Modeling Real Estate Market Responses to Climate Change in The Coastal Zone

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Abstract. Regional land use patterns influence and are influenced by the climate system in important ways, and the most economically important of these interactions take place in the region's coastal zone. Changing flood risks threaten the value of billions of dollars worth of coastal real estate as well as the viability of coastal communities. This paper presents an agent-based model to capture some of the main features of the housing market that emerges from interactions between autonomous buyers and sellers. We use this model to investigate the adaptive responses of real estate markets to changing patterns of flooding and flood insurance policies by means of parallel theoretical and empirical efforts. The model includes interactions among households and municipal government through property tax collection and dissemination of flooding risk information. Empirically, we use detailed data from a flood-prone coastal community in Monmouth County, NJ, USA to calibrate our model.

Keywords: Flooding Risk; Real Estate Market; Agent-based Model

1 Introduction

Sea-level rise caused by global climate change creates a general displacement of the shoreline at all coastal margins, including those on barrier islands, bay sides, and the mainland. As sea level rises, the effects of storms produce greater inundations and are able to reach further inland [1]. Smaller storms, which were of little concern before, now reach levels and locations which were attained rarely in the past [13,14,15,16,17,18]. Based on historical patterns of extreme high water events from 1979 to 2008 along US coast, Tebaldi and his fellow researchers [18] also found out that the return periods of extreme storm surges have become shorter. Most US coastal areas will face previously rare storms more frequently.

In January 28, 2013, Federal Emergency Management Agency (FEMA) released updated flood maps for New York and New Jersey areas that previously had operated according to maps issued in 1986. The updated maps cover a larger area and twice as many structures as the previous maps. However, they do not consider future sea level rise and may underestimate the extent of flood risk in the region [1]. The lessons from Sandy indicated the New York City area is not ready for storm surges like that due to Hurricane Sandy, let alone higher flooding risk in the future.

A flood event is a big threat to property values and lives in coastal communities. Before the establishment of National Flood Insurance Program (NFIP) in 1968, people lived and built in the coastal areas without any sort of regulation. Private insurers did not provide insurance against flood risk in flood-prone real estate markets. The Federal government responded only to major flooding events, and then in a disaster management mode. Generally, coastal residents before 1968 were responsible for all the potential flooding damage. After the Ash Wednesday storm and hurricanes Betsy and Camille in 1962, NFIP was established to identify flood-prone areas and provide subsidized flooding insurance to coastal residents whose local jurisdictions agreed to adopt and enforce ordinance to reduce flooding risk. The Flood Disaster Protection Act of 1973 established a mandatory flood insurance purchase requirement. Today, NFIP insures 5.7 million homes nationwide near coasts or flood-prone rivers [12].

This paper will combine sea level rise and the impact of a flooding insurance program together and model how those two aspects are likely to affect households' location choices in a coastal town (see Figure 1). Using an agent-based approach, this paper establishes a bottom-up analytical framework to show how local real-estate markets respond to flood events and how local governments choose adaptive actions.

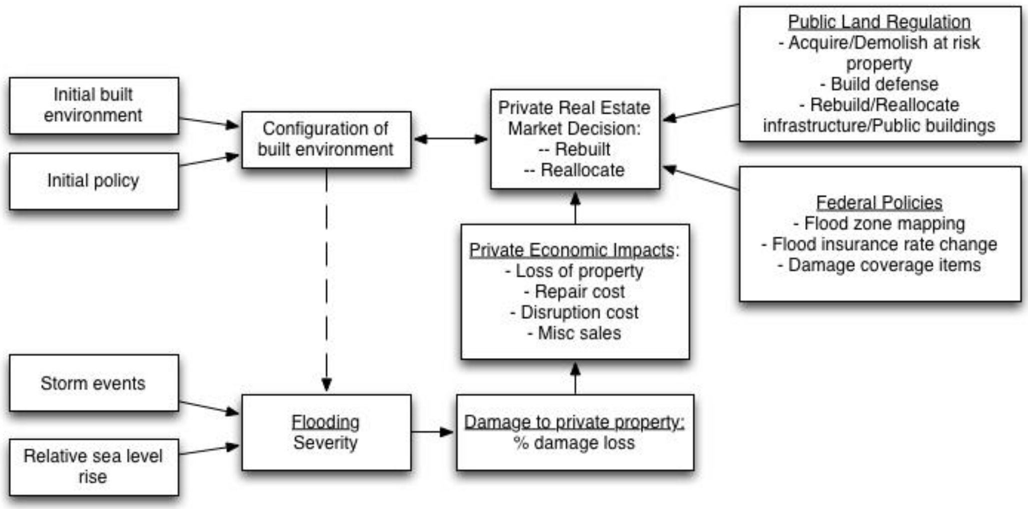


Fig. 1. Scope of Coastal Real Estate Market Adaptation Model

2 The Model

The model is constructed using NetLogo [19,22]. A real property data base of Highlands, New Jersey consisting 2,617 parcels are distributed over 55 x 55 pixels grid. Our conceptual topography has low-lying, medium, and high-elevation areas (see Figure 2). Based on elevation, parcels can be grouped into three categories:

- **Waterfront Lots** consist of 534 parcels in the first row of the grid that is adjacent to the shoreline;
- **Flood-zone Lots** consist of 849 parcels that are located in sections of the grid located in low-lying areas that do not have a water view;
- **Elevated Lots** consist of 271 parcels located in medium-elevation areas that do not have a good water view;
- **Water-view Lots** consist of 963 parcels located at higher elevations compared to other lots. These lots have a good water view and each grid cell is ten feet higher than the lower grid cell next to it closer to the shoreline.

