly empirical hedonic pricing model within an agent-based model of a coastal real estate market. She reaches this point in steps, first, building a stylized agent-based model (ABM) (Filatova, van der Veen, & Parker, 2009; Filatova, Voinov, & van der Veen, 2011), and then adding a hedonic pricing model to it (Filatova & Bin, 2014).

This paper adopts the approach of Filatova (2015b) by adding a hedonic price sub-model to our previous, stylized model (Chandra-Putra et al., 2015). The current model also innovates because it is spatially explicit, includes neighborhood effects, incorporates multiple homeowner adaptation possibilities (rebuilding in place, elevation of buildings, and exit), models local policy levers and national flood insurance rules, and supports comparative policy analysis. The results bring a new empiricism to ABM that increases the value of its policy insights.

Policy debate centers on the question of how to reduce individual and social costs of flood events without dictating behavior in what many desire to be a free marketplace. Peterson (2014) notes that, since Hurricane Katrina, climate-related damages have caused US$150 billion in losses per year to the U.S. real estate industry. Insurance agencies have been charging higher premiums to homeowners as a result (Kunreuther, 2006), even as public assistance is reducing the use of private insurance (Kousky, Michel-Kerjan, & Raschky, 2018). Extreme climate phenomena and frequent losses encourage some people to leave these communities, thereby changing their demographic make-up and real property values (O'Neill, van Abs, & Gramling, 2016). Property market participants do not all have adequate preparation to anticipate losses. City managers, building code officials, urban planners, and disaster managers will fail to make cities more climate resilient unless they engage market actors such as real estate investors, developers, and insurance companies. Ultimately, resilience, a salient topic for this journal (Meerow & Newell, 2015), depends on the capacity and willingness of stakeholders to act, individually and collectively.

The research questions motivating this study are:

1. How do coastal real estate markets respond to flood events?
2. Which types of public policies work better from a societal perspective to reduce flood costs?
3. What are the tradeoffs associated with these policies?

2 | METHODS

This study integrates an ABM model with the heterogeneity of a property value estimation model, flood insurance model, microeconomic demand/supply model, and individual and collective resilience behavior model. The hedonic property pricing model identifies influential factors that estimate the property value and flood insurance purchase. Details are available in Chandra-Putra (2017). The model of the coastal real estate market is created based on two municipalities in Monmouth County, New Jersey. Parcel map, floodplain map, sales data, and flood insurance data for these two towns are collected from various sources. Data on flood risk perceptions and mitigation and adaptation strategies are based on previous studies conducted by Monmouth University Polling Institute (2013), Boulware (2009), and Howard, (2014).

The simulation experiment starts with a spatially explicit parcel model of a city, in which each parcel is attributed with property information, neighborhood characteristics, location characteristics, flood zone characteristics, and flood insurance purchase characteristics. These attributes

TABLE 1 A comparison metrics for Union Beach and Highlands

	%SFHA[a]	HHI rank	CHI rank	Average FEMA IA assistance	No home owners insurance	PIF/ housing units	Premium amounts (millions)	NFIP payouts (millions)
Union Beach	87 (#3)	19	24	$5,772	46%	0.53 (#3)	$1.4 (#7)	$89 (#3)
Highlands	51 (#7)	29	37	$3,711	70%	0.37 (#5)	$1.5 (#5)	$57 (#5)

Data source: Hoopes Halpin (2012).
[a]SFHA or Special Flood Hazard Area refers to land areas identified by the United States Management Federal Emergency Agency (FEMA) as areas that are high risk for flooding or floodplains.

are updated over time through co-simulation with the ABM model that simulates the stakeholder individual and social behavior. The stakeholders that include government, developer, bank, insurer, homeowners, and home sellers, vary in, and act based on, the roles that are assigned to them.

The purpose of the model is to explore real property market resilience toward coastal flooding. Therefore, the calibration and validation of the models highlight the importance of planning and policy formation regarding the real property market. In order to achieve this objective, the research adopts the following experimental workflow of: (a) simulate flood risk awareness and adaptive responses of real property market stakeholders, and the resulting real estate market values; (b) investigate the behavioral effects on other interesting sub-markets such as flood insurance market and real property markets based on tenureship (i.e., owner-occupied and absentee-owner properties); (c) validate the resulting models with actual market data from two towns; and (d) explore “what-if” scenarios.

