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CLIMATE CHANGE ADAPTATION: LESSONS FROM URBAN ECONOMICS

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ABSTRACT

In an urbanizing world economy featuring thousands of cities, households and firms have strong incentives to make locational investments and self protection choices to reduce their exposure to new climate change induced risks. This pursuit of self interest reduces the costs imposed by climate change. This paper develops a dynamic compensating differentials model to explore how the "menu" offered by a system of cities insures us against emerging risks. Insights from urban economics offer a series of testable hypotheses concerning the economic incidence of spatially tied climate change risk.

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Introduction

As world population and per-capita income continue to grow, global greenhouse gas emissions will rise. If China and the United States follow through with their recent promises announced in November 2014 to reduce their emissions over the medium term, this would "bend the carbon curve" but energy demand in the developing world continues to soar (Wolfram et. al. 2012). The world's atmospheric carbon dioxide level currently stands at 396 parts per million and continues to rise. This trend means that we will face climate change and this raises the question of how we will cope with this ambiguous challenge.

Urbanization and competition between cities to attract households and firms offers a credible pathway for adapting to climate change. The vast majority of urbanites work inside and thus their productivity is less affected by climate conditions than the agricultural sector. The diffusion of air conditioning in cities in the developing world will attenuate productivity effects associated with extreme heat (Dell, Olken and Jones 2014). Urbanization raises per-capita income because cities economize on trade costs and facilitate learning, trade and specialization (Glaeser 2012). With higher incomes, individuals have greater resources to spend on self protection and governments collect greater revenues that allow them to provide public goods. The majority of the world's population lives in cities and this urbanization share is predicted to grow to be 60% by the year 2030.[1]

This essay develops a dynamic compensating differentials model to explain and predict how urban households will use a variety of markets to adapt to the new challenges and opportunities we will face. The menu of choices offered by a system of cities reduces our exposure to climate change risk. The hedonic research approach for understanding the demand and supply of spatially tied differentiated products is crucial for predicting how the system of cities is affected in both the developed world and the developing world (Rosen 1974, 1979, 2002). Within a system of cities in a nation such as the United States, there are hundreds of different cities for households and firms to choose from. Within a large metropolitan area such as New York City, there are many neighborhoods to choose from. While Wall Street has

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[1] http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

traditionally clustered in Southern Manhattan, there is no reason why financial firms must continue to agglomerate there if Southern Manhattan faces significant flood risk. Such activity could move to the “higher ground” of the Connecticut suburbs where hedge funds have already clustered. The large menu of neighborhoods and cities offers households and firms implicit insurance against new shocks. In an age of skyscrapers, a city such as Hong Kong features a population of 67,000 people per square mile. If all 7.3 billion people on the planet lived at this density, then we would need to identify 109,000 square miles of “higher ground” to build our future cities. In a world where Asia alone has a land area of 17.2 million square miles, the urban population can re-organize in relatively small geographic places that are forecasted to face less climate risk.

To focus this essay, I will not discuss the topic of how agriculture will adapt to climate change. I recognize that urbanites eat food but the price variability that urbanites will face for buying food is diminished by free trade in agricultural produce, storable output, and futures markets in agricultural output. In richer nations, the food budget share shrinks. For example, in the United States in 2013 only 13% of expenditure was spent on food.[2] This indicates that food price increases translate into small urban household negative income effects. In a world featuring free trade in agriculture and millions of competing farmers, the basic logic of spatial diversification (i.e that bumper wheat crops in Russia may occur in years when Kansas has low wheat output) should provide some confidence that the aggregate food supply will not vary greatly from year to year. Farmer adaptation to climate change is an emerging research topic (Fisher et. al. 2012, Lobell et. al. 2011 Roberts and Schlenkler 2010, Mendelsohn and Dinar 2003, Mendelsohn 2000, Kurukulasuriya et. al. 2006).

The emerging field of environmental and urban economics yields a set of testable predictions concerning how self interested households, firms and local governments will respond to the anticipated but evolving threats posed by climate change. The themes of competition, choice, innovation and experimentation are the basis for my optimism concerning our collective ability as urbanites to withstand this emerging threat. Nations featuring multiple cities with low migration barriers between these cities are uniquely suited to adapt to most of the emerging challenges associated with climate change. The hedonic models I present below sketch the

[2] See http://www.bls.gov/ro9/cexlosa.pdf

evolving compensating differentials equilibrium and help to inform about the economic incidence of climate change. These models are used to highlight the open empirical research agenda.

The Urban Household's Static Location and Investment Problem

All urban households are assumed to have the same utility function defined over being comfortable and safe. These "goods" cannot be directly purchased in markets. Instead, households have a Becker Household Production Function such that they produce these goods using their own time and market inputs and local public goods such as the topography of their neighborhood or government policies such as sea levees. Climate change impacts a household's propensity to be comfortable and safe. Access to market inputs allows households to offset some of these risks.

To begin to introduce spatial economics, the vector ξ_{ijt} represents the attributes of neighborhood i in city j at time t. This vector can be partitioned into two location specific sets of attributes. In equation (1), these attributes are defined as risks and amenities.

$$\xi_{ijt} = (risk_{ijt}, amenity_{ijt}) \tag{1}$$

Different locations will face different risks. Some will face extreme heat risk (i.e days over 95 degrees) while others will face greater natural disaster risk. The second piece of the vector consists of location specific average features such as annual winter and summer temperature and humidity. These are the classic location local public goods that the cross-city hedonic literature has focused on (Rosen 1979, Roback 1982).[3] In that literature's hedonic equilibrium, cities with nicer amenities tend to feature lower wages and higher rents than cities with lower quality of life. This variation in wages and rents provides a private goods

[3] To simplify this section, I will not follow Rosen and Roback and construct a general equilibrium model featuring firm locational choice and real estate developers' housing supply. Such risk neutral profit maximizing entities will compare their revenues and costs from producing in a given location relative to their other opportunities. As I discuss below, the expectation of climate change risk may lead real estate developers to build cheaper less durable housing in order to allow home owners to have the option to more cheaply vacate an area that is learned to face higher climate change risk.

compensating differential so that households are roughly indifferent across heterogeneous geographic areas.

This location specific time varying vector of attributes affects a person's expected utility from living in neighborhood i in city j at time t. In particular the typical consumer maximizes, her expected utility by choosing a location, private consumption and investments in self protection subject to the budget constraint.

$$U(i,j,t) = \max \quad p(risk_{ijt}, e_1) * U(C, h(amenity_{ijt}, e_2)) \tag{2}$$

Subject to: $$C = Income_{djt} - rent_{ijt} - \delta_t * e_1 - \gamma_t * e_2 \tag{3}$$

In equation (3), d indexes individuals by their demographics (i.e more educated people may earn more by working in labor market j at time t). Note how climate change affects expected utility. The risk associated with any specific location affects a person's survival probability. While areas differ with respect to their risk, a person can invest in self protection expenditures e_1 to reduce her death risk.[4] This approach adopts the Ehrlich and Becker (1972) self protection model without introducing formal insurance markets.[5] The utility function is defined over private consumption, C, and the location's amenity index. I adopt a Becker Household Production function, the h() in equation (2), that indicates that the household produces comfort through choosing an amenity index (i.e. living in coastal Santa Monica in Los Angeles versus living in humid Houston). The household's comfort can also be enhanced by market investment in e_2. For example, air conditioning is a prime example of a market input that can offset a location's disamenities. The household purchases this e_2 vector at a market price of γ.[6]

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[4] A public health case study examines the impact of several days of extreme heat in Adelaide, South Australia. Elevated death rates were reported but the authors point to different rates of ownership of air conditioning as a likely key factor (Nitschke et. al. 2011).