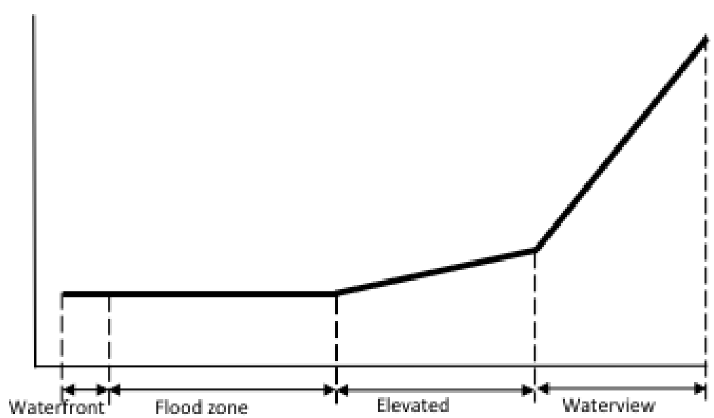


Fig. 2. The Topography of Initial Conceptual Coastal Town

2.1 Agents

The model consists of three types of agents: Households, Bank, and Real Estate Properties.

Households

Based on *Households'* activities in the real estate market, we group them into three categories: Homebuyers, Homesellers, and Homeowners. Each unit of time or "tick" represents one year. Each year, homebuyers search for properties available in the town. Initially, homebuyers look for houses and if there are no houses available, they start looking for empty lots. Homebuyers consider buying properties firstly from private sellers, then from a bank. Homebuyers consider geographical location in buying properties. Properties located at the waterfront location are the most desired ones, followed by the properties located at water-view and elevated zones, and the least desired ones are properties located in the flood-zones. Homebuyers also prefer properties with the highest price that is affordable to them.

Homebuyers are given a maximum of three years to look for a desired property before they are forced to leave the market. Upon the buying of the properties, homebuyers move into the town and become homeowners. The length of owning properties depends on their income level that may fluctuate ranging up to ± 20% that determines whether they can afford to continue paying the mortgage or not. Repair or rebuilding costs resulted from flood events are also some other fees that homeowners have to pay in order to keep their properties. If they can no longer afford to pay all the required fees, they will be forced to sell their property. Foreclosure occurs if after three consecutive years the property is still on the market. Homesellers may also sell their properties if the opportunity arises to make windfall profits or if they must move out of town due to reasons unrelated to real estate.

Bank

The Bank owns all empty lots and foreclosed homes. Unlike homesellers, the bank decides the prices for all properties on sale and they are non-negotiable. Properties sales by the bank also determine the housing market performance in the region. It adjusts the value of both buildings and land in the region.

Real Estate Properties

The simulation starts with an empty town in which all land lots belong to the bank. Land lots have attributes such as *land_type, elevation*, and *land_value*. The land type attribute refers to the four types of categories of a property discussed above. Elevation refers to the z-axis of the location of the land lot. Z-axis equals to zero at sea level. Initially, all land lots have the same land value of $5000. Demand-supply principles of economics apply to adjust the land values. This is reflected in the transaction prices agreed between homebuyers and homesellers (or the bank).

In our model, all houses are single-family detached houses that have similar construction. Houses are attributed with building value. Based on 2000 Census, the median housing value in Monmouth County, NJ is $203,100. In our case study towns, the share of building value to total assessed value is around 0.47 (see Table 1). We calibrate the model with real assessed values data. Each year, homeowners decide either to restore their homes based on their affordability to pay the repair fees or to let the houses depreciate in value. Annual restoration cost is about 2% of the building value. The houses will remain at the original condition after the restoration. In a post-flood event, homeowners may also decide to repair and elevate the house up to ten feet above the ground to reduce future flooding risk. The cost to elevate a house is 50% of the building value. Some homeowners who have suffered flooding damages invest in elevating their homes by taking out a second mortgage. This mortgage payback period is set to 20 years.

Building Value/Assessed Housing Value		
Town	Ratio	STDEV
Sea Bright	0.4766	0.1216
Highlands	0.4674	0.1382
Middletown	0.4746	0.1233

Table 1. Share of Building Value in Case Study Towns (Data: 2000 Census)

2.2 Flooding

Flood loss estimation is calculated based on three sub-modules: an annual probability distribution of local flood depths, stage-damage function that calculates damage percentage given flood level, and an economic module to convert a damage level into a monetary loss (Figure 3).

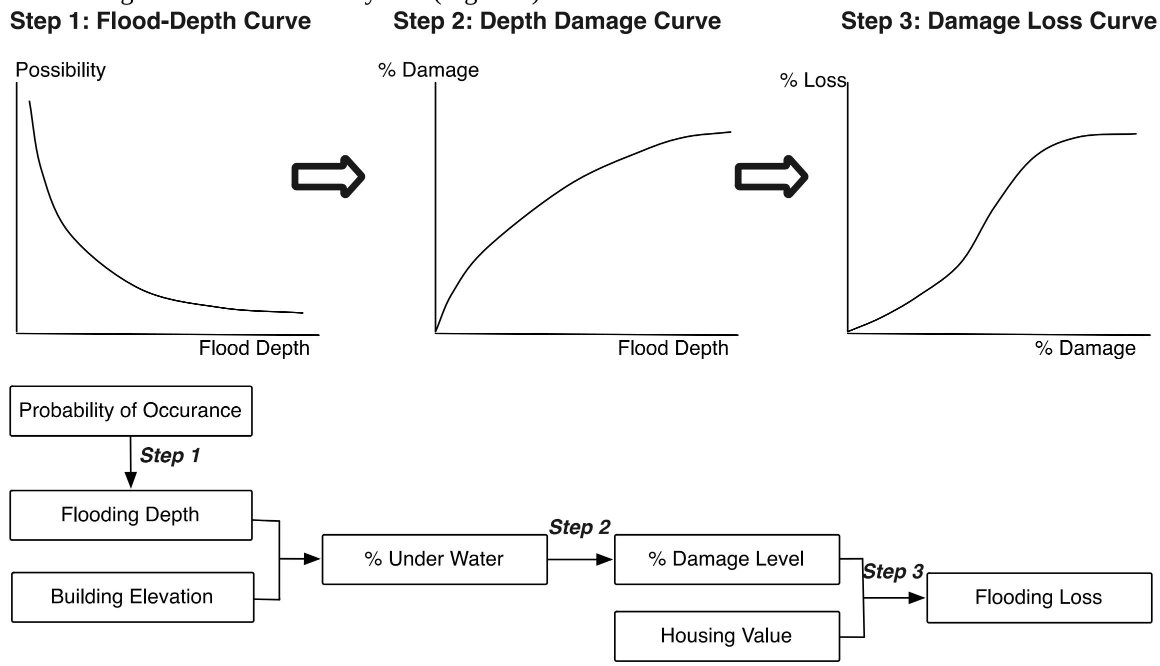


Fig. 3. Flooding Damage Calculation Flow Chart.

