



Urban Growth and Climate Change

Matthew E. Kahn

Institute of the Environment and Department of Economics, University of California, Los Angeles, California 90095; NBER, Cambridge, Massachusetts 02138; email: mkahn@ioe.ucla.edu

Annu. Rev. Resour. Econ. 2009. 1:16.1–16.17

The *Annual Review of Resource Economics* is online at resource.annualreviews.org

This article's doi:
10.1146/annurev.resource.050708.144249

Copyright © 2009 by Annual Reviews.
All rights reserved

1941-1340/09/1010-0000\$20.00

Key Words

global externality, tragedy of the commons, adaptation, incidence, cities, global warming

Abstract

Between 1950 and 2030, the share of the world's population that lives in cities is predicted to grow from 30% to 60%. This urbanization has consequences for the likelihood of climate change and for the social costs that climate change will impose on the world's quality of life. This paper examines how urbanization affects greenhouse gas production, and it studies how urbanites in the developed and developing world will adapt to the challenges posed by climate change.

1. INTRODUCTION

Climate change is the leading environmental challenge we face. Climate scientists continue to investigate the amount by which we must reduce global greenhouse gas (GHG) production to mitigate the impacts of climate change (Hansen et al. 2008). They measure the atmospheric concentration of carbon dioxide in parts per million (ppm). “Very roughly, stabilization at 500 ppm requires that emissions be held near the present level of 7 billion tons of carbon per year for the next 50 years, even though they are currently on course to more than double” (Pacala & Socolow 2004).

The fundamental challenge posed by climate change is that GHG emissions represent a global externality. No individual, firm, or nation has an incentive to unilaterally reduce its emissions. Such an action would be costly and would have only a minor impact on reducing aggregate global GHG emissions. Given that the world’s population equals roughly 7 billion, global annual average per-capita carbon emissions would need to decline to 1 ton to achieve the aggregate goal described by Pacala & Socolow (2004). To put this target in perspective, if a person drives merely 2130 miles per year using a vehicle whose fuel economy is 25 miles per gallon, then this person would already exceed this target. Each person in the United States is currently producing 18 tons of carbon dioxide per year.

Is city growth exacerbating this problem? Around the world, people are moving to cities. In 1950, 30% of the world’s population lived in cities. In 2000, this fraction grew to 47%, and it is predicted to rise to 60% by 2030 (United Nations 2004). This paper melds insights from urban and environmental economics to answer two main questions. First, does urban growth increase or decrease world GHG emissions? In the absence of explicit carbon incentives, we examine how city growth affects GHG production. Second, as climate change takes place, how will different cities in developed and developing nations cope and adapt?

Cities are the engine of capitalist growth. Over time, people move from rural to urban areas as they seek a higher standard of living. In cities, people earn higher incomes and thus have the financial resources to purchase more consumption products ranging from private transportation to larger homes. Urbanization increases the demand for residential and commercial electricity consumption. Although urbanites produce more emissions per capita than do rural residents, they also choose to have fewer children. Urbanization also facilitates discovery and diffusion of new ideas. Although these last two factors suggest that urbanization could actually reduce the world’s stock of GHG emissions, up until this point the sheer scale of consumption growth has overwhelmed the beneficial effects of urbanization. One major reason for this is the lack of strong incentives to economize on GHG emissions. In the absence of a global carbon tax, this retards targeted induced innovation intended to reduce GHG emissions.

In the first section of the paper, I investigate how urban growth affects GHG production when there are no explicit carbon mitigation incentives and contrast this with the likely consequences of urban growth on GHG production in a world that adopts aggressive carbon pricing.

No matter how much we reduce the global stock of GHG emissions, we will experience some climate change. The second half of the paper focuses on urban adaptation to climate change. I examine how it will affect urban quality of life in different cities around the world. How will cities adapt to climate change? Which cities will gain and which will

lose? As I document below, climate change is predicted to have significant effects on the average temperature and rainfall of major cities throughout the United States. The best models of future temperature and rainfall indicate that over the next 75 years, Southern California's cities such as Los Angeles will suffer a sharp reduction in climate amenity levels while a few cities in Florida will experience improvements in their climate amenity bundle as a result of climate change.