[5] To simplify the analysis, I will not discuss formal private insurance markets. The potential for moral hazard associated with public provision and regulation of private insurance (i.e capped insurance premiums) to coastal urban residents is an important future adaptation research topic.

[6] An extension of this model would introduce a time budget constraint and allow the person to reallocate his time (such as spending less time outside on a hot day) to reduce his exposure to extreme outdoor heat conditions (Neidell 2009).

The budget constraint presented in equation (3) highlights that the person earns a location specific income and pays market rents to live in housing in that location. The person then buys the self protection products.

In equilibrium, the hedonic pricing gradients for $Income_{djt}$ and $rent_{ijt}$ will be a function of the structural utility functions of the households as well as the production functions for survival, and comfort and the distribution of ξ_{ijt}. Holding the price of self protection from risk and amenities constant (the δ and the γ), in the compensating differentials equilibrium, each person of a given human capital level will be indifferent between living in every neighborhood/city. The hedonic income and rent gradient will adjust so that cities featuring greater risk and lower amenities will pay higher wages and feature lower rents.[7] This compensating differential will shrink if the price of market offsetting goods declines and if these goods are highly productive in offsetting risk. Areas along coasts will bundle together both amenity and risks. The market pricing gradient will price both attributes (Bin et. al. 2008).

Using this model, one can conduct comparative static to measure the impact of climate change on the typical consumer's well being. Such a modeler would have to take a stand on how how the ξ_{ijt} distribution will evolve over space and time. Weitzman (2009) stresses the possibility that unknown climate sensitivity is such that high levels of global greenhouse gas

[7] This model of individual locational choice abstracts away from the economies of scale in production and consumption. Suppose that there are economies of scale in consumption because variety producers face fixed costs in production. In this case, if many people agglomerate close together, firms will find it profitable to offer new varieties and this will increase consumer well being (Waldfogel 2009). There are obviously search benefits in larger markets related to cities as marriage markets (Edlund 2005). The model presented above can be considered as sketching the co-ordinating mechanism such that self interested people who want to be safe and comfortable locate in areas knowing that other people are solving a similar problem and they will thus co-agglomerate on the mutually agreed upon "higher ground". In such locations, they will enjoy the consumer varieties and matching opportunities that I have not formally modeled. To repeat, I am not modelling the endogenous amenities that emerge when people agglomerate but I am optimistic that such amenities will emerge in those areas with relatively high future ξ levels. Consider Las Vegas today and how a desert landscape can be a highly valued "consumer city".

emissions may shift the equivalent of ξ_t such that fat tail disastrous scenarios arise.[8] In such "macro one sector models", people are passive victims of the cumulative GHG emissions stock they have produced. By assumption, there is no "higher ground" for them to migrate to and there is no learning process through which future generations identify which areas are relatively safer.

What urban economics can contribute here is a focus on spatial substitution effects. At any point in time, shifts in the ξ_{ijt} distribution vary across space. For any given place, I expect that there will be serial correlation (and thus some predictability) about the types of shocks that different cities will experience.[9] Certain geographic areas are at greater risk from extreme heat and flooding than others and these shocks are likely to be persistent (i.e Los Angeles drought, Miami flooding). Tol et. al. (2006) provide a case study of how affected areas in Western Europe will adapt to the challenge of sea level rise. I acknowledge that if ξ_{ijt} follows a random walk then forward looking investors and households will face much greater adaptation challenges but the point of the entire climate science research agenda is to create predictive models of the spatial and temporal impacts of climate change. Those areas whose relative quality of life is expected to be high and their risk is low will experience an influx of households and firms seeking to move there. The hedonic spatial pricing gradient will evolve to reflect these expectations.

An understudied key parameter in determining our ability to move to "higher ground" is the local elasticity of real estate supply. Can new housing be built in the geographic areas that are less affected by climate change An active research field has studied both how topography (Saiz 2010) and local land use regulation (Glaeser 2012, Kahn 2011) limits how much housing is built. If new housing can be built in the relatively safer areas then rents will not rise much as people move to those areas.

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[8] Costello et. al. (2010) document that Weitzman's results are sensitive to whether there is loose but finite upper bound on how much temperature could rise in the future due to climate change.

[9] In Kahn (2014), I contrast risks due to terrorism versus risks due to climate change. I argue that terrorists seek to be less predictable so that we cannot adapt and be prepared for their next attack. In contrast, "Mother Nature" is not so strategic and the serial correlation of such climate shocks enhances our ability to predict the future.

Equilibrium rent declines in areas experiencing increased risks will be attenuated if market and local government self protection investments are effective in offsetting risk. The logic of compensating differentials is such that prices adjust so that differentiated products (i.e cities and neighborhoods) are roughly perfect substitutes (Rosen 2002). As rents fall in the affected areas, consumers there will have access to greater private consumption and this will partially compensate them for the extra risk they face.

The popular media almost comically suggests that coastal residents will simply drown as climate change unfolds. Such a passive response to an anticipated challenge violates the rational expectations hypothesis and contradicts the standard logic of economics that consumers act proactively to achieve their life goals (which include achieving comfort and safety).

The Lucas Critique Predicts that Reduced Form Forecasts Overstate the Cost of Climate Change

An emerging empirical research agenda has attempted to predict the future costs of climate change (see Kahn 2009, Albouy et. al. 2012, Deschenes and Greenstone 2011). As I discussed in the last section, the correct approach for quantifying such costs would be to adopt an expenditure function approach and to calculate how much each person would be willing to pay in private consumption to not have to face the new risks. Such an answer would depend on the prices of self protection goods. Continuing innovation in self protection technology means that the same person would be willing to pay less in the future because of such improvements.

A recent empirical literature has ignored this point in predicting the consequences of climate change on economic activity. In my own 2009 paper, I'm guilty of adopting this approach (Kahn 2009). I estimated a cross-sectional hedonic real estate pricing gradient where I asked how much higher was real estate prices for a standardized housing unit in areas with better climate conditions versus other areas (i.e contrasting San Francisco with Houston). This exercise yields an estimated hedonic real estate gradient which I define as R($amenity_{ijt}$) . In a second step, I took climate change forecasts of each U.S county's average climate conditions l years from now. Under the assumption that the spatial hedonic gradient is a stable over time, I then used equation (4) to calculate the impact of climate change on real estate prices in every county in the United States.

$$\Delta Rent_j = Rent(amenity_{ijt+l}) - Rent(amenity_{ijt}) \qquad (4)$$

Deschenes and Greenstone (2011) conduct a similar analysis predicting location specific death rate increases given current climate change forecasts. They estimate a current mortality regression across U.S counties as a function of extreme heat days in the county. They then use a climate forecasting model of how many hot days a county will experience l years from now. Assuming the mortality gradient is stable over time, they use equation (5) to predict the extra deaths caused by climate change.

$$\Delta\, p(risk_j) = p(risk_{jt+l}) - p(risk_{jt}) \qquad (5)$$

These predictions represent our best guess as of time t of the likely impact of expected climate change at time t+l if there is no change in household behavior (i.e holding e1 and e2 at their current levels and holding locational patterns constant). But, the logic of the Lucas Critique requires that we consider how e_1 and e_2 will change because of anticipated climate change (Lucas 1976).

