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# Optimal real estate capital durability and localized climate change disaster risk[☆]

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ABSTRACT

The durability of the real estate capital stock could hinder climate change adaptation because past construction anchors the population in beautiful and productive but increasingly-risky coastal areas. However, coastal developers anticipate that their assets face increasing risk and this creates an incentive to seek adaptation strategies. This paper models climate change as a joint process of (1) increasingly destructive storms and (2) a risk of sea-level rise that submerges coastal property. We study how forward-looking developers and real estate investors respond to the new risks along a number of dimensions including their choices of location, capital durability, capital mobility (modular real estate), and maintenance of existing properties. The net effect of such investments is a more resilient urban population.



## 1. Introduction

A majority of the United States population lives—and an even larger share of the nation's GDP is generated—within 80 km of coast (Rappaport & Sachs 2003). Many of the nation's most beautiful and productive cities are located along oceans and rivers. New York City, Miami, Seattle, Washington DC, San Francisco and Los Angeles are prime examples. As sea level rise takes place, could urban economies and the value of their real estate capital be severely impacted?

Miami provides a salient example. This metropolitan area is home to six million people. The city is located six feet above sea level. In summer 2013, Rolling Stone magazine published a long article predicting that Miami is doomed because of imminent sea level rise.[1] Hedonic real estate pricing studies have measured the price discount for housing facing greater flood risk (Bin et al., 2008; Bin & Landry, 2013). In coastal cities, there are millions of durable real estate structures built at different times in the past. These assets could be stranded if climate change decimates specific geographic areas.

This paper studies how localized climate change risk affects real estate investment. Forward-looking real estate investors face choices over constructing new housing and investing in maintaining the existing real estate stock. We seek to understand how these choices are affected by expectations of evolving local climate change risk. If less housing is built in risky areas, then fewer people will live there. If investors spend less on maintenance existing housing depreciates faster in risky areas, the region will attract lower-income households. Thus, real estate capital investment in climate change affected areas determines the economic incidence of climate change and has key implications for how we collectively adapt to the emerging climate change challenge.

We study the investment and valuation of durable real estate capital for capital built in cities that face differential climate risks. We contrast three cases. The first is the business as usual case in which real estate capital lasts for a fixed number of years in the future. In the second case, we study the optimal durability of the capital stock when it faces new localized risk of destruction. The third case introduces *Lego capital* which can be disassembled, transported to a safe inland location, and re-assembled there. This separates climate risk to capital from climate risk to land: while landowners in climate-struck cities will still see a decline in demand, developers can be convinced to build more housing in Miami today if they can rely on demand for housing tomorrow in climate-safe Denver. Lego capital would alleviate the

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[1] "By century's end, rising sea levels will turn the nation's urban fantasyland into an American Atlantis. But long before the city is completely underwater, chaos will begin" (see http://www.rollingstone.com/politics/news/why-the-city-of-miami-is-doomed-to-drown-20130620).

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problem identified by Glaeser and Gyourko (2005). They argue that Detroit's durable housing stock, built up during the boom years of the 1950s, has persisted for decades as car production jobs left Detroit; this imbalance between supply and demand caused sharply declining home prices. More-educated households left the city faster and thus left a lower-income set of households behind, and the authors demonstrate that this was due to the low house prices induced by durable capital. Lego capital would have allowed homeowners in the Motor City to keep their houses when their jobs moved elsewhere, leaving behind a capital stock better-matched to the level of demand.

If capitalists drag all of their capital away from coastal cities and there is no new construction, then only landowners are exposed to the flood risk. In studying how real estate construction and maintenance responds to local fundamentals, our paper builds on the housing supply literature including the within city filtering literature (Sweeney 1974; Bond & Coulson, 1989; Brueckner & Rosenthal, 2009) and the afforementioned cross-city durability literature (Glaeser & Gyourko, 2005).

In many urban models (e.g., Ottaviano & Peri, 2012), capital is fixed and labor is mobile. This need not be the case: moving costs such as those created by local endogenous social networks limit the mobility of labor, while capital is not fixed in the Lego economy.[2] This role reversal will affect analyses of the expected changes in house prices and welfare in response to climate shocks. In particular, the incidence of climate shocks is more likely to fall on households (and landowners, a group which may overlap) and less so on developers.

### 1.1. Durable coastal real estate capital

Coastal real estate is beautiful and attracts relatively high-income households (Lee and Lin, 2017). In an age and country of cell phone and transportation access, the major risk to the coastal urban population from sea level rise and natural disasters is a loss of real estate capital—as documented by Kahn (2005), richer nations suffer fewer deaths than poorer nations. Even the deadly Hurricane Katrina of 2005, which ended the lives of nearly 1000 individuals, is estimated to have caused far more property destruction to the typical affected resident.[3] The value of coastal properties in Florida at risk of sea level rise is measured in the trillions.[4] The combination of rising per-capita income and increased access to smart phones and disaster alerts are likely to sharply lower future deaths from coastal climate change incidents.[5]

To simplify the discussion let each city be defined by a single attribute: whether it is located on a coast. Let inland cities be unaffected by climate change, and let coastal cities be more beautiful and feature a more temperate climate.[6] Assuming that all households face zero migration costs and have the same preferences over consumption, housing quality and the coastal location, there will be a rent premium for the coastal cities. Climate change risk represents "new news" that will differentially affect coastal and inland cities.