3 | CASE STUDIES OF UNION BEACH, NJ AND HIGHLANDS, NJ

The simulation experiments are based on two municipalities that are located in Monmouth County, New Jersey. They are Union Beach and Highlands, which both were significantly affected by Hurricane Sandy in 2012 (see Table 1). More FEMA assistance to individuals was given to Union Beach (mean = $5,772) than to Highlands (mean = $3,711). According to the Household Hardship Index (HHI), Union Beach scored 70, which is higher than Highlands scored at 67 on a scale of 1 (least hardship) to 100 (greatest hardship). Similar scores also apply for these municipalities regarding the Community Hardship Index (CHI) (see Table 1). Prior to Sandy in 2012, only 30% of homeowners insured their homes in Highlands, and 54% of households were protected in Union Beach. Regarding the National Flood Insurance Program (NFIP) Community Rating System (CRS), a voluntary program participated in by communities to reduce flood risks, Union Beach is in class 6, which makes the town eligible for up to a 20% discount on their flood insurance premiums. Highlands has not yet participated in the CRS program. The number of payouts to the Sandy-affected policyholders is high for both Union Beach and Highlands, which shows that the scale of damages caused by Hurricane Sandy is similar between the two municipalities.

To develop a more realistic representation of the two towns, data on the local demographics is collected to characterize the agents in the simulation. Union Beach is a borough in Monmouth County with a total population of 6,245 and 784 persons-per-square-mile (equivalent to 302 persons-per-square-kilometer) in density (U.S. Census, 2010). U.S. Census in the same year also accounts for 2,111 households residing in the borough. The borough has 2,269 housing units with the median house price, $181,898 and 14% of the total units are renter occupied. The demographics include 91% White, 2% Black or African American, 2% Asian, 3% from other races, 2% more than one race, and 11% Spanish speakers. Population under the age of 18 were 24% of the people, 9% from 18 to 24, 27% from 25 to 44, 31% from 45 to 45, and 9% were 65 years of age or older. According to the Census’s 2006–2010 American Community Survey (in 2010 inflation-adjusted dollars), median household income was $61,347. Some 33% of households have an income below the ALICE threshold.[1] Geographically, water makes up 5% of the total area of 1.889 square miles (equivalent to 4.9 km^2) and located an average of 3 feet (equivalent to 0.914 m) above sea level. The borough that was incorporated on March 16, 1925, and borders municipalities of Hazlet, Keansburg, and Keyport, which all are in Monmouth County.

Only 11 miles (equivalent to 17.7 km) eastward from Union Beach, Highlands is a borough that overlooks Sandy Hook and the Atlantic Ocean with larger water areas, 44% of the total area of 1.369 square miles (equivalent to 3.546 km^2), and located 13 feet (equivalent to 4 m) on average above sea level. The borough was incorporated 25 years earlier than Union Beach, on March 22, 1900. According to the 2010 U.S. Census, the borough’s population was 5,005 and 709 persons-per-square-mile (equivalent to 1,932 and 274 persons-per-square-kilometer) in density. The demographics of the borough do not show much difference from Union Beach. The racial makeup is 93% White, 2% Black or African American, 1% Asian, 2% from other races, 2% more than one race, and 6% Spanish speakers. In the borough, 14% of the population are under the age of 18, 7% from 18 to 24, 29% from 25 to 44, 37% from 45 to 64, and 13% are 65 years of age or older. The median household income is slightly higher than Union Beach Borough at $89,415, adjusted to 2010 dollars (U.S. Census’s 2006–2010 ACS). The borough has 7,225 households, residing in 7,418

[1] ALICE or Asset Limited, Income Constrained, Employed refers to people who are employed and earn above the Federal Poverty Level, but do not earn enough to afford a basic household budget of housing, childcare, food, transportation, and healthcare.