At the heart of the Lucas Critique is the idea that rational agents re-optimize as the "rules of the game change". While Lucas focused on how optimal consumption and investment behavior evolves as government policy changes, the same logic can be applied to "Mother Nature changing the "rules of the game". More formally climate change shifts the distribution of ξ_{ijt} over time. Individuals will anticipate this and will change their locational choices and their self protection investments. These investments mean that the predictions based on the initial reduced form functions presented in equations (4) and (5) over-state the actual impact of climate change. As climate change unfolds, households will not be passive victims. They will seek out solutions and capitalist firms will deliver such solutions. I will return to this point below. The microeconomics of such innovation in terms of my model are lower prices for e_1 and e_2.

One hundred year evidence over the 20th century highlights this point. Bacera et. al. (2013) document that with the diffusion of air conditioning that the death toll from 95 degree or hotter days has sharply decreased (by roughly 90%) in the United States. Using data from India, similar results are found (Burgess et. al. 2013). This evidence supports the claim that innovation and the diffusion of such ever cheaper durables play a key role in protecting us. Urbanites earn greater income than rural people and thus are better able to afford these products. International competition and supply chains help to lower their prices over time.

Air conditioning is just one example of the rise of self protection products. The broad diffusion of cell phones and information technology helps to protect us from many emerging threats as they provide early warning systems altering the population concerning risks (Jensen 2007). Today, Tsunami warnings and Hurricane warnings have saved millions of lives.

Towards the end of this paper, I will argue that urbanization in the developing world is another adaptation strategy. If more farmers move to cities, they will face fewer climate change challenges. The reason I mention this point in this section is that Burke et. al. (2009) have conducted influential reduced form research in Sub-Saharan Africa in which they have calculated a different version of equation (5). In their setting, they estimate the probability of Civil War as a function of outdoor temperature and extrapolate how climate change will impact the future probability of Civil War in these nations. Using recent counts of deaths in these nations, they are brave enough to generate estimates of the extra Civil War deaths that will occur in the future because of climate change.

Again, the Lucas Critique is relevant here. If a larger share of African households will be living in cities in the future, does extra heat cause a diminished level of violence? Demsetz (1967) argued that the rule of law will emerge when the benefits of introducing such law exceed the costs of establishing them. As urbanization takes place, people live in closer proximity, specialize and trade. This will increase their incomes and will foster greater spending on private self protection and increase their demand for rule of law. Such laws should attenuate the threat of violence that Burke et. al. (2009) have documented. Such endogenous institutions mean that extrapolations based on equation (5) over-state future violence induced by climate change.

Extending the Residential Locational Choice Model to Incorporate Lifecycle Dynamics and Expectations and Learning

In choosing a city and a neighborhood within a city, forward looking urban households will tradeoff the price of real estate against the location specific amenities and expected future risks. If a specific area is expected to become increasingly risky, then all else equal, land prices will fall and a different subset of firms and households will locate there. For example, richer people may avoid areas that flood because survival is a normal good.

If households can costlessly migrate, then the static model presented above could be used in each time period to solve out for the evolving spatial compensating differentials. New news would arrive concerning ξ_{ijt} and the population would respond by re-organizing and a new hedonic gradient would be observed. An expenditure function approach could be used to evaluate the aggregate change in consumer surplus brought about by shifts in the distribution of ξ_{ijt}. The race between capitalist innovation and Mother Nature would determine whether the geography of a nation offers enough possible destinations and if market self protection inputs are productive enough per dollar spent on them to offset the damage imposed by climate change.

In reality, we know that households do face migration costs for leaving a given location. It takes resources to move and when people live in an area or grew up in that area they will have an attachment to both its attributes and to their local social network and they will value the local knowledge they have about the place. All of this location specific capital will be lost if a person moves away.

Recognizing this point, consider a simple overlapping generations model in which each person is a young adult, then middle aged and then old. The young face zero migration costs, while the middle aged can only move if they pay a migration cost. The old are not able to move. Anticipating this lifecycle, households face a dynamic programming problem as they seek to maximize their lifetime discounted expected utility.

This framework allows me to discuss economic incidence and expectations formation and to contrast the rational expectations versus the behavioral economics view of households. Moving entails both a financial cost and a loss of utility. To keep the problem simple, I assume that people are renters at all three stages of the life cycle. Young people and middle aged people have strong incentives to research their locational choice because they are locking in to a specific location. This raises the issue of how such agents form expectations about how ξ_{ijt} will evolve across space and time. In his 2014 Nobel Lecture, Hansen (2014) writes; “Agents inside our model, be it consumers, entrepreneurs, or policy makers, must also confront uncertainty as they make decisions. I refer to this as inside uncertainty, as it pertains to the decision-makers within the model. What do these agents know? From what information can they learn? With how much confidence do they forecast the future?”

Some sophisticated households (think of Mr. Spock from Star Trek) know that they “do not know” what climate change entails and thus will seek out flexible choices that have options embedded in them. There are other people (i.e Homer Simpson from The Simpsons) who may be blissfully unaware of the challenges that he will face if he chooses a specific location. Consider the following two by two matrix of evolving actuarial risk versus subjective beliefs.

	Geographic Specific Future Risk Level	
The migrant’s awareness of locational risk	Risky	Relatively Safe
Knows that he does not know	1	2
Does not know that he does not know	3	4

A benevolent paternalist will be most concerned about case #3 in the matrix above. This is the case where individuals who do not anticipate that they have taken a gamble have located in a place that faces greater actuarial risk of disaster. Such naïve individuals (climate deniers?) may underestimate probabilities of disaster or over-estimate the effectiveness of self protection by government and market products. The insurance industry can play a key role here as these profit maximizing firms price premiums that should signal to those in category #3 that they are underestimating risks (Kahn 2010).

Endogenous Depreciation of Place Based Assets

We have invested in place based real estate and infrastructure (i.e buildings, highways, power plants) that all could be at risk due to climate change events such as sea level rise. Suppose that there were capital markets for each of these assets. Standard asset pricing logic would predict that when the "event" (climate change induced sea level rise) becomes known that it will be priced before the actual event occurs. Consider coastal Miami. If there are condominium buildings that are expected to be submerged in the year 2050, then the resale value of these units will be lower in the year 2030 because forward looking buyers will recognize that they will own the present discounted value of rents from the condo for 20 years rather than the longer period if the condo building had not flooded.

What do real estate investors lose if forward looking spatial asset markets price such risk? At time t consider the present discounted value of a building that will be submerged in the year t+M. Suppose this building would have been usable until year t+L where L>M if no flooding would occur in the future. The owner of this building loses the ability to rent space in the building but saves on the upkeep investments he would have made. Equation (6) reports the value of the building at time t that will be submerged at the time t+M.

$$PDV\ of\ Profit\ at\ time\ t = \sum_{j=0}^{M}(rent(i)_{t+j} - invest_{t+j})/(1+r)^j \qquad (6)$$

$$i_t = \pi * i_{t-1} + invest_t \qquad (7)$$

Equation (7) displays the standard investment equation for the building's quality. This building depreciates over time unless the owner invests in maintenance and repair. Higher quality buildings command a rent premium so the rent is an increasing function of i.