A **Flood-Depth Curve** is used to calculate flood depth of a flood event. The detailed data is from historical data for Atlantic City, New Jersey [14]. Also, we assume the flooding depth is 0.1 feet for one year flood event and 10.05 feet for a 500-year level flood level. A logarithmic model fits the historical data well (see Figure 4). In our model, one flood event is generated annually. Thus, the model calculates the flood depth based on the possibility generated by our model. The formula used to calculate flood depth is:

$$\begin{aligned} Flood\ Depth &= e^{\frac{p-b}{a}} \\ \mathrm{a} &= -0.217987 \\ \mathrm{b} &= 0.503089 \\ \mathrm{p} &= possibility \end{aligned} \tag{2}$$

A **Depth-Damage Curve** relates flood damage to flood inundation parameters for residential buildings. Flooding inundation parameters such as flood depth, duration, and velocity all affect damage level. The relationship between flood depth and damage level is considered in the model. The model adopts FIA credibility-weighted building depth-damage curve for two-floor split-level single family house that without basement [4]. A power model fits the data well ($R^2 = 0.9862$). However, the model is a little off in projecting a flood depth more than 12 feet. To simplify the modeling process, the depth-damage curve is divided into three sub-**curves (see Figure 5):**

when $\mathbf{0 \le \boldsymbol{Depth} < 3\ \boldsymbol{feet}}$, % $\boldsymbol{damage} = \mathbf{0.076862} \times \boldsymbol{depth} + \mathbf{0.018314}$;

when $\mathbf{3 \le \boldsymbol{Depth} < 8\ \boldsymbol{feet}}$, % $\boldsymbol{damage} = \mathbf{0.033780} \times \boldsymbol{depth} + \mathbf{0.147560}$;

when $\boldsymbol{Depth} \ge \mathbf{8}\ \boldsymbol{feet}$, % $\boldsymbol{damage} = \mathbf{0.011743} \times \boldsymbol{depth} + \mathbf{0.323857}$;

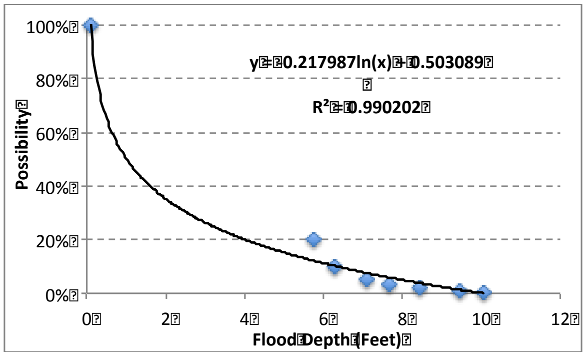


Fig. 4. Flooding Possibility Depth Curve

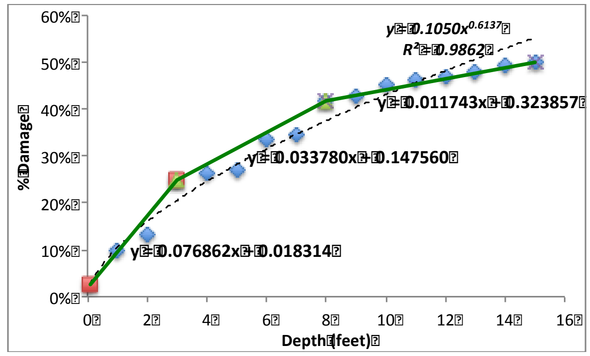


Fig. 5. Flood Depth Damage Curve

A **Damage Loss Curve**: Homeowners only consider the loss of a damaged building structure whenever there is a flood event. Loss of building contents is not included in the model. The model assumes *Loss = %damage x Building Value.*

2.3 Double Auction Market

In modeling the interaction between private homesellers and homebuyers, this model adopts the experimental economics of double auction markets. The goal of this approach is to achieve high levels of market efficiency quickly by running rounds of trading between buyers and sellers. Similar to experiments conducted by Gode and Sunder [7], this model provides three choices: bid, ask, and transaction. Whenever a bid and ask crossed, the transaction price was equal to the earlier of the two. Thus, four possible states are identifies: 1) no best ask (lowest ask price) nor a best bid (highest bid price); 2) a best ask and no best bid; 3) no best ask but a best bid; or 4) both a best ask and best bid.

This model, however, extends the previous double auction market model by introducing the role of a bank. A bank has similar characteristics to private sellers: it makes an offer and can contribute to the overall market price. It, however, does not have an auction mechanism with buyers. Homebuyers buy homes from a bank whenever they cannot find the desired properties offered by private sellers.

Initially, a homebuyer forms a bid price between his income level, adjusted by an affordability multiplier, and zero. A home seller randomly forms an ask price between the maximum reasonable market price and his buying price of the property. A selected home buyer then compares his bid with the best ask. If his bid is above the best ask, he accepts the best ask and the transaction occurs at the best ask. If his bid is below the best ask (or there is no best ask) and there is no best bid, it becomes the best bid. If his bid is below the best ask (or there is no best ask) and above the best bid, it overrides the best bid. If his bid is below the best bid, the bid is ignored. The rule also applies to a selected homeseller. If his ask below the best bid, a trade occurs at the best bid. A homeseller and a homebuyer that make a successful transaction are removed from the future trading. The process continues until there are no longer sellers or buyers that can make offers in the market.

2.4 Modeling Framework

In general, this model simulates households' movement logic into and out of a conceptual coastal town. Figure 6 shows the process of real estate market.