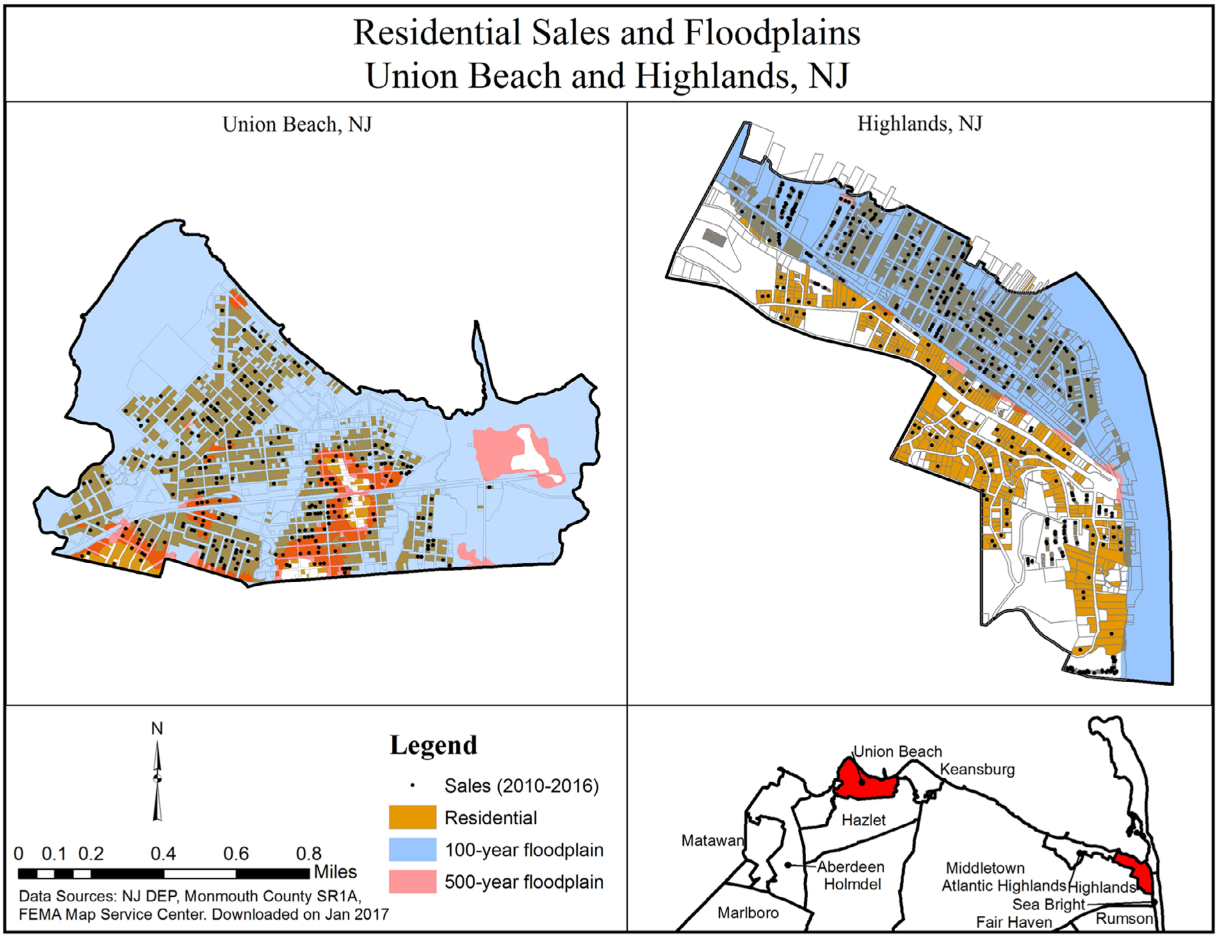

FIGURE 1 Residential property sales and floodplain maps for Union Beach and Highlands, NJ (2010–2017)
Data source: NJ DEP, Monmouth County OPRSS, US FEMA (2015).

housing units, of which 9% are renter-occupied. The median house price is $235,653, which is higher than in Union Beach. Figure 1 illustrates the sales for both towns during the periods 2010–2017. It also shows that many sales were located within the 100-year floodplain. Union Beach has a greater percentage of its land in floodplain areas than Highlands does as suggested from Figure 1.

Calibrating and validating the ABM model can be challenging since the model incorporates strong assumptions about behavioral rules followed by individual real property market participants and has more degrees of freedom than it has empirical observations (Levy et al., 2016). Data on the physical and demographic characteristics of the towns help bound the model's calibration and validation process.

Table 2 shows flood insurance data on the total payouts, the amount of collected premiums, and the number of policies is the estimated variables. Like many other towns that were hit by Hurricane Sandy in October 2012, the amount of flood insurance payouts for these towns spiked and exceeded the premiums accumulated over the years due to the storm surge damages caused by the coastal flooding. From the same table, it is noticed that although Union Beach has more policies-in-force than Highlands has, the amount of premiums collected from Union Beach is slightly lower than those from Highlands, indicating that participating in the FEMA CRS gives a premium discount to the Union Beach's policyholders. Regarding the number of claims caused by Sandy, Union Beach is greater than Highlands by $16,300,611. This is because Union Beach has a larger floodplain area (87%) than Highlands (51%).

4 | SIMULATION MODEL

This section provides an overview of the ABM model. It starts with an explanation of the overall modeling framework and follows with a discussion of the sub-models that are included in the ABM model. In the next sub-section, a discussion on agents follows where each represents a stakeholder in the actual real property market. To test the overall modeling logic of the proposed ABM model, a set of scenarios and its combinations are constructed and discussed in the following sub-section. Additional details are provided in the Supporting Information S1.

TABLE 2 Total payouts, collected premiums, and number of policies-in-force for the two towns for the period 2000–2014

	Highlands			Union Beach		
Year	Claims amount ($)	Collected premiums ($)	Policies-in-force	Claims amount ($)	Collected premiums ($)	Policies-in-force
2000	0	424,602	872	0	510,120	987
2001	0	446,790	900	1,758	539,408	1,008
2002	0	521,735	934	5,789	605,049	1,051
2003	0	598,170	958	0	647,020	1,059
2004	0	677,793	973	4,454	695,954	1,080
2005	53,306	786,112	1,052	21,584	764,453	1,088
2006	1,627	866,116	1,076	0	850,381	1,100
2007	6,602	1,007,396	1,108	18,494	980,752	1,127
2008	0	1,169,151	1,088	7,844	1,081,268	1,135
2009	0	1,247,751	1,088	7,125	1,170,548	1,156
2010	84,775	1,341,614	1,112	710,990	1,283,496	1,173
2011	4,557,490	1,420,880	1,181	549,723	1,330,254	1,173
2012	49,735,726	1,494,572	1,160	66,036,337	1,445,356	1,195
2013	0	1,618,235	1,216	2,242	1,484,063	1,236
2014	0	1,652,342	1,168	0	1,442,760	1,219

Data source: FEMA NFIP.