### 1.2. Optimal real estate capital durability in coastal and inland cities

Consider a landowner making an investment in real estate capital, where the durability of the capital—the expected lifespan $T$—is a choice variable, and the quality of the building diminishes over time. Increasing the durability of real estate is costly, but the owner is able to collect a stream of rental payments for a longer period of time. The value in year $t$ of a building is determined by the location and age of the building. Finally, buildings are subject to weather shocks that completely destroy the building. Define $r$ as the constant economy-wide safe interest rate and $\delta$ as the annual probability that the capital is intact and can be rented out.[7] The cost of constructing a building that can last for at most $T$ periods as *cost(T)*, which is assumed to be convex in $T$. The in-period timing of this investment game is the following: the landowner first makes a choice of T, then constructs the capital unit, and finally is able to rent it out in the same period.[8] After construction—or at the start of the year, if the capital unit was built previously—nature draws a weather shock for coastal property. With probability 1-$\delta$, the building is destroyed and the developer receives no revenue from the building from that period forward.[9] If this event does not occur then the developer receives the annual rent and a new draw from this distribution (the weather shock) is taken the next year.

Given this notation, the value of capital in location $c$ of age $j$ with lifespan $T$ is given by the value function

$$V(c, j, T) = \delta\left(rent(c, j) + \frac{1}{1+r}V(c, j+1, T)\right) + (1-\delta)\frac{1}{1+r}U(c), \tag{1}$$

where $U(c)$ is the value function of an empty location. Recalling that T is a choice variable for an empty location, the landowner's

[2] Morten and Oliveira (2016) find that 84% of moving costs are fixed; one component of this fixed cost is likely the cost of abandoning one's social network and establishing a new one. Leaving one's social network is likely to be particularly salient in immigrant enclaves like Miami and many other coastal cities. However, any fixed cost component will have the same effect.

[3] Hurricane Katrina is a noteworthy baseline precisely because the city of New Orleans was particularly vulnerable—much of it lies below ground, and the city has one of the highest poverty rates of any coastal city—and because the governmental response was particularly poor (see Sobel and Leeson 2006). If the statistical value of a life is just under $8 million in 2005 dollars (see Viscusi and Aldy, 2003), then even despite the vulnerabilities of the populace the loss of property was an order of magnitude larger—ensured losses alone accounted for $41 billion (http://www.insurancejournal.com/news/southcentral/2015/08/26/379650.htm).

[4] http://www.insurancejournal.com/magazines/features/2013/06/17/295207.htm.

[5] It is worth emphasizing that the inverse is also true: low-income, low-capital coastal countries without a large system of cities are much likelier than US cities to suffer devastating losses of life from the worsening storms and rising seas of climate change, and relatively small losses of durable coastal capital. As such countries get richer, the evidence suggests that their experience will converge to that of the US (Kahn 2005).

[6] Albouy et al. (2016) present a hedonic approach for relaxing this assumption. They model climate change as shifting a city's location in amenity space. For example, if Denver's winter temperature rises from 30 degrees to 36 degrees and if the real estate hedonic gradient is stable over time, then one can calculate how much Denver's climate amenity bundle will change (measured in $) due to climate change.

[7] A constant safe interest rate embeds multiple assumptions. First, there are complete markets such that agents have access to riskless bonds. Second, climate change will not affect structural parameters in the productive side of the economy, so $r$ will be unchanged in the face of climate change. Third, risky coastal property is a small portion of the economy, so that changes in the risk profile of coastal climate shocks does not affect the safe interest rate.

[8] The notation $U$ to capture the value function of a vacant location is to emphasize that the location begins the period unoccupied. In principle, the landowner could choose to hold the lot empty. By including the first period's rent directly, we have assumed that the landowner always finds it optimal to develop the location.

[9] The probability $(1-\delta)$ embeds two higher-level processes: a city-level risk and a property-level risk. Each coastal city faces a possibility of receiving an adverse weather shock in a given year. These shocks are i.i.d. across cities. Contingent upon a city receiving an adverse weather shock, each parcel within the city faces a possibility of being destroyed, and this second process is i.i.d. across parcels. The probability $(1-\delta)$ captures the unconditional likelihood of a particular parcel being destroyed, and it is this object which the developer considers. The assumption of complete destruction is a simplification: even after Hurricane Katrina, many buildings in New Orleans had salvageable components. Below, we consider the possibility that the owner may make ongoing investments in building maintenance. In this case, the $(1-\delta)$ weather shock is just the set of extreme weather events while the less extreme events are subsumed into the ongoing endogenous depreciation.

value function for an empty location is thus[10]

$$U(c) = \delta\left(rent(c, j) + \frac{1}{1+r}V(c, 1, T)\right) + (1-\delta)\frac{1}{1+r}U(c) - cost(T). \quad (2)$$

At the optimum, Eq. (3) holds:

$$\frac{\Delta U(c)}{\Delta T} = \delta\frac{1}{1+r}V(c, 1, T) - cost'(T) = 0. \quad (3)$$

This simple analysis assumes that real estate durability is a one-time choice variable: investors choose what durables to install and the quality of equipment and materials built into a home. A building sciences literature investigates these issues (see Chapman & Izzo, 2002; Noguchi, 2003). We proceed by introducing climate (as opposed to mere weather) risk and investigating the effects of allowing the investor flexibility along various dimensions of adjustment.