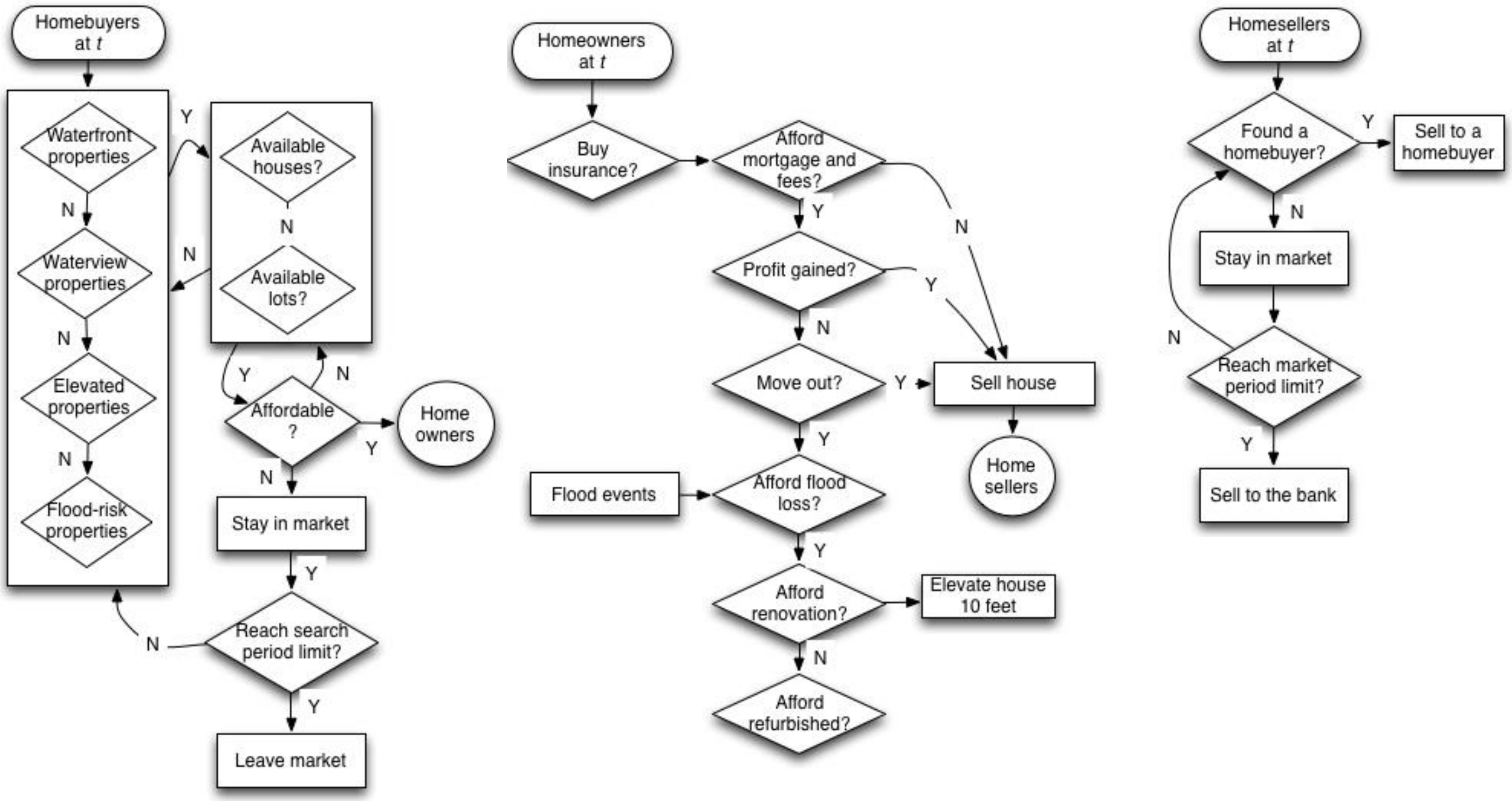


Fig. 6. The modeling framework

Buying decision.

A number of homebuyers enter into the town annually to look for their ideal homes. When homebuyers decide on the affordability of houses, their expected annual payment for housing needs to be lower than 30% of their annual income:

$$(30\% \times Income) \geq (Mortgage + Property\ Tax) \tag{1}$$

Here, annual mortgage calculation is based on Eq. 4.

$$Mortgage = \frac{P \times r}{1 - (1 + r)^{-N}} \tag{2}$$

Where: N is loan's term, the number of yearly payment. Our initial setting of mortgage duration is 30 years;
r is annual interest rate;
P is loan's principle, the amount borrowed from bank. We assume every home-buyer can afford 15% of down payment. They need to borrow 85% of the housing price from bank.

The property tax calculation is based on the market value of the house (Eq. 3).

$$Property\ Tax = Tax\ Rate \times Housing\ Price \tag{3}$$

In 2010, the property tax rate for case study towns is 2.154% in Highlands, 1.904% in Middletown, 1.145% in Sea Bright and 2.391% in Union Beach. In our model, we created a slider for *Property Tax Rate* based on the real data of case study towns. When homebuyers have foresight about future flooding risks, they also consider potential flooding loss to check their affordability (see Eq. 4).

$$(30\% \times Income) \geq (Mortgage + Property\ Tax + Expected\ Flood\ Loss) \tag{4}$$

The calculation of Expected Flood Loss is based on a 100-year flood event ($p = 0.01$). $Expected\ Flood\ Loss = 0.01 \times (Flooding\ Loss\ of\ 100\ Year\ Storm)$.

Selling decision.

Homeowners keep their houses based on their ability to pay the monthly mortgage and other fees. Unlike homebuyers, homeowners try to keep their homes. They are willing to pay up to 50% of their annual income for housing-related costs. If they cannot afford to pay the housing fees for more than 3 years, they will finally give up by selling their houses and moving out (Eq. 5).

$$(50\% \times Income) \geq (Mortgage + Property\ Tax + Flood\ Insur + Flood\ Cost) \tag{5}$$

Even if homeowners can afford to pay their housing related fees, homeowners may move out from their homes due to personal reasons. Another reason is to sell the property for a windfall profit.

Flooding Insurance.

Flood insurance premiums are calculated based on factors such as year of construction, building occupancy, number of floors, location of contents, flooding risk, location of the lowest floor in relation to elevation requirement on the flood map, and housing value (FloodSmartgov, 2013a). Table 2 shows NFIP's sampling of flood insurance premium in different flood risk areas.