4.1 | Modeling framework

The components and details of ABMs are commonly developed in stages. Buchmann et al. (2016) use the method in developing an ABM model of residential mobility, which includes adding the heterogeneous agents, the decision model structure, and the usage of input data and information. The ABM model used in the current paper is based on Chandra-Putra, Zhang, and Andrews' (2015) model ("the 2015 model") that models stakeholder behavior and interactions in a hypothetical coastal real estate market. The new ABM model not only considers the modeling elements that are used for calibration and validation purposes but also sub-models that constitute a more realistic representation of the real property market. As illustrated in Table S1-1 in the Supporting Information, the sub-models include (a) spatial model that is created using GIS; (b) hedonic property pricing model; (c) flood insurance model; (d) double auction market model.

The current ABM model includes significant additions that were not previously included in the 2015 model, including the sea-level data and spatially explicit data. While sea-level data describes the flooding events over the years, the spatial data gives characteristics not only to each property parcel such as whether the property is located in the floodplain or not, but also the neighborhood attributes and the structural attributes of the property. Another new component of the ABM model includes a more detailed flood insurance component that is developed based on the FEMA NFIP. Several types of flood insurance premium discounts such as through the CRS participation and deductibles, as well as the mandate for flood insurance purchase fall under this component category.

Agents in the model include home buyers, home owners/sellers, a developer/realtor combined agent, an insurer, and local government. Figure 2 illustrates these agents' behaviors that are included in the simulation model. See the Supporting Information for details and sources of calibration data.

4.2 | Simulation scenarios

The goal of running a simulation experiment is to provide insight on the indirect impact of coastal flood events on stakeholder's perception and adaptive behavior on flood risks. Systematically running the simulation experiment is also useful to test the performance of the ABM model. The model considers the following policy parameters: (a) CRS participation,[2] (b) Flood insurance mandate,[3] (c) Elevation mandate,[4] (d) Voucher,[5]

[2] Community Rating System (CRS) is an NFIP voluntary program that provides discounts on flood insurance premiums paid by any policyholder whose community meets and is recognized for the flood-risk reduction measures.

[3] Flood Insurance Mandate requires homeowners whose properties located in the floodplain to purchase flood insurance.

[4] Elevate Mandate requires homeowners whose properties located in the floodplain to elevate their homes.

[5] Voucher allows homeowners whose properties located in "A" or "V" flood zones to receive discounts on their premiums (Kousky & Kunreuther, 2014).