### 1.3. Introducing climate change risk

Now suppose that all coastal real estate developers learn that climate change will only affect coastal cities.[11] We assume that climate change has two affects. First, it reduces the annual probability that a coastal property remains intact from $\delta$ to $\pi$ where $\pi < \delta$. Second, climate change introduces a small probability that sea level rise inundates the property and renders both the capital and the land entirely unusable forever; we write as 1- $\kappa$ the probability of catastrophic sea level rise.[12] After climate change, the optimal investment problem for a developer with an empty coastal property can now be written as:

$$U(coast) = \kappa\ \left(\pi\left(rent(coast, j) + \frac{1}{1+r}V(coast, 1, T)\right) + (1-\pi)\frac{1}{1+r}U(coast)\right) - cost(T). \quad (4)$$

Of course, with probability $1-\kappa$ the property becomes worthless. The new optimality condition for capital durability in a coastal city is presented in Eq. (5):

$$\frac{\Delta U(coast)}{\Delta T} = \kappa\ \pi\frac{1}{1+r}V(coast, 1, T) - cost'(T) = 0. \quad (5)$$

Comparing Eq. (5) to (3), the developer will choose a smaller T as they place less weight on the likelihood of receiving rent on the property in the next period.[13] By building less-durable capital, the land owner is able to re-optimize sooner; the sunk cost is lower when the structure is less durable. It is important to note that we have modeled climate change as having no impact on the coastal amenity itself and thus no negative effect on the rental payments, conditional that the building is not destroyed and the property is not inundated. This means that climate change has no impact on the equilibrium rental differential between coastal and inland real estate.[14] By building capital more often, the average cost of coastal housing will rise, thereby lowering developer profit.[15]

In this first climate change model, we assumed that every developer is risk neutral and has rational expectations. An alternative way of modeling uncertainty is to follow Hansen and Sargent (2008) and introduce robust decision rules. If the developers in the coastal areas know that they do not know the future probabilities of property destruction, then those engaging in robust mini-max decision rules (seeking to reduce their losses in the worst states of the world while facing ambiguous risk) would be likely to build capital with an even shorter life in the coastal areas.

### 1.4. The quantity and durability of housing

We now relax the assumption that the developer builds just one unit of housing per parcel. In this case, the developer is building an apartment building and must choose how many units to build in addition to the durability of the building. Define $N$ as the number of units in the building. The risk neutral developer chooses the durability and the size of the building to maximize the expected present discounted value of profit:

$$U(c) = \kappa\ \left(\pi\left(N \times rent(c, j) + \frac{1}{1+r}V(c, 1, T, N)\right) + (1-\pi)\frac{1}{1+r}U(c)\right) - cost(T, N). \quad (6)$$

Under the assumptions that the cost function is convex in T and N, and the cross-partial derivatives are well-behaved, there is an interior solution satisfying:

$$\frac{\Delta U(c)}{\Delta N} = \kappa\ \pi\left(rent(c, j) + \frac{1}{1+r}V(c, 1, T, N)\right) - \frac{\partial cost(T, N)}{\partial N} = 0. \quad (7)$$

Climate change shrinks the probability that the building and the land itself survives each year, leading the developer to build fewer units in the coastal areas and continue to build less-durable capital.[16]

In this section, we have abstracted away from general equilibrium impacts on rents in the coastal area from such supply contractions because we have assumed that the coasts face no amenity risk. Residents of such areas face no death risk or amenity risk. Only the owner of the real estate capital and land is exposed to disaster risk. We have also assumed that the developer cannot raise her profit by substituting and only building housing in the inland cities—a result that could be derived by imposing a general spatial equilibrium.

### 1.5. Self-Protection

In the previous sections, we have assumed that there are no self- protection investments that a coastal real estate owner can engage in to reduce exposure to capital destruction risk. Yet, along coastal areas we observe home owners place their homes on stilts. In Bangladesh, and Holland, there are floating structures

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[10] Implicitly, at age $j = T$, the value of real estate is given $V(c, T, T) = \delta\ rent(coast, T) + \frac{1}{1+r}U(c)$.

[11] There may be information asymmetries between developers and users of real estate, or between types of either group. Lenders, insurers, and brokers all have compelling reasons for sharing information on evolving climate risks with potential buyers of coastal real estate. If developers are at an information advantage and do intend to sell to uninformed buyers, they will tend to produce too-durable capital. See McNamara and Keeler (2013) for more on the possible effects of climate change information asymmetries on housing market dynamics within an agent-based model.

[12] The first shock may not be immediately apparent even to climate scientists, but the second shock will be readily observable. Uncertainty (and disagreement) over the timing and magnitude of changes to the frequency of weather shocks can push in different directions: uncertain agents may assume the worst, while unconvinced agents may sort into risky locales.

[13] Of course, the second-order effects of the decreasing the probability that the property is intact will affect the value functions as well.