Building & Contents	Moderate to Low Risk (Zone B, C, X)		High Risk Area	
	Preferred Rate	Standard Rate	Preferred Rate	Standard Rate
$150,000/$50,000	343	1263	1695	3270
$250,000/$100,000	365	1717	2930	6410

Table 2. NFIP's Sampling of Policy Premiums for Qualified Structures with Basement or Enclosures (FloodSmartgov, 2013b)

In the model, we use *Premium Loss Ratio* and *Expected Flood Loss* to calculate flood insurance for each house. This will highlight the effect of flooding risk. *Premium Loss Ratio* is the ratio of flood insurance premium to expected annual flooding loss. An adjustable slider is set up on the modeling interface to test the impact of different rates of *Premium Loss Ratio* (Eq. 6).

$$Flood\ Insurance = Premium\ Loss\ Ratio \times Expected\ Flood\ Loss \quad (6)$$

3 Analysis

3.1 Sea-level Rise Scenarios

In the model, the *Flood Possibility Depth Curve* of three sea-level rise scenarios is (see Figure 7):

Basic: $Flood\ Depth$=(p−0.503089)(−0.217987), lim$p$→0yp=9.96**;**

Two Feet Rise: $Flood\ Depth = e^{(p-2.158832)/(-0.849299)}$, $\lim_{p\to 0} y(p) = 10.78$**;**

Four Feet Rise: $Flood\ Depth = e^{(p-1.420276)/(-0.596582)}$, $\lim_{p\to 0} y(p) = 12.67$**;**

In all scenarios, our *Flood-Depth Curves* under-estimates the severity of very extreme flood events ($\boldsymbol{p \to 0}$).

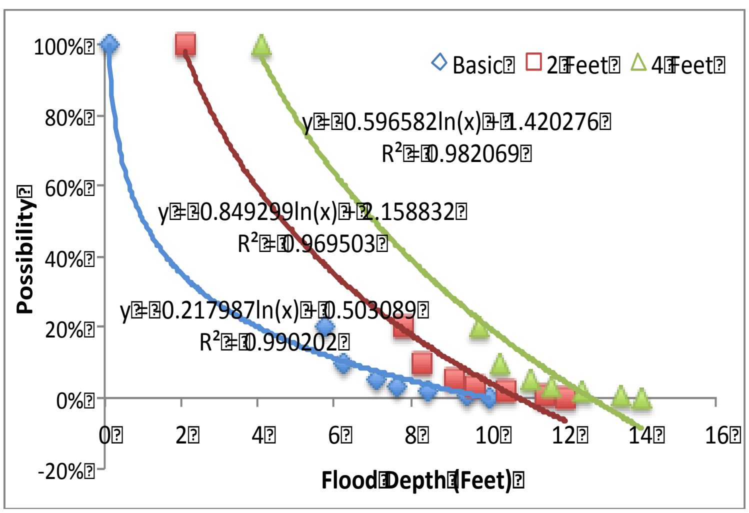


Fig. 7. Flooding Possibility Depth Curve for Sea-level Rise Scenarios

3.2 Free Market Scenario

Federal flood insurance policies cover physical damages to houses and personal property. As a basis for comparing behavior given the coverage and federal requirements of the flood insurance program, we adopted a contrasting free-market scenario to test how changes in NFIP affect the coastal real-estate market.

The free-market scenario is the basic flood insurance scenario in the model. Only homeowners who have foresight regarding future flood risk will consider buying flood insurance. Their decision is based on the *Premium Loss Ratio*. If *Premium Loss Ratio* ≤ 1, foresighted households will buy flood insurance. When a flood event happens, flood insurance will cover all the flood losses for insured houses. For houses without flooding insurance, residents need to pay all of the flood-related loss. These households will get loans from the bank to pay off all the flooding recovery cost. In our model, the mortgage duration for this type of loans is 10 years.

$$\begin{cases} Insuranced? = 0 & FloodCost = FloodLoss \\ Insuranced? = 1 & FloodCost = 0 \end{cases} \tag{7}$$

4 Results

Homebuyers search for their desired homes according to their preferred locations. The model is consistent with the assumption that homebuyers initially search for their desired homes at the waterfront zones, followed by waterview zones, elevated zones, and floodzones being the least desired location. Figure 8 describes this phenomenon during the first 25 years of coastal settlement.

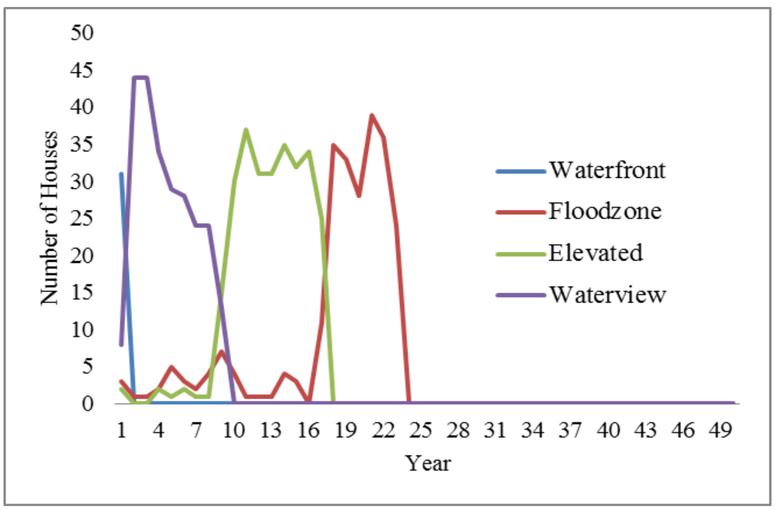


Fig. 8. Total number of houses built over time.

Figure 9 shows that there are flood events in the fifty years span. The floods are varied in depth. In year 12, 19 and year 45, there are major flood events that reach to eight feet depth. These flood events cause significant damage to homes. Figure 11 shows a significant flooding loss occurring in year 19, when homeowners are still not ready to make anticipated efforts, such as elevating their homes. The model allows homeowners to perform such efforts if they can afford to pay the fees. Since most homes are built within year 1 to year 25 and are already elevated in response to the 19th year flood, they do not have to worry about future flood events such as the one occurring in year 45. However, some homes still suffer from the flood (Figure 10).