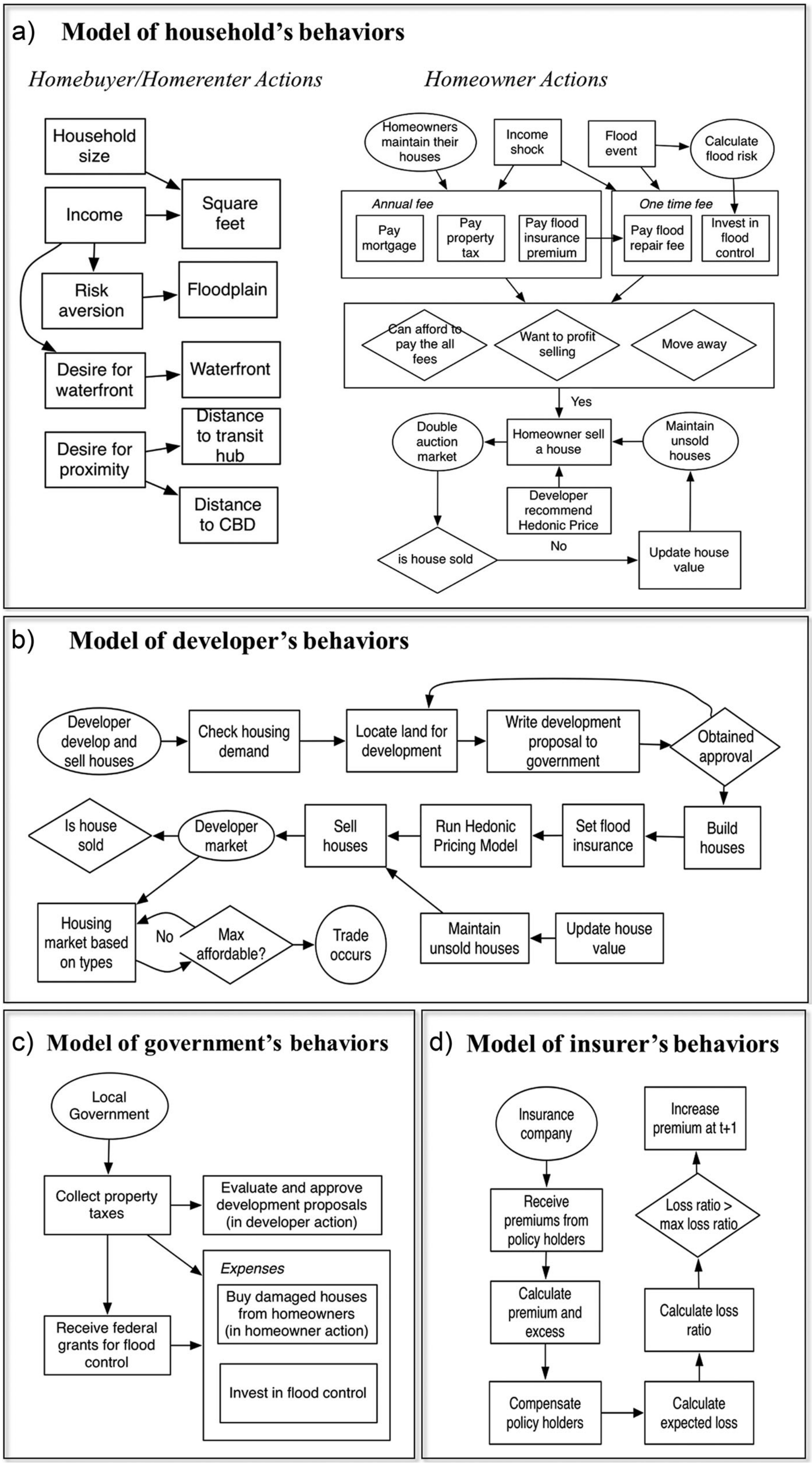

FIGURE 2 Model of behaviors flowchart

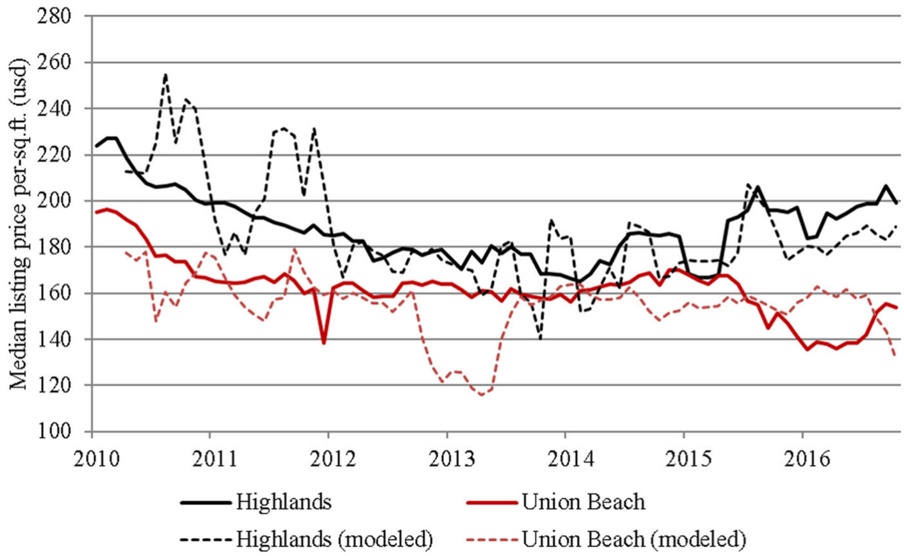

FIGURE 3 A comparison of observed property prices and modeling outputs for both municipalities
Note: Tabular data can be found in Table S2-1 in the Supporting Information S2.

(e) Disaster loans.[6] Therefore, the policy parameters inform the 32 permutated simulation scenarios. The simulation scenarios are intended to test the model components and details that include the hedonic pricing model, double auction market, and flood insurance model.

5 | CALIBRATION: HIGHLANDS, NJ SCENARIO

"Flood Insurance Mandate, Elevate Mandate, Disaster Loans" represents Highlands, NJ, in which high flood insurance premiums are expected along with low flood risk reduction efforts. High in property prices are also expected from the outputs of these simulation experiments. This scenario is used for calibrating the model, meaning that we adjusted parameters to yield results that better fit the data.

6 | VALIDATION: UNION BEACH, NJ SCENARIO

"Community Rating System, Flood Insurance Mandate, Elevate Mandate, Voucher (optional), Disaster Loans (optional)" scenario represents Union Beach, NJ, which participates in the CRS program. Therefore, the outputs from the simulation experiments are expected to show high flood risk reduction efforts among the stakeholders and low insurance premiums since the premium discount policy applies. Property prices are expected to be low in the scenario. This scenario is used for validating the model, meaning that we confirmed that the model outputs fit reasonably well with the observed data from a different town when using input data from that town.