Consider what the PDV of profit for this building would be if it had not submerged as presented in equation (8).

$$PDV\ of\ Profit\ at\ time\ t = \sum_{j=0}^{L}(rent(i)_{t+j} - invest_{t+j})/(1+r)^j \qquad (8)$$

The difference between equation (8) and equation (6) represents the loss in profit to the coastal building owner. Note the two key terms. The owner collects less rent in the future and makes fewer investments to reverse depreciation. The building's quality over time takes a different path when the time horizon is M not L.

The implication of this simple model is that real estate owners in coastal locations expected to flood will consciously depreciate their assets so that they lose less when the inevitable flooding occurs. This anticipation of the future means that the lost asset is not a valuable asset. If real estate owners anticipate that climate change imposes likely losses on their property then they may choose to forgo upkeep and simply let the asset depreciate. In this case, they suffer a loss in the rental flow of the asset but they suffer less of an asset loss when the asset is submerged by sea level rise. An often ignored point in the climate change literature is that the loss in the land value will be a pecuniary externality as the land value destroyed will be offset by the gain in land value where households now bid for land.

Who will live in the increasingly at risk cities in their durable housing? In an important contribution, Glaeser and Gyourko (2005) discuss the dynamic equilibrium implications of durable housing built in places such as Buffalo and Detroit at the peak of such cities' manufacturing booms but in recent years the factories have closed but the homes remain. They argue that the inelastic supply curve for housing combined with a declining demand to live there leads to low real estate prices and thus act as a poverty magnet. Will climate change induce the same effect? If poor people want to live in such risky places and enjoy very low housing prices, should they be allowed to make this bet? Bunten and Kahn (2014) argue that in areas where there is common knowledge that the place faces significant risk that new construction will stop but that the real estate prices there do not have to fall sharply if there are incumbents who greatly value the coastal area's amenities, or have built up a social network that they would lose if they migrated or if these individuals have a special comparative advantage in self protecting against risk (see Shogren and Stramland 2002).

Spatial versus One Sector Capital Stock Models

It is of interest to compare my spatial capital stock investment model with the one sector investment model of Dietz and Stern (2014). In the computable general equilibrium tradition, CGE modeling introduce a damage parameter such that the damage to the capital stock is a deterministic function of a polynomial of global average temperature. In their models the aggregate capital stock next period is written as a standard capital stock evolution equation with one twist (see equation 9).

$$K_{t+1} = (1 - Damage_t) * (1 - Depreciation) * K_t + \ Investment_t \qquad (9)$$

Damage imposed by climate change induced higher average temperature scales down the capital stock (see equation 12).

$$Damage_t = 1 - 1/(1 + b_1 * Temperature_t + \ b_2 * temperature_t^2) \qquad (10)$$

Equation (10) violates the Lucas Critique. It assumes that the relationship between average temperature and damage to the capital stock is a time invariant function and this assumes away all of the details concerning the evolution of investment in self protection and the spatial distribution of the world economy. The parameters b_1 and b_2 are reduced form parameters generated based on a structural model of economic geography such as the ones presented above. The microeconomic approach to climate adaptation acknowledges the possibility of the economic reorganizing itself so that the same temperature changes cause less damage to human capital and physical capital.

In my model presented above, real estate investors disinvest from coastal at risk areas (they spend less on maintenance). This money is invested in another spatial sector of the economy and the overall capital stock is not "damaged". If real estate investors anticipate that climate change may impact an area where they plan to build, and they expect to learn over time about the specifics of the new risk, then they will value having the option to re-optimize in the future (Dixit and Pindyck 1994). A less durable real estate stock would offer this opportunity, or a real estate stock that can be disassembled and rebuilt elsewhere (the equivalent of Lego pieces in prefabricated housing).

The Incidence of Place Based Productivity Shocks

When Hurricane Sandy struck in late October 2012, Southern Manhattan lost power for five days. What are the productivity effects of such climate events? If Chicago shuts down due to an extreme snowstorm for two days, does GNP decline by 2/365? I believe the answer is no as more and more urbanites can work from home. Consider the productivity of an economics professor. On such snowy days, she will have more research time! I am only half kidding. Professors do not have to meet in teams in face to face factory floor to produce our output. Assuming that the professor has access to backup power (and diesel generators are increasingly in demand), such a professor could continue to be highly productive.[10] Companies such as Amazon that rely on distribution networks could build in redundancies in their supply chains to be prepared for scenarios where specific transport routes are cutoff. Such contingency plans are costly but they represent another example of self insurance against climate shocks. These examples highlight how the modern economy has evolved to withstand climate shocks. Critics point to specific at risk geographic areas such as Southern Manhattan. Won't Wall Street flood? For decades, Wall Street has been the engine of New York City's economy. Looking ahead doesn't the New York City economy face a cloudy future given that Wall Street is located in low lying Southern Manhattan? My answer is simple. Wall Street is not productive because it is on Wall Street. Instead, the physical location called "Wall Street" has solved a co-ordination problem as skilled financial workers have sought face to face contact. If the physical area called "Wall Street" is now increasingly at risk due to climate change, then the financial agglomeration called "Wall Street" will re-agglomerate on higher ground somewhere else. For those who worry about co-ordination failures, I would counter that while possible that there are "big fish" such as Goldman Sachs who could as leaders in a leader/follower game and commit to move to Connecticut and other firms would then follow.

[10] Information technology complements the amenity and productivity value of cities (think of Uber and other Smart Phone Aps and access to email and news alerts) (see Glaeser and Gaspar 1998). Computer scientists are optimistic that the Internet will always be up and running (Strickland 2010). How people will access the Internet during emergency conditions is clearly an important adaptation issue.

In the modern urban economy, human capital (not physical places) is the golden goose.[11] Implicit in the pessimists' view is that physical places are the key source of productivity for urban growth. Such a view contradicts the emerging wisdom in urban growth theory as surveyed in Glaeser (2012) and Moretti (2012). If Manhattan faces existential threats due to climate change, industry will leave to its suburbs. Land owners and placed based politicians will bear the incidence but neither productivity nor the economy will suffer.

Improvements in Forecasting City Specific Future Challenges

As the dynamic programming problem of migration highlights, urbanites will be seeking better information about the specific risks that cities will face. Both academic researchers and major cities all over the world are engaging in high resolution forecasts of what climate change will mean for different cities. Such research focuses on how the ξ_{ijt} evolve. One example is the San Diego Foundation's 2050 Study titled; "A Regional Wake Up Call". This report highlights that San Diego is expected to be 4 degrees F hotter on average, experience sea level rise of 12 to 18 inches and face rising water and electricity demand and will face more wildfires of higher intensity. One dramatic map (see Figure One) highlights what San Francisco will look like after 200 feet of sea level rise![12]

A prime example is my UCLA colleague Professor Alex Hall's work on forecasting how different Los Angeles neighborhoods will be affected by climate change. A map from his work is presented in Figure Two. Note that coastal communities such as Santa Monica are predicted to experience no increase in 95 degree days over the next 35 years. This suggests that a benevolent planner would sharply increase new housing supply in such areas but local zoning

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[11] The impact of climate change on physical places is an active research subject. Hornbeck (2012) investigates how the 1930s Dust Bowl affected both the place and the people. He documents the migration patterns away from the affected area. Hsiang and Jina (2014) collect geocoded data on cyclones and document the impact of these natural disasters on affected economies.