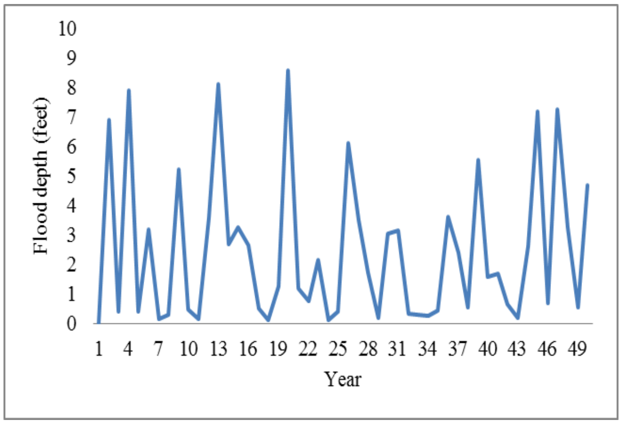


Fig. 9. Flood depth over time (in feet).

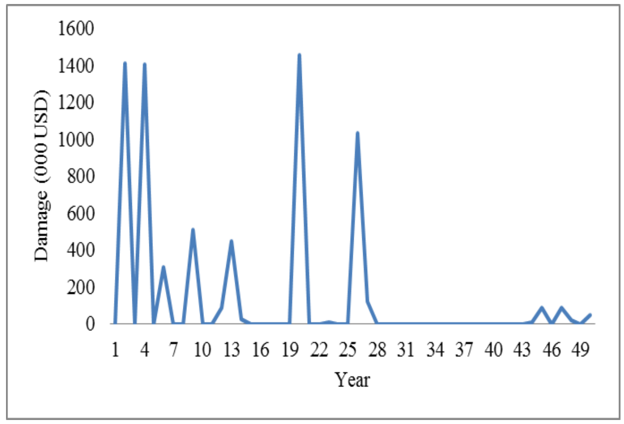


Fig. 10. Total value of flooding damage over time (in thousands USD).

It is interesting to observe the implementation of a double auction market in the modeling of real estate market responses to climate change in coastal zone. The trend movement of transaction prices is one of the most difficult parameters to look at. There is almost no trend that can be observed in the 50 year simulation period (Figure 11, 12). Hence, there is almost no correlation between, for example, vacancy ratio and transaction. However, in the 200 year of observation, a negative correlation between the two starts to appear (Figure 13, 14).

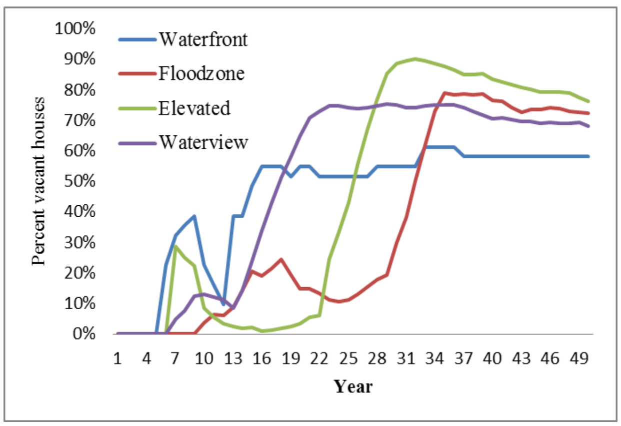


Fig. 11. Percent vacant houses in four market types (in percent) in 50-year simulation.

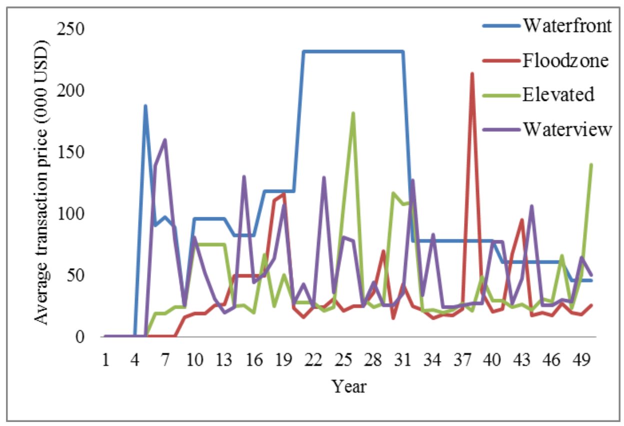
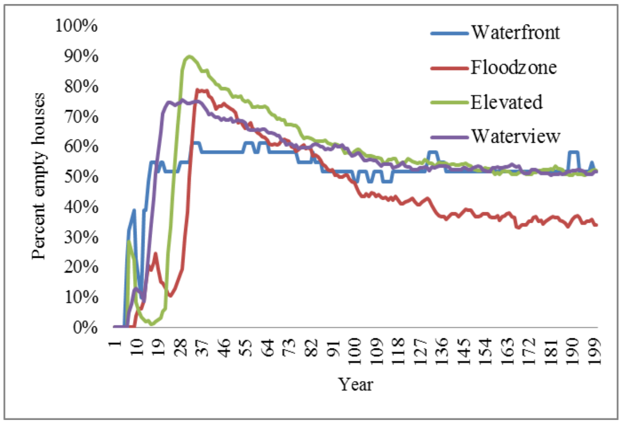


Fig. 12. Transaction prices in four market types (in thousands USD) in 50-year simulation.



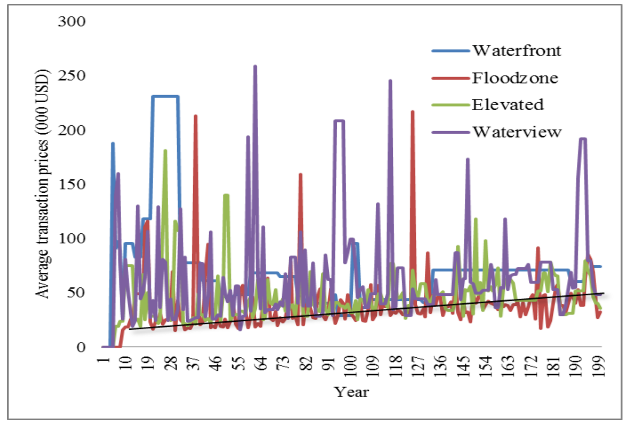


Fig. 13. Percent vacant houses in four market types (in percent) in 200-year simulation.