7 | OUTPUTS OF VALIDATION RUNS

By following a systematic simulation modeling experimentation strategy as the model is developed from simple sub-models into an integrated ABM model, a difference in the simulation run times is immediately detected. Simple models have relatively shorter run time than those created with a complex modeling logic. High variance in the results is also noticeable from running several replicates of sub-models with the same parameter settings. This is because the models are not fully calibrated with data, but instead, use stochastic variables. A data-driven ABM model shows more consistencies in the results. Nevertheless, the simulation outputs show that all of the models follow the expected patterns.

Figure 3 illustrates that the model performs well in predicting realistic trends in the property prices for both towns for the period 2010–2016. Prices for real properties in Highlands are relatively higher than those in Union Beach as indicated by the solid lines. The model outputs follow similar trends as indicated by the dotted lines. Figure 3 also shows the model performance regarding how property prices respond to Hurricane

[6] Subsidized Disaster Loan from the U.S. Small Business Administration.

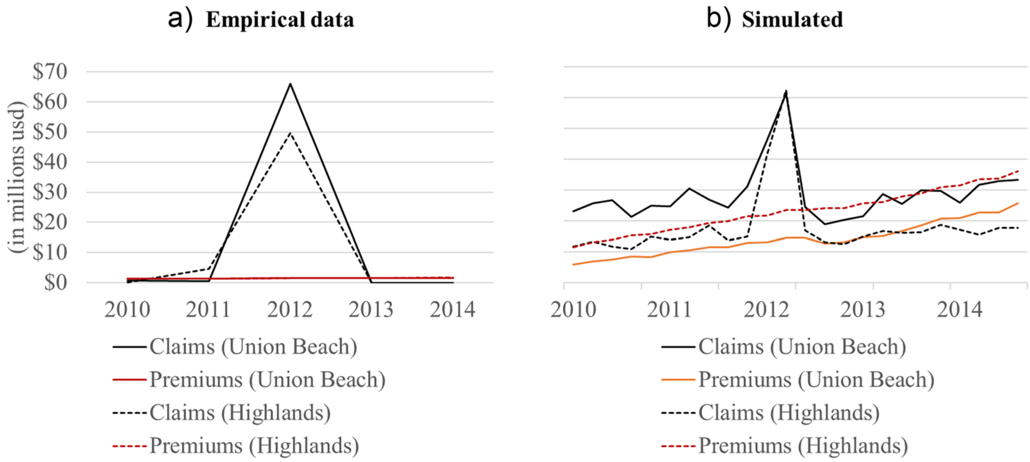

FIGURE 4 A comparison of actual and modeling outputs in terms of collected premiums and total payouts for both municipalities
Note: Tabular data can be found in Table S2-2 in the Supporting Information S2.

Irene and Hurricane Sandy in 2011 and 2012, respectively. Temporary price drops are seen during these periods before they recover in the following year.

The modeling outputs on flood insurance also follow similar trends as illustrated in Figure 4. In 2012, the total amount of claims exceeded the number of premiums as suggested by both actual data and model outputs for both Highlands and Union Beach. The model, however, performs better as shown in a stable increase in the number of premiums over the years. This is probably because of a low dropout rate for flood insurance policyholders. The likelihood for policyholders to keep their flood insurance depends on many factors; flood risk awareness is one of them. If homeowners are well informed by the FEMA floodplain maps, they will likely purchase flood insurance policies. It is also common for property owners to buy flood insurance after the recent occurrence of floods, especially after their homes were directly affected by the flood. In other words, purchasing flood insurance is also considered as one of the many homeowner's adaptive behaviors to flooding.

The data used for calibration was from a series of survey activities conducted by the Monmouth University Polling Institute in 2013 and 2014 to the residents in Monmouth County, who were affected by Hurricane Sandy. Several parameters adjustments on the model are made to make representation of both Highlands and Union Beach. The model is informed by the characteristics of the two towns in terms of the social, economic, and demographic make-ups, locations, and adaptive behaviors of the residents. The resulting projected adaptive behaviors show that the community in Union Beach has a greater foresight of future flooding risks, which is close to the resulting survey, than those in Highlands. The community in Union Beach is more satisfied with the recovery efforts more than those in Highlands. Both communities engage in the recovery efforts in the aftermath of flooding, which is similar to what the survey data indicates. The proportion of evacuees in both municipalities are also relatively similar. With the elevation requirement for the floodplain properties in Union Beach, more residents in the community raise their properties than those in Highlands. The survey data also indicates a similar result of homeowners raising their properties after Sandy. Regarding the number of homeowners repairing the property as a flooding adaptation strategy, more damaged properties are improved in Highlands than those in Union Beach. Survey data on repair strategy, however, is not available for calibration.

8 | WHAT-IF SCENARIO OUTPUTS

The first modeling experiment we conduct is to help understand how the real estate market responds to a hypothetical change in the frequency of storm events. In the scenario shown in Figure 5, in which Highlands is hit by a 100-year flood every 5 years, the modeling output shows a slow increase in the property transaction price. On the other hand, a faster increase on the projected property transaction price is observed when a 100-year flood hits the town at a longer return period (10-year return period). Similar trends are also visible in the simulation scenario using Union Beach. Flood return period influences flood risk, which is capitalized in the real property price.