Climate change also poses a set of high-risk, low-probability events for cities (Weitzman 2009). Cities differ with respect to the levels of risk that they will face and their ability to handle these expected blows. Some coastal cities will experience more severe floods while other cities will suffer from worse heat waves. Given that cities differ with respect to the objective risk that climate change poses, what is the optimal role for the federal government in terms of paying for local public goods such as sea walls? Are moral hazard effects a significant concern? For example, could government investment in coastal protection increase the number of "victims" who locate in coastal areas as public investment crowds out private self-protection?

It is important to investigate how city residents expect to cope with climate change. Around the world, the median voter lives in a city. This paper's analysis is useful for understanding how voters in different cities form expectations concerning how climate change will affect their daily life. Self-interested voters are more likely to support aggressive carbon mitigation if they believe that they will significantly suffer under the business as usual scenario (Cragg & Kahn 2009). Expectations of the incidence of climate change play a key role in determining whether voters prioritize climate change as an important policy issue.

2. URBAN GROWTH'S IMPACT ON GREENHOUSE GAS PRODUCTION

Total GHG emissions are equal to income per capita multiplied by population and GHG emissions per dollar of income. This accounting identity highlights the role that scale and composition effects play in determining pollution production. This product can be calculated at any level of geographical aggregation, ranging from a household to a city to a nation to the world. Given that the marginal damage caused by GHG production is independent of where it is produced, we ultimately care about the world's production of GHG emissions. This equation highlights the mitigation challenge. World population is growing and world per-capita income is growing more quickly than population growth.

How does city growth affect a nation's GHG production? Cities are the key engine of economic growth because they economize on the transportation cost of goods, workers, and ideas (Glaeser 1998). Cities facilitate learning as well as the generation and diffusion of new ideas (Duranton & Puga 2001, Audretsch & Feldman 2004). By encouraging specialization and facilitating trade, cities raise our per-capita income (Glaeser & Mare 2001).

Richer consumers spend more on goods and energy, and a by-product of this activity is more GHGs. The income elasticity of the demand for energy is typically found to be between 0.8 and 1.1 (Nordhaus 1979, Gately & Huntington 2001). The aggregate consequences of income growth can be seen in Beijing, China. In 2001, there were 1.5 million vehicles in Beijing. By August 2008, its vehicle total had grown to 3.3 million. Prominent environmental writers such as Jared Diamond are deeply worried about the growth of the middle class in the developing world:

Per capita consumption rates in China are still about 11 times below ours, but let's suppose they rise to our level. Let's also make things easy by imagining that nothing else happens to increase world consumption—that is, no other country increases its consumption, all national populations (including China's) remain unchanged and immigration ceases. China's catching up alone would roughly double world consumption rates. Oil consumption would increase by 106 percent, for instance, and world metal consumption by 94 percent.

If India as well as China were to catch up, world consumption rates would triple. If the whole developing world were suddenly to catch up, world rates would increase elevenfold. It would be as if the world population ballooned to 72 billion people (retaining present consumption rates).

Diamond (2008, p. A21)

Although vehicles are the most salient example, we can expect to see sharp global increases in the consumption of electricity and residential durables ranging from ovens to refrigerators. Cross-national environmental Kuznets curve research (Schmalensee et al. 1998) has demonstrated that per-capita carbon dioxide emissions rise sharply for nations as they make the transition from low income to middle income and then flatten out as national per-capita income increases further. Unlike in the case of urban lead emissions, richer nations do not appear to be much “cleaner” than middle-income nations (Hilton & Levinson 1998).¹ Recent research has examined the relationship between greenhouse gas emissions and per-capita income within major developing countries such as China. Auffhammer & Carson (2008) created a panel data set of 30 Chinese provinces covering the years 1985 to 2004.² They found that a province/year's log of GHG emissions is an increasing and concave function of province/year log of per-capita income.

GHG mitigation represents the ultimate global free-rider problem. Unlike in the case of localized externalities such as urban air pollution or urban water pollution, local and national regulatory authorities have little incentive to regulate such emissions. Even for a nation such as the United States, the basic free-rider logic holds. Sunstein (2007) argued that the fundamental problem is that China and the United States produce roughly 45% of the world's GHG emissions, but that as climate change takes place, these two nations will suffer a much smaller percentage of its costs. If these nations expect to experience large losses from climate change, then they would have a private incentive to mitigate their emissions and to work cooperatively.