[14] We ignore the general equilibrium effects that may result from changing the mix of coastal vs. non-coastal property. Of course, sea level rise creates new coastal properties, partially offsetting the loss, and the US has a large amount of unoccupied non-coastal land, so this assumption may be innocuous.

[15] While this would usually lead to a reduced supply of housing, bunten (2017) shows that density-based zoning restrictions may bind, in which case cost increases won't necessarily reduce supply. The example of Miami is one of the faster-building coastal cities, but zoning restrictions may bind in other affected cities like Boston.

[16] We are assuming that the cross-derivative of the cost function either equals zero or is positive.

(Ritzema, 2008). We now follow Ehrlich and Becker (1972) and allow coastal real estate owners to invest in costly self-protection. For a one-time expenditure equal to *f*, they can reduce their property's annual risk exposure. For simplicity, we return to the assumption of a single housing unit per unit of land.

In the coastal area, the investor's decision problem is now to choose;

$$U(c) = \kappa \left( \pi(f) \left( rent(c, j) + \frac{1}{1+r} V(c, 1, T) \right) + (1-\pi) \frac{1}{1+r} U(c) \right) - cost(T) - f. \quad (8)$$

A simple example is to assume that self-protection means climate change will not affect destruction probabilities, i.e. $\pi(c) = \delta$. In this case, the optimal durability will look similar to the "no climate change case" if the inundation risk $\kappa$ is not too different from 1. In intermediate cases where it is too costly to completely offset climate change, the real estate owner will still choose a more durable capital stock than in the case with no self-protection. Ex-ante investment in self-protection substitutes for ex-post insurance (i.e., endogenously choosing less-durable capital).

In this first case, private investors paid for their own structure's self-protection. But, in many cities such as New Orleans the local and federal governments could continue to erect levies or even sea walls to protect coastal property. Such federally subsidized self-protection policies can be introduced into the model by augmenting the probability that the capital survives each period to be modeled as

$$probability\ \ property\ survives = \pi\left(f_{private}, f_{public}\right)$$

In this augmented survival function, the probability that a property survives is an increasing function of private self-protection and government self-protection. Whether these two inputs are complements or substitutes will differ on a case by case basis but it is clear that if the federal government invests more in self-protection, the forward looking investor will build a more durable, larger structure in the coastal area. It is well-known that post-disaster federal aid has the potential to create spatial moral hazard (Kousky et al. 2006) and incentivize over-building in flood-prone and other at-risk areas.[17] Here, we highlight that pre-disaster aid will also induce greater levels of investment—although if the public investments are effective, the greater investment will reflect actual risk rather than moral hazard.

## 2. Endogenous depreciation

Now assume that the developer can pay a fee of *M(age)* to offset building depreciation from aging. This maintenance fee is an increasing function of the building's age. This investment does not lengthen the life of the building, but improves its quality in each year that it is made. Further, assume that the preferences are such that "maintenance premium" shown below increases with building age *j* more slowly than *M(j)*. In the absence of climate risk, an investor who owns a building of age *j* will make this maintenance investment if Eq. (9) holds:

$$\pi\ \ \kappa\ \ (rent(c, j, maintained) - rent(c, j, not\ \ maintained)) \geq M(j) \quad (9)$$

The developer will be less likely to pay this maintenance fee in the face of climate change because the expected revenue from this costly investment declines. This means that the anticipation of climate change risk will accelerate the depreciation of the quality of the existing capital stock. In equilibrium, any particular building will spend less time in the maintained state after climate change. Past research has modeled the filtering process such that neighborhoods make a comeback after older housing is scrapped and replaced with new housing (Brueckner & Rosenthal, 2009, Sweeny, 1974, Rosenthal, 2014). This effect exists here, as developers may choose a shorter lifespan *T* when they also allow their buildings to depreciate faster. Additionally, real estate investors would anticipate the climate change "tax" on new investments and would be less likely to invest to upgrade the depreciating durable housing. The composition effect ensures that the overall quality of the coastal housing supply declines as fewer buildings are in the maintained state in each period. The downward dimension of filtering would speed up without a comparable increase in redevelopment rates, resulting in a lower-quality stock of housing in coastal cities.[18]

## 3. The option value of "Lego" real estate

Consider a new type of real estate capital stock that features an explicit option to disassemble it and move it to "higher ground". By paying a cost of *d*, a real estate owner retains the option to disassemble an existing property and to transfer it to another location. To appreciate the possible adaptation benefits of such a capital stock briefly consider the extreme case in which *d* equals zero so that homeowners can costlessly carry their home to another location when a short term threat (such as a hurricane) emerges. In such a "turtle" economy, neither life nor capital (i.e., the turtle and its shell) would be destroyed by natural disasters. The capital would move to higher ground for a short time (and rents for this land would be paid) and then the capital would move back to its original location.

In this section, we analyze how this option affects a real estate investor's optimal durability investment and maintenance investment relative to the case presented in the previous section in which the capital was "stuck" in the coastal city. To fix ideas, we refer to this section's capital as "Lego" resembling the children's building blocks that can be assembled and disassembled.[19] Engineering work on modular building highlights that this is a feasible possibility.[20] Directed technological change will only improve this technology (Acemoglu & Linn, 2004).