Policy scenarios are the primary focus of the what-if analysis. First, we investigate the benefits of the CRS program to understand whether the effects of flooding on CRS communities are different from those in non-CRS communities. There are four evaluation categories on community actions in the FEMA CRS. Communities enter the program by implementing flood reduction efforts, which are evaluated based on the availability of public information, mapping and regulations, flood damage reduction, and flood preparedness. CRS participating communities are eligible for discounts up to 45% in the flood insurance premium. Homeowners residing in the CRS communities are modeled to have better foresight on flood risk. Lower damages caused by flooding are also expected on these owners' properties. Though their properties are insured, thereby, the

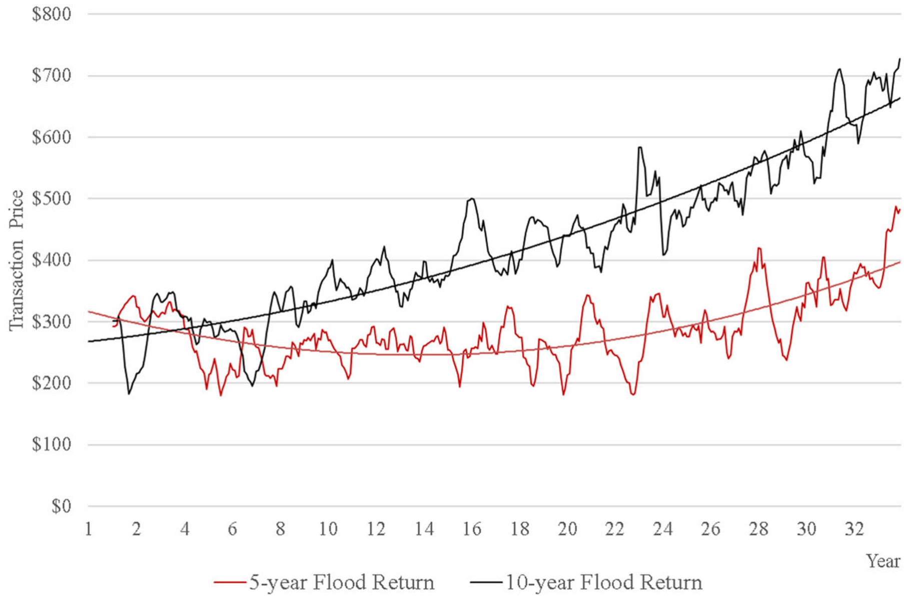

FIGURE 5 Modeling outputs on real estate transaction prices in Highlands, NJ, under two different hypothetical flood return periods
Note: Tabular data can be found in Table S2-3 in the Supporting Information S2.

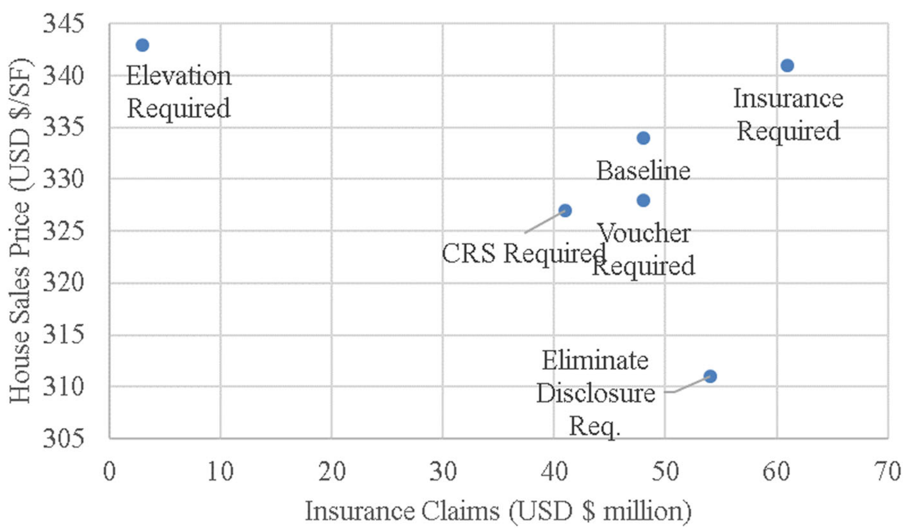

FIGURE 6 Flood risk policy tradeoffs
Note: Tabular data can be found in Table S2-4 in the Supporting Information S2.

insurance program benefits because there are lower payouts. The modeling quantifies this benefit of CRS as follows: a 10% increase in the number of households with better foresight regarding flood risks will yield a 28% reduction in flood insurance payouts.