This logic has not slowed states such as California from unilaterally pursuing climate change mitigation regulation. In 2006, Governor Arnold Schwarzenegger signed the California Global Warming Solutions Act of 2006 (AB 32). This law commits California to reduce

¹Future microeconomic research should investigate why the marginal increase in GHG is a decreasing function of income. One possible explanation is cobenefits. Consider coal-fired power plants. They emit both GHGs and local pollutants. If their GHG production is reduced, then local air quality also improves and the populace immediately enjoys improvements in public health.

²It is useful to contrast these results with other environmental Kuznets curve studies (see Kahn 2006). For local pollutants such as lead, we know that, as nations grow richer, emissions rise owing to scale effects of more driving using leaded gasoline. As nations grow richer, they enact regulations that lower pollution per mile of driving, and lead emissions start to decline as a function of national income. Hilton & Levinson (1998) demonstrated for a cross section of nations how both scale and technique effects vary as a function of national income. The early environmental Kuznets curve literature argued that a per-capita income turning point exists such that for richer nations economic development is positively correlated with reduced pollution levels. More recent research has documented that this finding is not robust (Harbaugh et al. 2002).

its GHG emissions to 80% below its 1990 levels by 2050. The California Air Resources Board is the regulatory agency charged with meeting this goal. It has proposed a bundle of regulations including increasing commercial and residential building energy efficiency, forcing electric utilities to supply power with an ever-growing share of power generated by renewable energy sources, and making utilities participate in a cap and trade market. California is responsible for only 5.9% of the nation's GHGs despite the fact that roughly 18% of the nation lives in California (<http://www.purdue.edu/eas/carbon/vulcan/research.html>). The United States is responsible for 25% of the world's GHG emissions. Holding the rest of the world's GHG emissions constant, an 80% reduction in California's emissions today would reduce the United States' emissions by 1.18% and the world's emissions by 0.3%. This arithmetic highlights that unilateral action yields small aggregate effects.

Urbanization triggers two offsetting forces. Urbanization slows national population growth through changing fertility patterns.³ This can offset some of the GHG produced as a result of the urban productivity effect. Women have numerous employment opportunities in cities. This encourages women to marry later and delay having their first child. Anticipating that they will live in an urban area with labor market opportunities gives school-age women a greater incentive to invest in their human capital. Given that cities raise women's wages and offer a thick local labor market, women have greater opportunities outside the home. This raises the opportunity cost of having children. Urban land is more expensive than rural land, which provides an incentive for smaller household sizes. Urbanization also facilitates idea generation and diffusion. Proximity enhances the ability of firms to exchange ideas and be cognizant of important new knowledge (Audretsch & Feldman 2004).

3. URBAN ADAPTATION TO CARBON PRICING

The adoption of a credible carbon-trading market, or a carbon tax, could incentivize polluters to change their behavior. These policies could induce innovation to reduce GHG emissions per dollar of output (Metcalfe 2007, Stern 2008).⁴ Despite the fundamental free-rider problem, regional carbon-trading agreements have been implemented in Europe (see Ellerman & Buchner 2007, Kruger et al. 2007) and in North America's East Coast (<http://www.rggi.org/home>) and West Coast (<http://www.westernclimateinitiative.org/Index.cfm>).

If the United States participated in a national cap and trade system, how would cities adapt? Cities differ with respect to their marginal contribution to GHG production. Under the assumption that a ton of carbon dioxide is priced at \$43, Glaeser & Kahn (2008) documented that the marginal social cost of moving a household from a high GHG city such as Houston, Texas, to a low GHG city such as San Francisco, California, is roughly \$600 per year. Relative to a "green city" such as San Francisco, Houston's humid summer climate requires much more electricity consumption for air conditioning. Houston's cheaper housing encourages households to buy more housing and this increases their energy consumption. Houston's low population density and spread out employment means that people rely on private vehicles for transportation and few use public transit.

³For a sociologist's perspective the causal role of urbanization in explaining differential rural/urban fertility, see the work of White et al. (2005).

⁴Metcalfe (2007) based his analysis on a starting tax of \$15 per ton of carbon dioxide. This rises over time such that it equals \$50 in year 2005 dollars by the year 2050. This is a much smaller number than Stern's (2008) estimate of a marginal social damage cost of \$85 per ton of carbon dioxide.