Fig. 14. Transaction prices in four market types (in thousands USD) in 200-year simulation.

There is a correlation between homeowners' ability to foresee flood events and their foreclosure market behavior. Figure 15 shows how foresighted homeowners suffer less from having their houses foreclosed, indicating that they have a safety net, insurance, to pay their flooding loss. In contrast, homeowners who do not foresee these flood events have to let their houses go into foreclosure.

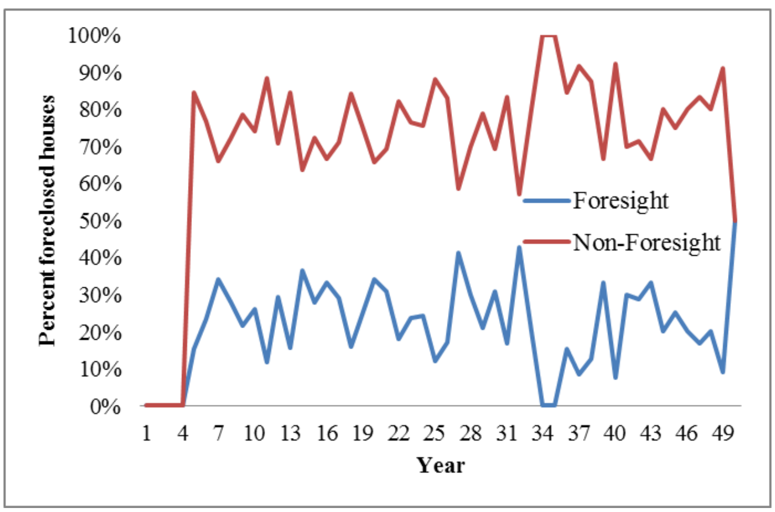


Fig. 15. Percent of foreclosed houses by types of homeowner (i.e. foresight, non-foresight)

5 Conclusion

To date, this study has demonstrated a plausible modeling logic that captures essential features of residential real estate markets in vulnerable coastal areas. Next steps include calibration of the model with local home sales price data, and investigation of additional policy scenarios beyond the laissez faire base case. Future research could develop a model of a complete real estate market including residential, commercial, and industrial properties; validate the model in additional municipalities; parsimoniously scale up the model for use in regional analysis; and extend the model to include municipal decision making.

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Appendix: The ODD Protocol[1]

1 Purpose

The purpose of the model is to investigate the adaptive responses of real estate markets to changing patterns of flooding and flood insurance policies by means of parallel theoretical and empirical efforts.

2 Entities, state variables, and scales

Agents/individuals. The model has different types of agents.

- *Household* are categorized into three different groups: Homebuyers, Homesellers, and Homeowners. Household has attributes as follow:
  - *color* ; color id
  - *income* ; income (usd)
  - *best_house* ; best house yet found
  - *person_land* ; connecting land
  - *person_house* ; connecting house
  - *search_time* ; time period a homebuyer searching for a desired property
  - *stay_time* ; time period a homeowner owning a property
  - *warning_time* ; time period a homeowner to pay the annual fees
  - *selling_time* ; time period a homeseller to sell the property
  - *floodFree_Preferred?* ; a homebuyer preference on a property location
  - *traded?* ; if a homebuyer/a homeseller already make a trade or not
  - *annual_fee* ; amount of annual fee need to be paid by a homeowner (usd)

- *Bank* owns all empty lots and foreclosed homes. Bank has attributes as follow:
  - *person_land* ; connecting land
  - *person_house* ; connecting house
  - *traded?* ; if a bank already make a trade or not

- *Houses* are dwellings built on top of land patches. Houses are attributed with:
  - *house_person* ; connecting person
  - *house_land* ; connecting land
  - *elevated?* ; if the building is elevated or not
  - *building_value* ; building value (usd)
  - *onmarket?* ; if the house is available in the market or not
  - *property_tax* ; property tax (usd)
  - *fees_duration* ; duration of mortgage
  - *floodingloss* ; amount of loss because of flood events (usd)
  - *insured?* ; if the building is insured or not

- *Spatial units* are pixel grid cells with attributes as follow:
  - *land_person* ; connecting person
  - *land_house* ; connecting house
  - *land_type* ; type of land (e.g. waterfront, floodzone, elevated, waterview)
  - *elevation* ; elevation (feet)
  - *land_value* ; land value (usd)

Environment. The model has two types of environmental variables.

- Economic variables: *market price, insurance fees, mortgage fees, flooding loss*
- Environmental variables: *flooding events, flood depth*

Collectives. The model has seven agentsets, collections of agents.

- *Homebuyers* ; households who take roles as homebuyers
- *Homeowners* ; households who take roles as homeowners
- *Homesellers* ; households who take roles as homesellers
- *Waterfront_properties* ; houses and lots located at the waterfront zones (the first row pixel grid)
- *Floodzone_properties* ; houses and lots located at the floodzones and without waterview
- *Elevated_properties* ; houses and lots located at the higher ground but without waterview
- *Waterview_properties* ; houses and lots located at the higher ground and with waterview

One time step represents one year and simulations were run both for 50 years and 200 years. One grid represents 1 parcel and the model comprised of 2,617 parcel data.

3 Process overview and scheduling

```
to setup
    setup-global-variables
    get-input-files
    setup-land-patches
    setup-houses
end

to go
    while [ticks < MAX_TICKS] [
       reset-output-parameters
       flood-event
       house-process
       market-process
       data-store
       tick
    ]
    data-output
end

to person-process
    setup-persons
    ask persons [
       ifelse homebuyer [
            set search_time ++
            if search-time > BuyerSearchLength [ leave-market ]
       ]
       [ if homeseller OR bank [
            income-shock
            maintain-house
       ]
    ]
end

to house-process
    ask houses [
         if owned [
            agingrepair
            floodrepair
            elevate
```

```
        fee-add
    ]
]
end

to market-process
    setup-banks
    let market_type 0        ;;; 0-waterfront 1-floodzone 2-elevated 3-waterview
    while  [market_type < 4] [
        market-run
        landvalue-update
        set market_type  (market_type++)
    ]
    reset-banks
end
```

4 Design concepts

Basic principles. The model adopts microeconomics model of double auction market and expand it by incorporating several different markets and externalities such as price restriction by the government agent.