Next, we investigate tradeoffs among a broader set of policies. Results are summarized in Figure 6, which shows results along important private and public dimensions: median house sales price (US$ per square foot) and town-wide insurance claims (US$ million) for Highlands, NJ. A baseline scenario in which CRS is optional for towns and flood insurance is optional unless the homebuyer has a mortgage is shown to allow comparisons.

9 | DISCUSSION

The policy analysis summarized in Figure 6 is our primary discussion topic. Each policy reveals strengths and weaknesses, summarized as follows:

- If the goal is to minimize insurance payouts, requiring all homes in the floodplain to be elevated is the optimal choice, but it comes with a consequence of making housing more expensive—the widely discussed gentrification of the shore phenomenon.

- If the goal is low-cost housing, then eliminating all flood risk disclosure requirements is the optimal choice, but it comes with a consequence of high insurance payouts because homebuyers keep getting surprised by unexpected storm events—not too different from today's baseline experience.
- If the goal is to reduce household financial risks, then requiring flood insurance is the optimal policy, but it locks in high levels of insurance claims even as the risk reduction is capitalized into higher housing prices.
- If the goal is more modestly to encourage homeowners to buy insurance by providing a discount voucher to homes in the "A" or "V" flood zones, then claims to not change much from the baseline amount, but housing sales prices also fall slightly because homebuyers continue to be surprised by flood events.
- If the goal is to ensure that a decentralized real estate market has well-informed buyers, then requiring CRS in coastal towns is the optimal policy because it reduces insurance claims modestly, although housing prices also drop modestly because not all buyers pay attention to flood risk information.

These results show that there is an efficiency versus equity tradeoff associated with allowing risky coastal settlements. A laissez faire approach makes living on the shore more affordable for home buyers but more risky for both those individuals and for society at large. The corrective of providing blanket insurance encourages socially costly risk taking. A strong regulatory approach gentrifies the shore and makes it more a playground of the rich, while also reducing the costs to the rest of society. Policies that pursue a middle ground depend on getting better information into the hands of decentralized decision-makers and hoping they pay attention.

The results answer our three motivating research questions:

1. *How do coastal real estate markets respond to flood events?* Flood risk is capitalized into housing prices. But if storm events happen infrequently, the market quickly forgets. Flood risk is only one of the many considerations that go into real estate transactions. Many participants in these transactions do not want an informed purchaser.
2. *Which types of public policies work better from a societal perspective to reduce flood costs?* The least costly policy from a societal perspective is stringent regulation of structures in flood zones. Informational and incentive-based policies are less effective.
3. *What are the tradeoffs associated with these policies?* The most efficient policy is also the most inequitable policy. The analysis illustrates that "better" policy can mean various things, but this tradeoff seems unavoidable. Lawmakers can continue to tinker with halfway measures that are fairer but less effective, and at least they can reduce outright perverse incentives.

In the long run, market forces seem likely first to displace those who currently live there with who can afford flood risk, and then the rich will stay on until rebuilding and hardening are no longer worth it. However, if policymakers seek a more graceful transition, they should require disclosure of flood risk information, regulate building practices more stringently, and manage the retreat from the shore. Part of this strategy should likely be to improve fairness by ensuring public access to the shore for recreation.

10 | CONCLUSIONS

Resilience in practice relies on an understanding of socioeconomic and ecological systems and in the analysis of the interacting systems and their vulnerabilities. This paper suggests that there is a real tension between society's desire to control the change resulting from the interactions, and a more hands-off focus on the capacity of the systems to adapt to the change. Resilience concepts that systematically link physical (spatial) and ecological aspects have invited researchers to develop models that can deal with both changes and behavioral responses to the changes.

ABMs have promising features that we find useful in the analysis of complex phenomena, particularly coastal flooding. Despite its limitations, our ABM model successfully serves the motivation to explore coastal flooding and stakeholder responses. The ABM model uses explicit GIS maps to provide a realistic representation of the spatial environment. In addition to decision mechanisms embedded within the model, the ABM model also co-simulates with a hedonic pricing model to mimic the price estimation behavior of the real property developers.

The calibration and validation simulation runs suggest that the ABM model well-represents real property markets in both Highlands and Union Beach. Insights from running the simulation scenarios suggest several points related to public policy. First, any flood risk reduction effort such as elevating the property's structure lowers the number of claims in the aftermath of flooding. Another policy impact related to financing flood insurance is the premium discount programs such as the FEMA CRS program and voucher provision (Kousky & Kunreuther, 2014) as two of the many modes to increase the flood insurance penetration rates in communities. The modeling outputs also suggest the importance of information dissemination (one of the CRS components) in raising the people's awareness of flood risk. Further, the outputs indicate that many of the sales occurring after Sandy were due to foreclosures or buyouts or homeowners leaving the community.

Future work could incorporate interactions between infrastructural and real estate decision-making, dive more deeply into specific policy scenarios such as managed retreat, and capture the nestedness of local property markets within larger metropolitan areas, and of intergovernmental relations linking local, state, and national policies.

CONFLICT OF INTEREST

The authors have no conflict to declare.

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