Houston's electricity is generated by dirtier power plants than those which generate San Francisco's electricity. A majority of California's power plants are fired by natural gas rather than the dirtier coal used by other power plants. The study by Glaeser & Kahn (2008) quantifies cross-city differences at a point in time (year 2000). How this ranking of cities would change in the presence of a carbon tax and how these city rankings compare in developing countries such as China and India remain open questions. The baseline carbon production differentials between cities such as San Francisco and Houston indicate that the adoption of carbon pricing would be capitalized into local land prices and wages. All else being equal, San Francisco's rents would rise relative to Houston's.

The durability of residential and commercial buildings introduces differential effects from carbon pricing in booming cities versus declining cities. Consider growing cities in the western United States such as Las Vegas, Nevada, and Phoenix, Arizona. As these cities grow, new residential and commercial buildings will be constructed. Facing a carbon tax, real estate developers will have incentives to produce buildings whose marginal energy consumption is less than the incumbent capital stock's average. Contrast these growing cities with shrinking cities such as Buffalo, New York, and Detroit, Michigan. In such cities with very cold weather and low amenities, there is little new construction. In the face of carbon pricing, two possible outcomes emerge: One possibility is that carbon pricing will accelerate the demolition of older energy-inefficient buildings. This logic is similar to the claim of how higher gas prices affect the scrappage rate of used sport utility vehicles. This is especially likely in cities whose power is generated by coal-fired power plants. Whether real estate owners in declining cities will make significant investments in retrofitting existing buildings to improve their energy efficiency is an open question. This hinges on whether energy efficiency investments are capitalized into real estate prices and what are the short-term present discounted value of electricity expenditure savings. In a booming city, the real estate owner who chooses to retrofit an existing building gains the short-run electricity expenditure savings and will gain from the capitalization effect upon selling the asset. The present discounted value of these two terms will be compared with the cost today of retrofitting the building. Such retrofit costs are unlikely to vary across cities.

Another possibility is that carbon pricing will encourage densification within cities and more people will live closer to the city center. How large could these effects be? The 1970s OPEC oil shocks provided one "natural experiment." Urban economists do not believe that this increase in the price of gasoline pushed many people to live in the center cities. Instead, people responded by purchasing smaller, more fuel-efficient vehicles. Today, urban economists are celebrating the high quality of life in consumer center cities (Glaeser et al. 2001). Recent reductions in crime have dramatically improved center-city quality of life (Levitt 2004). Reyes (2007) predicts that crime rates will continue to decline.⁵ Street safety and high gas prices both encourage people to live in new urbanistic walking

⁵She argues that urban lead exposure is a key determinant of crime. In a nutshell, she argues that, in the 1950s, an increasing number of households were buying cars fueled by leaded gasoline and driving them around their new suburban homes. Although no individual car driver intended to pollute the air, an unintended consequence of rising leaded-gasoline consumption was elevated lead levels. This created public health problems as exposed children suffered from IQ loss and were more prone to attention deficit disorder. The criminology literature has documented that these two factors increase a person's likelihood of becoming a criminal. Indeed, urban crime levels increased from the 1950s to the 1970s. Then, in the early 1970s, the U.S Environmental Protection Agency started its regulatory efforts. With fewer vehicles using leaded gasoline, ambient lead emissions declined, so children born after 1972 were exposed to less ambient lead. And as they became adults (starting in the early 1990s), they committed fewer crimes relative to earlier cohorts.

communities. Weak urban public schools appear to be the last hurdle discouraging adults with young children from living in center cities.

Carbon pricing would encourage electric utilities to rely less on coal-fired power. Based on year 2004 data from the Environmental Protection Agency's EGRID database, the average emissions factor for coal-fired power plants is 50% higher than the average emissions factor for noncoal-fired power plants (see <http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html>). U.S. states in regions such as the South East feature high average-emitting power plants. In the presence of carbon pricing, these electric utilities would have a strong incentive to change the composition of their power generation and to green their techniques. A health benefit of these efforts is that local air pollution would decline. A cobenefit of taxing carbon dioxide is that ambient pollution from coal-fired power plants would fall. Major cities close to coal-fired power plants would enjoy an improvement in local ambient air quality as these plants cleaned up their emissions.