Emergence. Transaction prices and homeowners' selling behaviors are modeled as emerging from the adaptive traits of household agents. These results are expected to vary in complex and perhaps unpredictable ways when the agents' characteristics as well as the surrounding environment changed. Results pertaining to the environment are not emerging such as the initial moving in patterns. Homebuyers initially buy lots located at the waterfront zones, then waterview zones, then elevated zones, and lastly lots located at the floodzones.

Adaptation. Homebuyers who consider flooding risk by purchasing flood insurance will not experience great loss from the flood events. Homebuyers buy the highest price affordable to maximize property values at the least cost possible. Homebuyers prefer to buy homes located at waterfront and waterview zones providing better property values. Homeowners who elevate their homes providing less damage from the future flood events.

Objectives. Homebuyers' objective is to get the best affordable properties. Homeowners' objective is to pay the least possible mortgage and other annual fees in order to keep the properties as long as they can. Homesellers' objective is to sell above the market price. Government' objective is to protect housing market values by making flooding adaptive actions such as mandating homeowners to elevate their homes and to buy flood insurance.

Learning. Homeowners who previously did not consider flooding risk, buy flood insurance and elevate their homes upon the occurrence of flood event.

Prediction. Homebuyers who buy flood insurance have the ability to predict future flood events. The timing for homeowners to sell their homes at profit shows the ability to predict future housing market prices.

Sensing. A homebuyer enters the housing market sensing the availability of properties that best-fit to his locational preference and affordability. A homebuyer makes a bidding offer based on his affordability and the best offer in the market. The mechanisms by which agents obtain information are modeled explicitly, and they make decisions based on these rules and mechanisms.

Interaction. Homebuyers compete to each other in looking for their desired properties. The same rule also applies to homeowners who are trying to sell their properties. Auction model is the mechanism used to represent the communication between homebuyers and homesellers.

Stochasticity. Flood events are measured stochastically with certain probability.

Collectives. The four housing markets in the model determine the grouping of homeowners. Transactions between homebuyers and homesellers in a single market determine the housing market price, building values, and land values of all properties in the market.

Observation. Data are collected in yearly basis. Data included are flood depth, storm damage (usd), percent damage, sell high for profit, sell low due to affordability, number of sales by bank, number of sales by private sellers, building value, land value, vacancy rate, transaction price, home buyers income level.

5 Initialization

The initial state of the world is at time t = 0 of a simulation run. Each time tick represents one year. A housing parcel data consisting 2,617 parcels are distributed over 55 x 55 pixels grid, land patches. The model topography has low-lying, medium, and high-elevation zones. Based on elevation parcels are grouped into three categories: waterfront lots consist of 534 parcels are located at the first low grid that adjacent to the shoreline, floodzone lots consist of 849 parcels are located on grids also at the low-lying areas, elevated lots consist of 271 parcels is the medium elevated area, and waterview lots consists of 963 parcels are located in the higher points compare to other lots' types locations. There were no houses on top of these land patches.

Each year, 600 homebuyers enter into the market. The values of their attributes are: traded?=false, search_time=stay_time=warning_time=0, person_house=nobody, person_land=nobody.

6 Input data

The model use input from a data file of Highlands, NJ parcel data to represent processes. This data is also used for calibrating and validating the model.

7 Submodels

Each time tick represents one year. Each year, the model runs processes as follow:

- *Setup* ; setup all necessary variables
  - *setup-globalvars* ; setup all global variables
  - *data-input* ; read input files
  - *setup-patches* ; setup land patches 55 x 55 pixel grid
  - *setup-houses* ; setup all houses variables (not included initially)
  - *dataparcel-get* ; read particular parcel data

- *go* ; run simulation iteratively at every time tick
  - *reset-outputparams* ; reset all output parameters
  - *flood-event* ; run random flooding events
  - *house-process* ; run processes for all houses
    - *house-agingfix* ; homeowners repair houses due to aging
    - *house-floodrepair* ; homeowners repair houses due to flooding
    - *house-elevate* ; homeowners elevate houses
    - *fee-add* ; add a necessary fee need to be paid by a homeowner
    - *fee-decrduration* ; determine the duration for a fee
    - *house-sell* ; run sell process
  - *person-process* ; run processes for all persons
    - *setup-persons* ; setup persons' variables
    - *income-shock* ; run random income shocks to homeowners
    - *maintain-house* ; run maintain house processes for homeowners
  - *market-process* ; run double auction market
    - *bankagents-setup* ; setup banks agents to handle all unowned properties
    - *market-run* ; run market processes
      - *buyers-initial* ; initiate buyers' variables

        - *sellers-initial* ; initiate sellers' variables
        - *trading-initial* ; initiate order book used for trading mechanism
        - *doTrade* ; run trading processes between homebuyers and homesellers
            - *formBidPrice* ; assign random bid offers to home buyers
            - *formAskPrice* ; assign random ask prices to home sellers
            - *traders-traded* ; finalize successful traders
        - *transPrice-set* ; set transaction market price if a trade is successful
            - *traders-update* ; homeowners can make transactions
                - *buy-property-deal* ; finalize the purchase
                - *property-better-affordable* ; if the property in question has the highest affordable price tag
                - *buy-property-from-bank* ; homeowners buy properties from a bank
        - *sellersbank-buy* ; run a process for homeowners to buy properties from a bank
    - *landvalue-update* ; update land value caused by the transaction
    - *bankagents-reset* ; remove all bank agents from the model at the end of every time tick
- *data-store* ; store all output data into an array
- *data-output* ; print all output data into a file

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[1] Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: A review and first update. Ecological Modelling. 221(23), 2760 – 2768.