For an existing piece of capital of lifespan *T* and age *j* at location c, introducing the option to move to location $c'$ (at cost *d*) in advance of any weather events leads to a new value function:

$$V(c, j, T) = \max \left\{ \begin{array}{l} \kappa\left(\pi\left(rent(c, j) + \frac{1}{1+r}V(c, j+1, T)\right) \right. \\ \quad \left. +(1-\delta)\frac{1}{1+r}U(c)\right), \\ V(c', j, T) - d - \left(p(c') - p(c)\right) \end{array} \right\}. \quad (10)$$

The final term on the lower line, $p(c') - p(c)$ represents the price premium for land in a safe location $c'$ relative to a coastal loca-

[17] See Greg Ip's Wall Street Journal piece http://www.wsj.com/articles/cities-built-to-endure-disaster-1444401240.

[18] If households vary by income and willingness to pay for building quality, this composition affect may in turn change the composition of households who choose to live in coastal areas. High-income households would seek the higher-quality buildings of inland areas, leaving the lower-quality buildings in coastal cities for lower-income households. Productivity in coastal cities could be expected to fall for reasons of agglomeration. Positive assortative matching could then induce a further decline in the population of more productive households in coastal areas.

[19] Mobile home communities already hold over eight million housing units nationwide. An interesting empirical question would be whether mobile homes will become more prevalent in communities facing more severe climate risks.

[20] Some examples of relevant websites include: http://your.kingcounty.gov/solidwaste/greenbuilding/documents/Design_for_Disassembly-guide.pdf, http://www.willscot.com/specialty/retail-commercial http://nreionline.com/technology/high-rise-debut-modular-construction-poised-take http://en.wikipedia.org/wiki/Commercial_modular_construction, http://www.modular.org/ https://palomarmodular.wordpress.com/2012/05/08/relocating-a-modular-building/.

tion. For an existing piece of coastal capital of age $j$ with maximum lifespan is $T$ that now faces increased risk of climate change, the owner will move it to higher ground this period if:

$$\delta\left(rent\left(c', j\right) + \frac{1}{1+r}V\left(c', j+1, T\right)\right) + (1-\delta)\frac{1}{1+r}U\left(c'\right) - d - \left(p\left(c'\right) - p(c)\right) > \kappa\left(\pi\left(rent(c, j) + \frac{1}{1+r}V(c, j+1, T)\right) + (1-\pi)\frac{1}{1+r}U(c)\right) \quad (11)$$

Note that in location $c'$, the probability that capital is intact is $\delta > \pi$ and there is no risk of sea level rise. In these senses, this location is safer, and $p(c') - p(c)$ is the premium for land in the safe location. In principle, this gap could be very large but in practice the large quantity of unoccupied land in the inland United States suggests it may not be substantial.

In Eq. (11), the right term is the value of not moving the property and earning an expected rental flow weighted by the probability of capital destruction and of sea level rise. The left term is the present discounted value of moving the property to "higher ground" to the safe inland city. The asset owner must pay for new land to "park" the structure, and must pay the moving cost, but collects the expected value of the inland rental stream and the value $p(c)$ of at-risk land (if any). An augmented version of Eq. (5) above would dictate the optimal choice of property size and durability.

For an investor considering building a new structure in the coastal area, the optimal structure durability and size will be a function of whether the property can be moved in the future. This option is more valuable if the future fat tail coastal risk is known to be unknown or if the distribution is known then in the case where there is "fat tail" risk. In terms of our model, the option is more valuable if investors face time-varying parameters $\kappa_t$ and $\pi_t$ which are likely to decline over time, or if they are drawn each period from a fat-tailed distribution. The standard logic from the Dixit & Pindyck (1994) option value model is that there is a value to delaying a decision until the uncertainty is resolved. In this real estate economy, the uncertainty is never resolved during the life of the capital asset (except in the negative with sea level rise or capital destruction) but the owner recognizes an implicit insurance against worsening climate risk via the migration option.

The option to move puts an implicit lower bound on the value of capital in coastal locations. Facing the durable capital risk $1-\pi$ each year, the owner of "Lego" capital will be more likely to build more durable capital, and a larger structure and to invest more in its maintenance. Note that the expected PDV of marginal revenue from these investments will be higher than in the case where there is no option to leave.[21] The owner of the option can always choose not to exercise the option. As the economic returns to durability and maintenance increase, the coastal Lego capital stock will not filter down the quality spectrum over time any more rapidly. The mix of households will not tilt towards lower income as it might with un-maintained property, and so the option to move will also limit the probability of a Detroit-style poverty trap.

[21] When homeowners supply housing services to themselves and labor to the labor market, it is plausible that Lego capital will ensure higher returns both because it is safer for the capital to remain in the region longer, and because this implies that more workers will remain in the area for longer—preserving the productive capacity of coastal regions, and also limiting the shift in the local capital supply curve. However, the rent received by a developer is susceptible to change if an evolving climate will affect both producer and consumer amenities in labor and housing markets.

The ability of real estate owners to carry their capital away from the risky area means that the supply of housing to the risky area is more elastic. This means that fewer people will live in risky areas as the risk increases, even if the amenity-value of living in coastal areas is unaffected by climate change.