Policy makers such as the California Air Resources Board, the agency responsible for meeting the goals set in AB 32, have voiced tremendous optimism that carbon pricing will offer a "free lunch" as households and firms will experience a net reduction in the present discounted value of their electricity expenditures (http://www.arb.ca.gov/cc/scopingplan/document/economic_appendix1.pdf). Such environmental regulators are implicitly embracing a behavioral economics viewpoint that, in the absence of carbon pricing and carbon regulation, households and firms would simply satisfice rather than ruthlessly minimize their electricity expenditures. This claim, which appears to be a close cousin of the Porter Hypothesis, merits further research to test whether real-world consumers and firms need regulatory mandates to push them to make energy efficiency investments that have negative net costs. The California Air Resources Board has also argued that its requirements that electric utilities sharply increase the percentage of their power generated by renewables will catalyze new "green" industry corridors in major cities such as Los Angeles and San Francisco. If firms enjoy sharp learning-by-doing effects such that their costs decline as a function of cumulative experience, then government mandates that require green technologies can help to jump start new urban cores. Whether a new green jobs cluster similar to Silicon Valley emerges remains an open question. If the U.S. government adopts anticarbon measures, then this would create a demand-side push that would encourage such green innovation.

4. URBAN ADAPTATION TO CLIMATE CHANGE IN THE UNITED STATES

Even if we could reduce our GHG emissions to zero starting today, we will still experience the consequences of climate change. Relative to a rural agricultural world economy, will we suffer less because we live in cities? Is an urban household insulated from the effects of climate change relative to rural households? Urban households live an indoor life where one's productivity is not a function of outdoor climate. In contrast, farmers know that the quantity and quality of their output is directly related to climate.

Climate change will shift the distribution of temperature and rainfall by varying amounts in different locations. Given that urbanites value quality of life, it is important to consider which cities in the United States will be net "winners" and "losers" as a result of changes in the climate amenity bundle. Quality of life is a key determinant of which cities attract the skilled. The greater number of highly skilled people living in San Francisco

than in Detroit must be a function of selective migration rather than any inherent productivity effect from living in San Francisco. From this, we can predict that “consumer cities” with a high quality of life will attract the skilled and thus experience economic growth (Shapiro 2006, Glaeser & Gottlieb 2006, Glaeser et al. 2001).

But this raises the issue, what determines a city’s quality of life? Admirers of San Francisco would point to its temperate climate, low pollution levels, amenity beauty, and low crime levels as major attractors. For a city such as San Francisco, climate change will shift its average monthly climate and rainfall. This, in turn, will expose the population to greater air pollution levels as pollutants such as ozone reach their highest levels in the summer heat.

Given the predictability of these climate changes, compensating differentials theory predicts that cities that are now exposed to cooler winters and warmer summers will experience declining home prices and rising wages (Blomquist et al. 1988, Gyourko & Tracy 1991). This logic is based on an open-city model where households can vote with their feet and migrate across cities. If migration costs are zero, spatially tied attributes such as climate will be capitalized into wages and rents such that the marginal household becomes indifferent about living in a “nice” city as opposed to one with a low quality of life. Climate change is likely to change this spatial equilibrium.

To investigate the possible size of these effects, I use county level data from the year 2000 Census of Population and Housing. I estimate some simple hedonic home-price regressions. The dependent variable is the county’s average home price. I control for no explanatory variables except for a vector of county climate variables. Provided by Olivier Deschenes, these climate data are also used in other work by Deschenes & Greenstone (2007a,b). In the regressions here, the key explanatory variables are a county’s average temperature and average rainfall, both measured in January and July from 1968 to 2000. Table 1 shows one ordinary least squares regressions based on Equation 1.

Table 1 Cross-county hedonic home price regression (year 2000)^a

	Beta ^b	t-stat
January rainfall (measured in inches)	36339.89	11.37
January rainfall squared	-4236.50	-11.42
January temperature (degrees F)	1608.20	5.53
July rainfall	-22834.13	-5.64
July rainfall squared	1566.56	2.85
July temperature	-6527.14	-13.09
Constant	595167.40	19.97
Observations	3105	
R2	0.282	

^aRegressions weighted by county for population in year 2000. See Equation 1 in the text. The unit of analysis is a county. The dependent variable is the average home price in the county.

^bThis table reports ordinary least squares regression coefficients (Beta) and each regression coefficient estimate’s t-statistic (t-stat).

$$\text{Home Price}_i = \alpha + \beta * \text{Climate}_j + \varepsilon_j. \quad (1)$$

I take the ordinary least squares estimates of β and use these as index weights. These index weights represent the marginal valuation of winter and summer temperature and rainfall in the year 2000.

