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Modeling coastal land and housing markets: Understanding the competing influences of amenities and storm risks

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A B S T R A C T

The costs from coastal storms and hurricanes are expected to increase with climate change yet populations in coastal areas continue to grow. In this paper, we develop a dynamic spatial simulation model of coastal land and housing markets and study the competing influences of storm risks and amenities. The model is parameterized to the Mid-Atlantic region of the United States, where hurricanes occur relatively infrequently, and then used to assess how spatial patterns of development would change if storm frequency increases. Results show that spatial patterns change very little—approximately 45 percent of the land area in the coastal region is developed by the final model period in both the baseline and high storm risk scenarios and the coast sees more development than inland areas in all scenarios. The countervailing coastal amenity matters more with the percent developed in the coastal region varying between 29 and 51 percent depending on the scenario. Perhaps more importantly, we find that heterogeneous households sort differently on the landscape in our different scenarios. When storms are more frequent, average land prices near the coast are 1.2–11.8 percent lower, which leads to households with lower average incomes locating there. The results highlight the difficulty policymakers may have in altering private land and housing market outcomes to reduce storm costs in coastal regions.

1. Introduction

The economic costs of extreme weather events have been rising in the United States and around the world (Benson and Clay, 2004; Gall et al., 2011; Kousky, 2013). There is some debate about the reasons for the increase, but most studies agree that the primary driver is an increase in exposure—that is, more people and properties, and more valuable properties, located in harm's way (Pielke and Downton, 2000; Pielke et al., 2008; Bouwer, 2011; Hallegatte et al., 2013). Moreover, these trends are expected to continue in the future. Hallegatte et al. (2013) estimates that population and Gross Domestic Product (GDP) growth alone will increase average annual flood losses in the 136 largest coastal cities in the world from $6 billion to $52 billion by 2050, with climate change leading to even larger losses.

According to the United Nations Atlas of the Ocean, 44 percent of the world's population lives within 150 km of the coast, which is more than the total number of people on earth in 1950 (United Nations, 2011). The National Oceanic and Atmospheric Administration (NOAA), estimates that 39 percent of the U.S. population lives in coastal shoreline counties, which account for only 10 percent of U.S. land area (NOAA, 2013). The population density of these counties increased by 28 percent between 1970 and 2010, and NOAA predicts the number will be an additional 6.5 percent higher in 2020 (NOAA, 2013). If climate change leads to an increase in the frequency of the most severe coastal storms, which is the current projection for the U.S. Atlantic coast (Kossin et al., 2017; Emanuel, 2013), and sea level rise exacerbates the impacts of those storms through worsening storm surge flooding, as most scientists predict (Slangen et al., 2014; Lin et al., 2012), the economic costs of disasters will increase in the future.

In order to design effective policies to reduce those costs, one needs to understand the factors that explain the dynamics of coastal development. Why does population continue to grow in coastal areas when those areas are the most at risk from weather-related disasters? This is the question we explore in this paper. Specifically, we analyze two of the competing influences that exist in coastal areas: the pull of coastal amenities and the push of expected costs due to storms and hurricanes. Using a dynamic spatial simulation model of housing and land markets, we assess how these two factors affect spatial patterns of development and the evolution of land and house prices in a coastal region over time. We conduct two simulation exercises. First, we assess how higher storm risks, all else equal, might affect the location choices of households and resulting land and house prices compared to a baseline climate

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scenario. We then carry out sensitivity analyses on the coastal amenity—specifically, we assess how different coastal amenities affect land use outcomes, holding all else equal.

The model is an economic agent based model (ABM) with three types of agents: landowners, a real estate developer, and housing consumers. The ABM incorporates substantial heterogeneity in agents and is able to analyze both the dynamic and spatial patterns of development (Irwin, 2010; Iftekhar and Tisdell, 2015). The stylized setting abstracts from many other complicating real-world factors that can make interpreting results difficult and allows us to isolate the individual effects of amenities and storm risks (Felsenstein and Lichter, 2014).

In the model, landowners decide each period whether to sell their land to the developer; the developer buys land and builds houses to satisfy consumer demand; and consumers that are heterogeneous in income and preferences choose housing, which is characterized by lot size, house size, and location. In making their choices, consumers maximize utility subject to a budget constraint, and their utility depends partially on house location—i.e., houses located closer to the coast have a higher embodied coastal amenity value. At the same time, there is also an expected cost associated with locations closer to the coast: the property damage caused by coastal storms and hurricanes. We intentionally abstract from considerations of insurance markets and storm mitigation activities (such as installation of hurricane straps and shutters or house elevation). We also assume housing consumers understand the expected costs associated with coastal storms at each possible location on the landscape and fully internalize those expected costs in their decision-making.[1] Our objective is to remove these complicating factors and analyze what the market outcomes would look like if fully informed and rational consumers make tradeoffs of amenities and risks in their location decisions. Policymakers, the general public, and some academic studies point to failures in the market for flood insurance (Michel-Kerjan 2010; Michel-Kerjan and Kunreuther, 2011), a lack of good understanding about storm risks (Botzen et al., 2015), and decisionmaking based on heuristics and other behavioral rules other than utility maximization (Dillon et al., 2011; Meyer et al., 2014) as reasons for the continual rise in costs from coastal storms. This paper explores whether it is simply the appeal of coastal amenities – e.g., recreation access, aesthetics and views – that outweighs expected storm costs.