## 4. Model extensions

In this section, we present several model extensions that offer promising pathways for future research.

### 4.1. Productivity impacts of coastal disinvestment?

In our discussion so far, we have ignored the fact that coastal cities are productive places as well as amenity-rich. Desmet et al. (2015) present a general equilibrium model in which coastal flooding could severely impact local productivity. In their model, productivity is higher in places where population density is higher and since the coastal areas are more densely populated, productivity is higher there and thus in their model sea level rise causes productivity risk. In a human capital based model of urban growth, firms can move away from coastal areas to "higher ground" and enjoy human capital spillovers at their new location (Glaeser et al., 1995). Essentially, Wall Street could reconstitute elsewhere and replicate the productivity gains that Wall Street currently enjoys. Urban economics research tends to emphasize the role that human capital plays in urban growth. Such a person based, rather than a place based, explanation for urban growth suggests a certain optimism that coastal productive agglomerations (such as Wall Street) can move to "higher ground". For example, Wall Street can reconstitute in the Connecticut suburbs as key firms such as Goldman Sachs lead and other firms follow.

A more catastrophic destruction of Wall Street may make it more challenging to reconstitute elsewhere, in which case we may see larger productivity declines. However, a slow-motion disaster like sea level rise may leave sufficient time for the firms and individuals possessing local knowledge to migrate to higher ground.

### 4.2. Risk perception heterogeneity

Suppose that the population differs with respect to beliefs about the severity of climate change damage for the coasts. The existence of "climate deniers" (people who under-estimate the true probability of devastating coastal events) could increase new housing construction in risky places. If there are sufficient "climate deniers" and there is a resale capital market then this group may purchase the capital and choose not to move it. In this case, cities such as Miami could remain heavily populated even in the Lego economy case.

The insurance industry provides one counter-veiling influence in this case. Capital owners in coastal areas who seek out insurance would be quoted extremely high insurance premium prices (assuming the insurance industry is pricing reflects actual evolving risk probabilities). In this case, the capital owners may update their subjective probabilities or respond by building less durable capital. Alternatively, they may choose to purchase less insurance. Lego capital and insurance will also be substitutes: if a lender demands a costly insurance plan for fixed capital, climate-denying borrowers will find it sensible to construct Lego capital despite their climate beliefs.

If the set of investors contains both climate deniers and non-deniers, Lego capital may still help produce a beneficial outcome. As the non-deniers see rising waters and move their capital to higher ground, negative demand shocks will have a smaller negative price effect a la Glaeser and Gyourko (2005). While deniers may be wrong about the probability of climate risk, they could still be right about its price effects. This outcome depends on their not being "too many" climate deniers, an assumption consistent with findings that future climate risk is already salient in at-risk land markets (Severen et al., 2016).

### 4.3. Coastal housing demand heterogeneity

There are at least two different reasons for why people may continue to value living near the coast even if there are homogenous beliefs about the challenge posed by climate change. These explanations include income variation such that the rich are able to effectively engage in self-protection, and location-specific social capital.

Income heterogeneity will produce *ex ante* sorting whereby the rich bid up the price of attractive coastal real estate due to its high-quality amenities. Richer households will be better able to insulate themselves from weather and climate shocks. This has been shown at the macro level (Kahn, 2005). Self-protection against the risk of climate change means that richer people face less risk than the average person (Ehrlich and Becker, 1972).

Localized social capital provides a second explanation for why incumbents in coastal areas may continue to be willing to pay to live there, even if climate change negatively affects amenities (Glaeser et al., 2002). The presence of an endogenous moving cost (e.g., due to having established social and professional networks in one's initial area) induces a wedge between the willingness to pay of the incumbent residents of Miami and those who settle in an alternative locale. Before settling in different cities, two individuals could have identical willingness to pay for coastal areas but once one settles in Miami and builds a network this individual will now be willing to pay a premium to live there despite its rising risk. For long term residents of Miami, they have built up a social network such that if they moved away from the area, they would be likely to lose this location specific attribute unless the group could co-ordinate their migration to "higher ground".

### 4.4. Place based disaster national government insurance

The expectation that the federal government will pay for ex-post insurance encourages more people to live in disaster prone areas. Such federally subsidized public goods and government subsidized insurance provides an incentive for land owners in coastal areas to build more durable housing, to invest more in its maintenance and to be less likely to exercise their "Lego" option to leave the areas.

At first glance, such spatial subsidies create a spatial moral hazard effect as the federal government is implicitly subsidizing risk taking by those who choose to live in coastal locations. But, it is well known in the migration literature that older people and less educated people are less geographically mobile. This means that this group is at increased risk from place based shocks. How to protect this group from such shocks without exacerbating moral hazard effects remains an open policy design question (Sobel & Leeson, 2006). An open political economy question focuses on the incentives of place-based politicians who govern coastal at risk areas. Their political clout is likely to be an increasing function of the count of people who live in these areas. This raises the issue of "human shields". Are coastal place-based politicians rewarded by luring more people to live in increasingly risky areas because this allows them to attract more federal protection dollars (see Kousky et al., 2006)?[22]

[22] For evidence from North Carolina see http://blog.ucsusa.org/north-carolina-governor-purdue-balks-on-sea-level-rise-science.