[12] http://www.citylab.com/weather/2014/11/a-map-of-san-francisco-after-a-catastrophic-rise-in-sea-levels/382436/

may preclude this (Kahn 2011). This is an example of how local politics precludes relatively low cost climate adaptation strategies.

As far as I know, most of the city specific assessments of climate change's impacts have focused on rich cities. A valuable investment would be to conduct similar assessments in the developing world.

Endogenous Innovation and Demand Fueled by Richer Urbanites Seeking Solutions

The climate scientists are providing potential entrepreneurs with plenty of clues concerning the set of products and services that future urbanites will need to adapt to climate change. Competition between entrepreneurs will increase the dimensionality of these self protection strategies and reduce their price per unit of quality. Obvious examples of such adaptation strategies includes more efficient air conditioning, renewable power generation that allows households to reduce their exposure to infrastructure failure risk, foods that can withstand spoilage, and housing materials that ventilate and that are sturdy enough to handle flood and wind conditions. Smart meters allowing households access to real time information about pricing. One Hollywood example is that after Hurricane Katrina, my UCLA colleague Thom Mayne teamed with Brad Pitt to develop a new set of Floatable Homes so that future floods cause less coastal damage.[13]

Acemoglu and Linn's (2004) endogenous innovation framework offers a framework for considering how entrepreneurs respond to the challenge of climate change. Define the market size for any adaptation friendly product to be the affected urban population, N, and define p as the probability of a sale. Define Price as the unit price of the product. Define F as the fixed cost to producing the variety and define c as the constant marginal cost for producing the variety. In a one period economy, the firm will enter this market if $N*p*Price - F - c*N*p$ is greater than zero. Entrepreneurs are more likely to invest in costly R&D to develop adaptation friendly

[13] http://www.nola.com/arts/index.ssf/2009/10/world_famous_architect_thom_ma.html

markets because the extent of the market is so large. Such competition will lower the market prices of self protection and help poor people to protect themselves.

Urbanization facilitates this process. Investment in human capital and urbanization are complements. As more of the world's population urbanizes, they will invest more in their education and thus there will be more future potential entrepreneurs who develop breakthrough technology.

Local Government Official Incentives to Invest in Adaptation

In an open system of cities, mayors compete with each other to attract people and jobs. Suppose that local government officials seek to maximize their tax revenue base because this increases their political power. Returning to equations (6) and (7) and recall that in the homogenous population case that the rational investors disinvest in the affected city's real estate. This causes falling rents both because investors to pay more upkeep and due to the emerging capitalized risk. Both of these factors mean that property tax revenue for the city would decline.

If there are public goods that the city invests in that makes the city safer, then private investors will respond by investing more in the housing stock (Kousky et. al. 2006). An unintended consequence of such spatial investment by local authorities could be to crowd out private self protection as more people migrate to publically protected areas. In a federal system, powerful local mayors have incentives to seek out federal transfers. This raises the possibility of spatial moral hazard as one region of the country implicitly cross-subsidizes coastal area development (Boustan, Kahn and Rhode 2013).

Limits to the System of Cities Optimism

An important and open question concerns whether the lessons from the U.S system of cities apply globally with a special focus on LDC cities. While I believe that the answer is "yes", this claim merits future research along the lines that I will now sketch. To motivate this question, consider that more than a billion people will move to cities over the next decades and climate change is likely to accelerate this urbanization trend (see Fuller and Romer 2014 on the opportunities and challenges posed by such urbanization).

Most other nations are smaller in size than the United States and thus feature fewer spatial diversification possibilities. While groups of nations such as the European Union feature free mobility across their borders, language, culture and history act as endogenous migration costs reducing the likelihood that potential migrants move to "higher ground" in another area. In nations with fewer cities, the menu of possible destinations shrinks down. This highlights the importance of considering international migration as one strategy for adapting to climate change.

The algebra of the rank-size rule provides some insights into the evolution of the system of cities as a nation's urban population grows. Vern Henderson has created a data base of the world's cities. It includes data on 31 cities in Bangladesh, 144 cities in India, 54 cities in Indonesia and 25 cities in Vietnam. Recall that rank-size rule states;

$$rank\ of\ city\ j\ in\ nation\ l \quad * population_j = population_{biggest\ city} \tag{11}$$

Given that there are 90 million people in Vietnam today, suppose that by the year 2040 that there are 110 million people in Vietnam and 70% of them live in cities. This would mean that Vietnam will be home to 77 million urbanites. Assuming no new cities are built, equation (11) predicts that Vietnam's biggest city will be home to 18 million people.

A classic model in development and urban economics in LDC nations is the Harris/Todaro migration model (Harris and Todaro 1969) . Rural people choose to urbanize based on a spatial arbitrage condition comparing their expected earnings in the country side versus the city. If climate change is expected to reduce farmer profits, this can lead to a sudden sharp surge in urbanization (Henderson, and Storeygard 2014).

A pessimistic prediction is that farmers will overwhelm the nearest cities as they urbanize but this claim makes two implicit assumptions. First it assumes that minimizing migration costs rather than maximizing potential wages net of rents drive the locational decision. Second, it assumes that the incumbent population does not respond to the new inflows. In two sector general equilibrium models, incumbents in cities where rents are rising and wages are falling will move to other cities (Borjas, Freeman and Katz 1997).

Urbanization raises people's income and this will allow them to purchase the self protection goods that I discussed in an earlier section. Several research teams are now investigating the demand for electricity in the developing world (Wolfram et. al. 2012). Set of durables that we take for granted but together provide protection, better housing (Brueckner 2014). These products protect the urban population from natural disaster risk. In Kahn (2005), I documented that richer nations suffer less death from natural disasters and conjectured that richer nations feature richer citizens who can better protect themselves and richer governments can provide better public goods. Kellenberg and Mobarak (2008) document that death rates are higher from natural disasters in fast urbanizing poor areas as these cities feature higher population density (and thus less spatial diversification) but still feature low income levels. A key issue here is whether urban leaders in the developing world have strong incentives to invest in public goods provision (clean water, electricity access) to recent migrants. At least in the case of Brazil, the answer is "no" (see Feler and Henderson 2010). If local leaders offer such public goods, migrants are more likely to move to such cities and this anticipated effect discourages some leaders from investing in improving the quality of life of urban squatters.

Conclusion: How Do We Protect the Urban Poor and How Do We Cope With Extreme Shocks?

I am pessimistic that a global treaty to cap world greenhouse gas emissions will be enacted in the medium term. This prediction motivated me to work on the urban economics of climate change adaptation. This essay has discussed what we do and do not know about this emerging research area. The system of cities offers the world's urbanites a menu of choices of where to live and work. Market innovation will lead to higher quality and cheaper products that help us to adapt to many of the risks and amenity threats posed by climate change.