The model is parameterized to the Mid-Atlantic region of the U.S., including to Mid-Atlantic storm frequencies and damages from major storms in the region, and then used to assess how development patterns and land and housing prices change if the storm frequency increases to levels in other parts of the U.S. The annual probability of a hurricane, based on historical events, is two times greater in North Carolina, three times greater in Texas and almost six times greater in Florida than in the combined states of New Jersey, Pennsylvania, Delaware, Maryland, and Virginia, the region defined here as the Mid-Atlantic. We perform a simulation exercise in which the probability of a storm is increased to the levels in North Carolina, Florida, and Texas, holding other factors constant. This exercise provides a view of how a region like the Mid-Atlantic might develop differently under conditions expected with climate change.

We explore the implications of our amenity function and how it changes with distance to the coast through sensitivity analyses. The hedonic literature in economics finds that the magnitude of the capitalized value of coastal amenities in house prices is lower at greater distances from the coast (Bin et al., 2008; Conroy and Milosch, 2011; Major and Lusht, 2004). We analyze alternative specifications for the rate at which that decline occurs. This allows us to assess, again holding all other factors constant, including storm probabilities, how the type of coastal amenity affects housing and land market outcomes.

The model forms part of a growing literature on spatial urban growth ABMs (see Huang et al., 2014, for a review), which represent fine-grained, spatially heterogeneous processes and features such as localized sorting of households on the landscape. Studies with ABMs focused on coastal land use include Filatova et al. (2011a) and Filatova (2014), both of which incorporate flood risks and amenities in a model of location choice, and Filatova et al. (2011b), which uses an ABM without flood risks to analyze policies to protect open lands and ecosystem services. Each of these studies has contributed to the ABM literature on coastal land markets. Filatova (2014) shows how GIS data from a real landscape – a small town in North Carolina in their application – can be used to move ABMs to real-world settings. Filatova et al. (2011b) indicate how a spatial ABM can be used for policy analysis. Filatova et al. (2011a) show how a survey on costal residents' risk perceptions can be incorporated into an ABM.

We see three contributions of our model and its applications. First, it more fully integrates some important economic fundamentals than the existing literature. For example, the model formally specifies housing as a bundle of attributes that includes the coastal (spatial) amenity and incorporates that in consumers' utility functions. This recognition that spatial amenities (and disamenities) are part of the housing "bundle" is a long-standing feature of hedonic property value models (Rosen, 1974) and models of so-called "Tiebout sorting" (Tiebout, 1956; Kuminoff et al., 2013), in which households endogenously sort themselves into communities based on local amenities and taxes. This feature is important because it allows for feedback effects through land and housing prices – i.e., as spatial features change, either exogenously or due to policy levers, agents adjust, which changes prices and leads to further adjustments. The model here accounts for these feedbacks explicitly through the theoretical construct and simulation exercises. Second, our model also includes house size and lot size as housing attributes, which allows for analysis of the density of development across the landscape. This provides another test for the reasonableness of the results as economic theory says that where land is more valuable, density should be higher, all else equal. Finally, the scenarios and sensitivity analyses conducted with the model shed light on the relative contributions of amenities and storm costs in determining land market outcomes, an important application for design of land use policies in flood-prone areas.

The model is able to provide some sense of how U.S. policymakers can expect households to trade off the various factors that affect spatial patterns of development in coastal areas. It abstracts from ecological and geophysical features of the landscape and thus is not a model about system resilience in a coastal setting (Murray et al., 2013). However, it says more about economic drivers of development in coastal areas than most of the existing literature. Future studies that couple models of human and natural systems in coastal settings, including market prices, income, and agent optimizing behavior, will be important next steps (Murray et al., 2013; Lazarus et al., 2016).

2. Materials and methods

We describe our ABM below, beginning with the model's basic theoretical structure, followed by parameterization for our geographic setting. A full model description using the Overview, Design concepts, and Details + Decision-Making (ODD + D) format (Grimm et al., 2010; Müller et al., 2013) is provided in the supplementary materials.[2] The model is similar in spirit to our earlier model described in Magliocca et al. (2011, 2012, 2015), but it incorporates key features of a coastal

[1] There is a large literature analyzing consumer perceptions of hurricane risk, using both revealed preference methods (Carbone et al., 2006; Gallagher, 2014; Hallstrom and Kerry Smith, 2005) and surveys and hypothetical experiments (Baker et al., 2012; Dillon et al., 2011; Meyer et al., 2014; Peacock et al., 2005; and Siegrist and Gutscher, 2008).

[2] The ODD + D protocol is common practice for agent-based models. Our ODD + D document and model code are included on the OpenABM website, version/1/view" > https://www.openabm.org/model/5637/version/1/view.