### 4.5. Zoning in safe inland cities

Throughout this paper, we have assumed that the rent in the inland cities is a constant and this implicitly assumes that all of these areas feature identical amenities and constant returns to scale with respect to the marginal cost of supplying more units. But imagine a case where the inland cities engage in stringent zoning or feature a topography such that it is difficult to build there (Saiz, 2010). In this case, capitalists who seek to move their capital away from Miami will face a higher equilibrium land cost for moving their property to the inland cities—or will only be able to move to a lower-cost area by accepting the lower rents in rural inland areas. If zoning precludes stacking the Lego piece on top of an existing building, this land cost could be high and this will slow down the arbitrage process of the capitalist leaving Miami.

bunten (2017) analyzes the aggregate implications of zoning restrictions in productive cities. Neighborhoods within large metropolitan areas have an incentive to discourage new housing construction to avoid the localized disamenities of congestion. An unintended consequence of this NIMBY-ism is that residents and economic activity are deflected to the distant edge of productive cities, or to less productive areas altogether. A similar dynamic could playout in "safe cities" and "safer" geographic areas within coastal metropolitan areas as these regions become relatively attractive with climate change. In this case, home prices will be higher than the marginal cost of constructing new housing because of this regulatory tax (Glaeser et al., 2005a, 2005b). Such a spatial price premium in safe places would discourage adaptation because owners of "Lego Capital" would be less likely to exercise their (higher-cost) migration option.

### 4.6. Expected immigrant flows to coastal cities and local housing supply

Coastal cities tend to be immigrant cities. Cities such as Los Angeles, Miami and New York City are well known for their large immigrant shares. This potential for immigration has implications for housing demand. For example, the Mariel Boatlift brought thousands of Cubans to Miami and in the short run this raised local rents (Saiz, 2013). As documented by Borjas et al. (1997), immigration to coastal cities is associated with equilibrium flows of natives of similar skills to other local labor markets. Taking this logic to the climate change risk case, if new immigrants are moving to coastal cities then even if natives move to "higher ground", if enough immigrants are expected then coastal real estate capital may be constructed to be durable and to be maintained for this group. In this case, such immigrants would find housing and it would be affordable but risky.

## 5. Conclusion

Climate change poses different new risks for real estate in different geographic markets. While there is much that climate scientists do not know about this emerging threat, land owners and real estate developers have strong incentives to consider climate risks when investing in real estate.

Forward-looking investors face the joint decision of choosing the durability, upkeep of an existing piece of capital and the decision of whether to keep the real estate capital in its current location or to move it to "higher ground". This exit option becomes increasingly attractive for owners of coastal property as the uncertainty associated with climate risk increases. Our model allowed us to study the interrelationship between these choices. For example, if capital owners are aware that they cannot move their capital and that it is at risk, then they will build less durable capital and maintain it less. Following the filtering hypothesis, such a depreciating capital stock is likely to house lower-income residents and thus may experience additional challenges in dealing with climate change (Sweeney, 1974; Glaeser & Gyourko, 2005).

Mobile "Lego" capital offers housing developers a potential solution to the risks of climate change. It also offers homeowners protection against another catastrophic risk: declining demand for coastal real estate in the face of climate change. Detroit has become emblematic of the challenges posed by declining housing demand due to labor market changes (Glaeser & Gyourko, 2005), and coastal cities may face similar declines if climate change decreases the value of local amenities. Housing capital that can be removed in the face of climate change can also be removed in response to demand changes, making the housing supply curve downward elastic and limiting the risk of the downward spiral faced by Detroit.[23]

This paper's framework offers several empirical predictions that merit future research. First, for geographic areas whose topography and location is such that they face significant risk of sea level rise, what investments are owners taking to both maintain the property and to reduce its risk exposure? Anecdotally, some owners are building sea walls, raising foundations, and otherwise mitigating the risks of sea-level rise.[24] In affected areas, are some developers nevertheless building new properties that could be wiped out in a significant flood? Again anecdotally, some cities are beginning to mandate that developers pay to upgrade infrastructure to deal with emerging risks.[25] An intermediate strategy would be to purchase coastal homes and convert them into natural wetlands to reduce coastal flood risk.[26] Such a strategy would minimize expected harm to current residents and provide some coastal protection.

## References


Acemoglu, D., Linn, J., 2004. Market size in innovation: theory and evidence from the pharmaceutical industry. Q. J. Econ. 119 (3), 1049–1090.

Albouy, D., Graf, W.F., Kellogg, R., Hendrik, W., 2016. Climate amenities, climate change, and American quality of life.. J. Assoc. Environ. Resour. Econ. 3 (1), 205–246.

Bin, O., Landry, C.E., 2013. Changes in implicit flood risk premiums: empirical evidence from the housing market. J. Environ. Econ. Manag. 65 (3), 361–376.

Bin, O., Crawford, T.W., Kruse, J.B., Landry, C.E., 2008. Viewscapes and flood hazard: Coastal housing market response to amenities and risk. Land Econ. 84 (3), 434–448.

Bond, E.W., Coulson, N.E, 1989. Externalities, filtering, and neighborhood change. J. Urban Econ. 26 (2), 231–249.