We have clustered on coasts and built up trillions of dollars of real estate in such areas (Rapappport and Sachs 2003) but these investments are not infinitely lived. With durable but depreciating capital, we always have the option to move to "higher ground". The agglomeration of skilled people is the source of ideas and trade (Glaeser 2011) and local endogenous amenities (Diamond 2012).

Our ability to provide new housing in relatively safe places offers an implicit insurance policy against climate change. Climate scientists will identify these areas and real estate developers will build there unless local land use regulation precludes this. Housing supply constraints in the developing world is an important future research area (Brueckner and Sridhar 2012). The hedonic real estate pricing function will price these assets. The equity issue that arises here concerns the standard of living of the urban poor. Given the spatial hedonic real estate pricing gradient and the price of self protection inputs, how much risk can they afford to avoid? In a 2013 Matt Damon movie called Elysium, the rich leave earth and move to the Moon to live well after the Earth has been devastated. This form of adaptation suggests that the rich and the poor have very different coping strategies. The poor tend to live in the riskiest areas and have the least ability to invest in self protection before or after shocks. Valuable research would construct a price index of measuring the required expenditure to achieve risk reduction and amenity consumption at different points in time.

In our urbanized, Internet modern economy, are there shocks that could suddenly transform us back into primitive people? If a sudden shock hit a U.S city, why would people die? Why hadn't they evacuated? How many people will have access to financial resources (think of a global bank's network of ATM machines), and be able to take their work with them (think of Google Docs). If the power grid is down, why don't people have access to batteries to power their durables? Why wouldn't the Internet provide information to dislocated people concerning where they can stay in the aftermath of a shock? Why wouldn't supermarkets in a 200 mile radius of the shock be prepared to ship food to the affected place to sell to the hungry? If southern cities experience major snowstorms, why haven't they purchased snow plows for clearing their airport's runways and highways? This "small ball" set of scenarios do not appear in a formal general equilibrium model of climate change but they represent the actual nitty-gritty of how we adapt. Note that it is the invisible hand at work using the Internet to co-ordinate this activity. If during an extreme storm, children's school is disrupted, why can't Internet training such as the Khan Academy fill the gap? I recognize that I am assuming that the Internet remains reliable but what is a shock that would down access to it? If we anticipate this, what backup plans can we implement? There might be sick people in hospitals and they would have trouble moving but this is a small group and such specific examples helps to anticipate such scenarios so that they suffer less when such shocks actually occur.

These questions are meant to pin down the scenarios of an “Arrow-Debreu” state tree. If we can anticipate the possible challenges, even if we cannot assign precise probabilities on their likelihood, doesn’t this create opportunities for arbitraging entrepreneurs? Will Julian Simon win this bet with Paul Ehrlich? Human ingenuity and individual locational and lifestyle choices together are a potent combination in aiding urbanites to adapt.

References

Acemoglu, Daron, and Joshua Linn. 2004. "Market size in innovation: theory and evidence from the pharmaceutical industry." *The Quarterly Journal of Economics* 119, no. 3: 1049-1090.

Aker, Jenny C., and Isaac M. Mbiti. 2010. "Mobile phones and economic development in Africa." *The Journal of Economic Perspectives*: 207-232.

Albouy, David, Walter Graf, Ryan Kellogg, and Hendrik Wolff. 2013. Climate amenities, climate change, and American Quality of Life. No. w18925. National Bureau of Economic Research.

Authority, Greater London. 2008. "The London climate change adaptation strategy."*Draft report*. *Greater London Authority, London*.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. 2013. .Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the 20th century. No. w18692. NBER.

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 Economics*, *84*(3), 434-448.

Borjas, George J., Richard B. Freeman, Lawrence F. Katz. 1997. "How much do immigration and trade affect labor market outcomes?." *Brookings papers on economic activity*: 1-90.

Boustan, Leah Platt, Matthew E. Kahn, and Paul W. Rhode. 2012. "Moving to higher ground: migration response to natural disasters in the early twentieth century."*The American Economic Review* 102, no. 3: 238-244.

Bunten, Devin, and Matthew E. Kahn. 2014. *The Impact of Emerging Climate Risks on Urban Real Estate Price Dynamics*. No. w20018. NBER Working Paper.

Burgess, Robin, Olivier Deschenes, Dave Donaldson, and Michael Greenstone. 2013. "The unequal effects of weather and climate change: Evidence from mortality in india." *Unpublished working paper*.

Burke, Marshall B., Edward Miguel, Shanker Satyanath, John A. Dykema, and David B. Lobell 2009. "Warming increases the risk of civil war in Africa."*Proceedings of the National Academy of Sciences* 106, no. 49: 20670-20674.

Brueckner, Jan K. 2013. "Slums in developing countries: New evidence for Indonesia." *Journal of Housing Economics* 22, no. 4: 278-290.

Brueckner, Jan K., and Kala Seetharam Sridhar. 2012. "Measuring welfare gains from relaxation of land-use restrictions: The case of India's building-height limits."*Regional Science and Urban Economics* 42, no. 6: 1061-1067.

Costello, Christopher J., Michael G. Neubert, Stephen A. Polasky, and Andrew R. Solow. 2010. "Bounded uncertainty and climate change economics." *Proceedings of the National Academy of Sciences* 107, no. 18: 8108-8110.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2014. "What Do We Learn from the Weather? The New Climate-Economy Literature." *Journal of Economic Literature*, 52(3): 740-98.

Demsetz, Harold. 1967. "Toward a theory of property rights." *The American economic review*: 347-359.

Deschenes, Olivier and Michael Greenstone, 2011 "Climate Change, Mortality and Adaptation: Evidence from Annual Fluctuations in Weather in the US," American Economic Journal: Applied Economics, 3(4) 152-185.

Desmet, Klaus, and Esteban Rossi-Hansberg. 2012. *On the spatial economic impact of global warming*. No. w18546. NBER Working Paper.

Diamond, Rebecca. 2012. "The determinants and welfare implications of us workers' diverging location choices by skill: 1980-2000." *Job Market Paper, Harvard University*.

Dietz, Simon, and Nicholas Stern. 2014. "Endogenous Growth, Convexity of Damages and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions." *Centre for Climate Change Economics and Policy Working Paper* 180.

Dixit, Avinash K and Robert Pindyck. 1994. *Investment under uncertainty*. Princeton university press.

Edlund, Lena. 2005. "Sex and the City." *The Scandinavian Journal of Economics*107, no. 1: 25-44.

Ehrlich, Isaac, and Gary S. Becker. 1972. "Market insurance, self-insurance, and self-protection." *The Journal of Political Economy*: 623-648.

Ekstrom, Julia A., and Susanne C. Moser. 2012. Climate Change Impacts, Vulnerabilities, and Adaptation in the San Francisco Bay Area: A Synthesis of PIER Program Reports and Other Relevant Research. California Energy Commission. Publication number: CEC-500-2012-071. *Climate risk information*. City of New York, 2009.

Feler, Leo, and J. Vernon Henderson. 2011. "Exclusionary policies in urban development: Under-servicing migrant households in Brazilian cities." *Journal of urban economics* 69, no. 3: 253-272.

Fisher, Anthony C., W. Michael Hanemann, Michael J. Roberts, and Wolfram Schlenker. 2012. "The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather: comment." *The American Economic Review* 102, no. 7: 3749-3760.

Fuller, Brandon, and Paul Romer. 2014. "Urbanization as opportunity." *World Bank Policy Research Working Paper* 6874.

Gaspar, Jess, and Edward L. Glaeser. 1998. "Information technology and the future of cities." *Journal of urban economics* 43, no. 1: 136-156.

Glaeser, Edward. 2011. *Triumph of the city: How our greatest invention makes US richer, smarter, greener, healthier and happier*. Pan Macmillan.

Glaeser, Edward L. & Joseph Gyourko, 2005. "Urban Decline and Durable Housing," Journal of Political Economy, vol. 113(2), pages 345-375.

Hansen, Lars Peter. 2014. "Uncertainty Outside and Inside Economic Models." Nobel *Prize Lecture*.

Harris, John R., and Michael P. Todaro. 1970. "Migration, unemployment and development: a two-sector analysis." *The American Economic Review*: 126-142.

Henderson, J. Vernon, and Adam Storeygard. 2014. "Is climate change driving urbanization in Africa?".

Hornbeck, Richard. 2012. "The Enduring Impact of the American Dust Bowl: Short and Long-Run Adjustments to Environmental Catastrophe."."*American Economic Review*. 102(4): 1477-1507.

Hsiang, Solomon M., and Amir S. Jina. 2014. *The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones*. No. w20352. National Bureau of Economic Research.

Hsiang, Solomon M., Marshall Burke, and Edward Miguel. 2013. "Quantifying the influence of climate on human conflict." *Science* 341, no. 6151: 1235367.

Huq, Saleemul, Sari Kovats, Hannah Reid, and David Satterthwaite. 2007. "Editorial: Reducing risks to cities from disasters and climate change." *Environment and Urbanization* 19, no. 1: 3-15.

Jensen, Robert. 2007. "The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector." *The quarterly journal of economics*: 879-924.

Kahn, Matthew E. 2005. "The death toll from natural disasters: the role of income, geography, and institutions." *Review of Economics and Statistics* 87, no. 2: 271-284.

Kahn, Matthew E. 2009. "Urban growth and climate change." *Annu. Rev. Resour. Econ.* 1, no. 1: 333-350.

Kahn, Matthew E. 2010. Climatopolis: How Our Cities Will Thrive in Our Hotter Future. Basic Books.

Kahn, Matthew E. 2011. "Do liberal cities limit new housing development? Evidence from California." *Journal of Urban Economics* 69, no. 2: 223-228.

Kahn, Matthew E. 2014. Urban adaptation to low-probability shocks: contrasting terrorism and natural disaster risk , Benefit-Cost Analyses for Security Policies: Does Increased Safety Have to Reduce Efficiency?, Edgar Elgar Press. edited by Carol Mansfield and Kerry Smith.

Kellenberg, Derek K., and Ahmed Mushfiq Mobarak. 2008. "Does rising income increase or decrease damage risk from natural disasters?." *Journal of Urban Economics* 63, no. 3: 788-802.

Kousky, Carolyn, Erzo FP Luttmer, and Richard J. Zeckhauser. 2006. "Private investment and government protection." *Journal of Risk and Uncertainty* 33, no. 1-2: 73-100.

Kurukulasuriya, Pradeep, Robert Mendelsohn, Rashid Hassan, James Benhin, Temesgen Deressa, Mbaye Diop, Helmy Mohamed Eid et al. 2006. "Will African agriculture survive climate change?." *The World Bank Economic Review* 20, no. 3: 367-388.

Lobell, David B., Wolfram Schlenker, and Justin Costa-Roberts. 2011. "Climate trends and global crop production since 1980." *Science* 333, no. 6042: 616-620.

Lucas Jr, Robert E. 1976. "Econometric policy evaluation: A critique." In *Carnegie-Rochester conference series on public policy*, vol. 1, pp. 19-46. North-Holland.

Mendelsohn, Robert. 2000. "Efficient adaptation to climate change." *Climatic Change* 45, no. 3-4: 583-600.

Mendelsohn, Robert, and Ariel Dinar. 2003. "Climate, water, and agriculture." *Land economics* 79, no. 3: 328-341.

Moretti, Enrico. 2012. *The new geography of jobs*. Houghton Mifflin Harcourt.

Neidell, Matthew. 2009. "Information, Avoidance behavior, and health the effect of ozone on asthma hospitalizations." *Journal of Human Resources* 44, no. 2: 450-478.

Nitschke, Monika, Graeme R. Tucker, Alana L. Hansen, Susan Williams, Ying Zhang, and Peng Bi. 2011. "Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis." *Environ Health* 10, no. 1: 42.

Nordhaus, William D. 2013. *The climate casino: Risk, uncertainty, and economics for a warming world*. Yale University Press.

Nordhaus, William D., and Zili Yang. 1996. "A regional dynamic general-equilibrium model of alternative climate-change strategies." *The American Economic Review*: 741-765.

Peters, S., D. Engel, B. Kelly, and E. Young. 2011. "San Diego's Changing Climate: A Regional Wake-up Call, A Summary of the Focus 2050 Study."

Rappaport, Jordan, and Jeffrey D. Sachs. 2003. "The United States as a coastal nation." *Journal of Economic growth* 8, no. 1: 5-46.

Roback, Jennifer. 1982. "Wages, Rents, and the Quality of Life." *The Journal of Political Economy*, 90(6): 1257-1278.

Roberts, Michael J., and Wolfram Schlenker. 2010. *Is agricultural production becoming more or less sensitive to extreme heat? Evidence from US corn and soybean yields*. No. w16308. National Bureau of Economic Research.

Rosen, Sherwin. 1974. "Hedonic prices and implicit markets: product differentiation in pure competition." *The journal of political economy*: 34-55.

Rosen, Sherwin. 1979. "Wage-Based Indexes of Urban Quality of Life." In *Current Issues in Urban Economics*, ed. Peter Mieszkowski and Mahlon Straszheim, 74–104. Baltimore and London: Johns Hopkins University Press.

Rosen Sherwin. 2002. "Markets and Diversity." *American Economic Review*, 92(1): 1-15.

Rosenzweig, Mark R., and Christopher Udry. 2014. *Rainfall Forecasts, Weather and Wages over the Agricultural Production Cycle*. No. w19808. National Bureau of Economic Research.

Saiz, Albert. 2010. "The geographic determinants of housing supply." *The Quarterly Journal of Economics* 125, no. 3: 1253-1296.

Shogren, Jason F., and Tommy Stamland. 2002. "Skill and the Value of Life." *Journal of Political Economy* 110, no. 5: 1168-1173.

Strickland, Jonathan. 2010. "What would happen if the Internet collapsed?" 10 February 2010. HowStuffWorks.com. <http://computer.howstuffworks.com/internet/basics/internet-collapse.htm> 15 November 2014.

Tol, Richard SJ, Maria Bohn, Thomas E. Downing, Marie-Laure Guillerminet, Eva Hizsnyik, Roger Kasperson, Kate Lonsdale et al. 2006. "Adaptation to five metres of sea level rise." *Journal of risk research* 9, no. 5: 467-482.