Borjas, G.J., Freeman, R.B., Katz, L.F., 1997. How much do immigration and trade affect labor market outcomes? Brookings Pap. Econ. Act. 1–90.

Brueckner, J.K., Rosenthal, S.S., 2009. Gentrification and neighborhood housing cycles: will America's future downtowns be rich? Rev. Econ. Stat. 91 (4), 725–743.

bunten, d., 2017 "Is the Rent Too High? Aggregate Implications of Local Land Use Regulation" UCLA Working Paper 2016.

Chapman, R.E., Izzo, C.A., 2002. Baseline Measures For Improving Housing Durability. US Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Desmet, K., D. K. Nagy, and E. Rossi-Hansberg. 2015. The Geography of Development: Evaluating Migration Restrictions and Coastal Flooding. No. w21087. National Bureau of Economic Research.

Dixit, A.K., Pindyck, R.S., 1994. Investment Under Uncertainty. Princeton University Press.

Ehrlich, I., Becker, G.S., 1972. Market insurance, self-insurance, and self-protection. J. Political Econ. 80 (4), 623–648.

Glaeser, E.L., Gyourko, J., Saks, R., 2005. Why is manhattan so expensive? Regulation and the rise in housing prices. J. Law Econ. 48 (2), 331–369.

Glaeser, E.L., Gyourko, J., Saks, R., 2005. Why have housing prices gone up? Am. Econ. Rev. 95 (2), 329–333.

Glaeser, E.L., Scheinkman, J., Shleifer, A., 1995. Economic growth in a cross-section of cities. J. Monet. Econ. 36 (1), 117–143.

Glaeser, E.L., Laibson, D., Sacerdote, B., 2002. An economic approach to social capital. Econ. J. 112 (483), F437–F458.

Glaeser, E.L., Gyourko, J., 2005. Urban Decline and durable housing. J. Political Econ. 113 (2), 345–375.

Hansen, L.P., Sargent, T.J., 2008. Robustness. Princeton University Press.

Lee, S. and Lin, J. (2017). Natural amenities, neighborhood dynamics, and persistence in the spatial distribution of income. Working Paper 17-03, Research Department, Federal Reserve Bank of Philadelphia.

Kahn, M.E., 2005. The death toll from natural disasters: the role of income, geography, and institutions. Rev. Econ. Stat. 87 (2), 271–284.

Kousky, C., Luttmer, E.F.P., Zeckhauser, R.J., 2006. Private investment and government protection. J. Risk Uncertainty 33 (1-2), 73–100.

McNamara, D.E., Keeler, A., 2013. A coupled physical and economic model of the response of coastal real estate to climate risk. Nat. Climate Ch. 3 (6), 559–562.

Morten, M. and J. Oliveira. Paving the Way to Development: Costly Migration and Labor Market Integration. *NBER Working Paper No. 22158*, NBER (2016).

Noguchi, M., 2003. The effect of the quality-oriented production approach on the delivery of prefabricated homes in Japan. J. Housing Built Environ. 18 (4), 353–364.

Ottaviano, G.I.P., Peri, G., 2012. Rethinking the effects of immigration on wages. J. Eur. Econ. Assoc. 10 (1), 152–197.

Rappaport, J., Sachs, J.D., 2003. The United States as a coastal nation. J. Econ. Growth 8 (1), 5–46.

Ritzema, H.P., 2008. Coastal Lowland development: coping with climate change: examples from the Netherlands. In: Proceedings of the International Workshop On Sustainable Paddy farming and Healthy Environment. Changwon city, Republic of Korea, p. 12. 30-31 October *2008*.

Rosenthal, S.S., 2014. Are private markets and filtering a viable source of low-income housing? Estimates from a "repeat income" model. Am. Econ. Rev. 104 (2), 687–706.

Saiz, A., 2010. The geographic determinants of housing supply. Q. J. Econ. 125 (3), 1253–1296.

Severen, C, Costello, C, Deschenes, O, 2016. A Forward Looking Ricardian Approach: Do Land Markets Capitalize Climate Change Forecasts?. National Bureau of Economic Research.

Sobel, R.S., Leeson, P.T., 2006. Government's response to hurricane katrina: a public choice analysis. Public Choice 127, 55–73.

Sweeney, J.L., 1974. A commodity hierarchy model of the rental housing market. J. Urban Econ. 1 (3), 288–323.

Viscusi, W.K., Aldy, J.E., 2003. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. J. Risk Uncertainty 27 (5), 5–76.


[23] Whether mobile capital is sufficient to prevent a downward spiral in the face of worsening amenities may depend on the social ties of households in addition to the physical ties of capital: households embedded in endogenous social networks may find it too costly to move regardless of a worsening climate (Morten and Oliveira 2016).

[24] For example, http://www.scientificamerican.com/article/seas-rising-but-florida-keeps-building-on-the-coast/.

[25] For example, http://www.miaminewtimes.com/news/miami-dade-could-ask-developers-to-pay-for-climate-change-costs-8576071.

[26] The Urban Land Institute has suggested this strategy for a Miami-area community, in tandem with (regulations that allow) denser development on higher ground: http://uli.org/wp-content/uploads/ULI-Documents/Miami-Presentation.pdf.