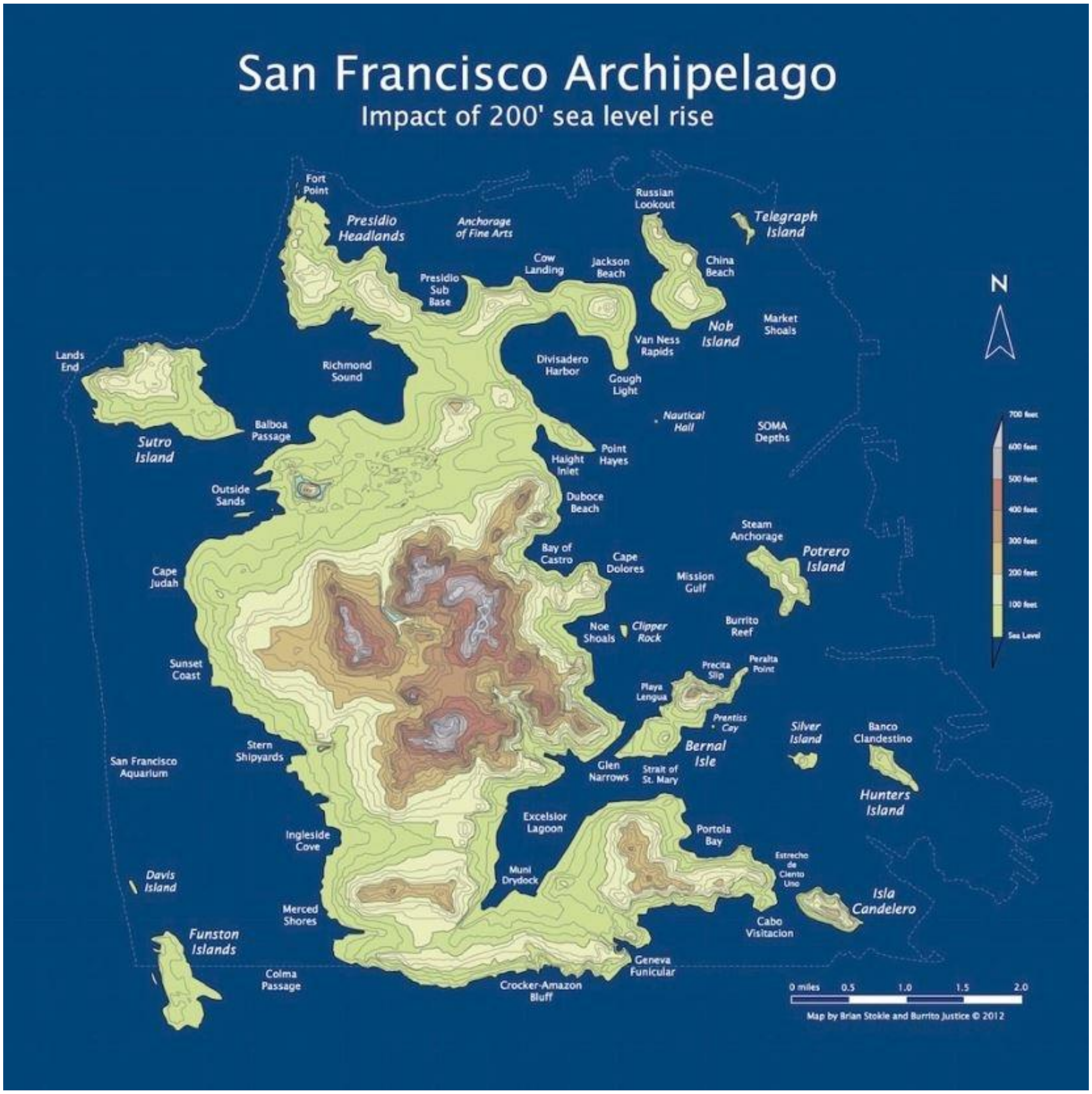
Weitzman, Martin L. 2009. "On modeling and interpreting the economics of catastrophic climate change." *The Review of Economics and Statistics* 91, no. 1: 1-19.

Waldfogel, Joel. 2008. "The median voter and the median consumer: Local< i> private</i> goods and population composition." *Journal of Urban Economics* 63, no. 2: 567-582.

Wolfram, Catherine, Orie Shelef, and Paul J. Gertler. 2012. *How will energy demand develop in the developing world?*. No. w17747. National Bureau of Economic Research.

Figure One

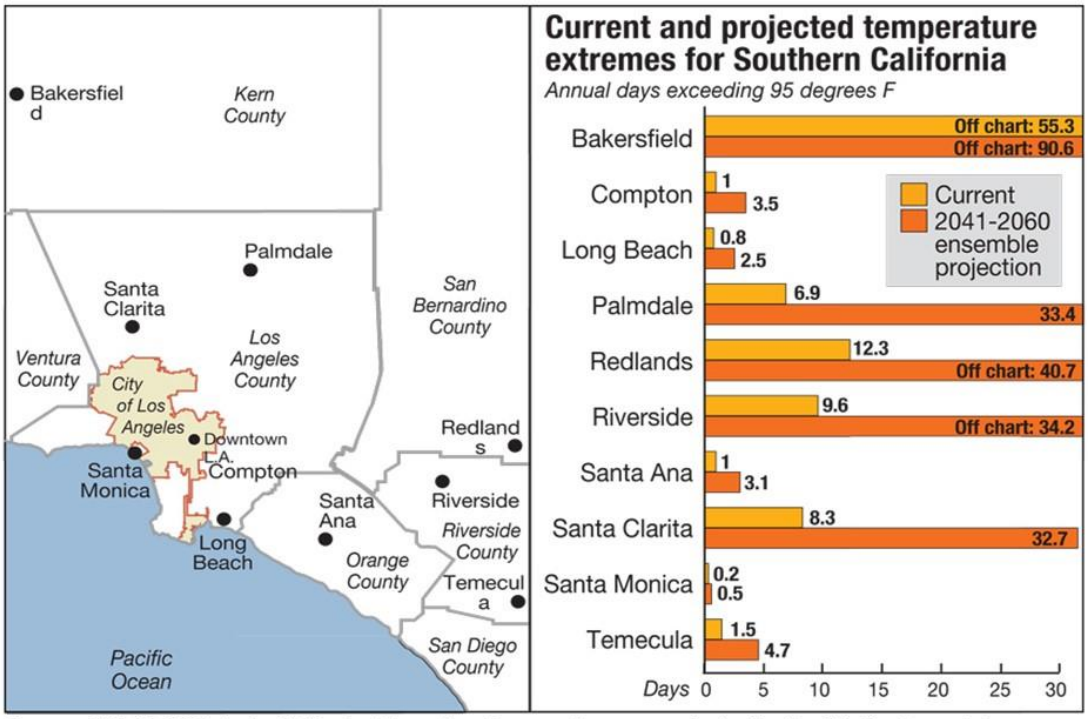
A Map of Future San Francisco after 200 Foot Sea Level Rise



Source: http://www.citylab.com/weather/2014/11/a-map-of-san-francisco-after-a-catastrophic-rise-in-sea-levels/382436/

Figure Two

A Prediction of Within Los Angeles Variation in the Future Count of Hot Days



Source: UCLA LARC study, 2012; chart based on the mean/average projected by the 19 climate models