Climate researchers have developed two different models of climate change's predicted effects for future temperature and rainfall by month by county: the CCSM Model and the H3A1FI Model (for more details, see Deschenes & Greenstone 2007a,b). These models yield county-level predictions over average temperature and rainfall by month between 2070 and 2099. I average the two sets of county-level predictions and use the average January and July predictions for rainfall and temperature. Define this vector of future county climate conditions as $\text{Climate}_{j\text{future}}$ and define the historical county climate conditions as $\text{Climate}_{j\text{past}}$. I then calculate for each county j , the predicted climate change index:

$$\text{climate change (measured in dollars)} = \beta * (\text{Climate}_{j\text{future}} - \text{Climate}_{j\text{past}}). \quad (2)$$

The estimate of β is based on estimates of Equation 1 (see Table 1, column 1). I calculate this dollar climate hedonic index for each county and then aggregate this to the metropolitan area level using the county's year 2000 population level as the weight. Intuitively, this index, measured in dollars, represents the expected dollar gain in metropolitan area quality of life as a result of climate change. Positive values of this index indicate metropolitan areas whose climate quality of life is expected to improve owing to climate change, and negative values indicate expected climate quality of life losses. In Table 2, I report the climate index change for all 53 U.S. metropolitan areas that had more than 1 million

Table 2 Predicted change in the climate bundle amenity (2000 to 2080)^a

Metropolitan area	MSA code ^b	Predicted change in the MSA's climate index ^c
Las Vegas, Nevada	4120	19971
Fort Lauderdale, Florida	2680	12109
West Palm Beach, Florida	8960	406
Tampa, Florida	8280	-10313
Orlando, Florida	5960	-11068
Phoenix, Arizona	6200	-17586
Portland, Oregon	6440	-20945
New Orleans, Louisiana	5560	-26613
Norfolk, Virginia	5720	-32457
Minneapolis, Minnesota	5120	-39151
Detroit, Michigan	2160	-41211
Rochester, New York	6840	-41702
New York City	5600	-42546
Milwaukee, Wisconsin	5080	-43401

Table 2 (cont.)

Metropolitan area	MSA code ^b	Predicted change in the MSA's climate index ^c
Jacksonville, Florida	3600	-45006
New Haven, Connecticut	5483	-48817
Sacramento, California	6920	-50724
Baltimore, Maryland	720	-50825
Hartford, Connecticut	3283	-51877
Salt Lake City, Utah	7160	-52006
Buffalo, New York	1280	-52587
Philadelphia, Pennsylvania	6160	-53649
Houston, Texas	3360	-53815
San Jose, California	7400	-54637
Cleveland, Ohio	1680	-54663
Boston, Massachusetts	1123	-54687
Washington, D.C.	8840	-54708
Denver, Colorado	2080	-57849
Seattle, Washington	7600	-59214
Chicago, Illinois	1600	-61211
Pittsburgh, Pennsylvania	6280	-61908
Columbus, Ohio	1840	-64360
San Antonio, Texas	7240	-67724
Raleigh, North Carolina	6640	-68573
Charlotte, North Carolina	1520	-71427
Greensborough, North Carolina	3120	-74576
Atlanta, Georgia	520	-75238
Indianapolis, Indiana	3480	-75335
Cincinnati, Ohio	1640	-77526
San Francisco, California	7360	-78052
Austin, Texas	640	-80162
Kansas City, Missouri	3760	-81612
Louisville, Kentucky	4520	-84651
Fort Worth, Texas	2800	-88857
St. Louis, Missouri	7040	-89137

Table 2 (cont.)

Metropolitan area	MSA code ^b	Predicted change in the MSA's climate index ^c
Dallas, Texas	1920	-89643
Nashville, Tennessee	5360	-93787
Memphis, Tennessee	4920	-97437
Oklahoma City, Oklahoma	5880	-98875
Orange County, California	5945	-127702
Los Angeles, California	4480	-128733
Riverside, California	6780	-136823
San Diego, California	7320	-144351

^aFor reference, see Equation 2 in text.

^bMSA, metropolitan statistical area.

^cValues are all in year 2000 dollars.

people in the year 2000. As a home owner in Los Angeles, California, I am struck by the bottom rows of the matrix: Los Angeles will suffer one of the largest climate amenity losses due to climate change. A look at the raw data reveals the issue. During the historical time period, Los Angeles was blessed with an average August temperature of 75°F. The climate change models are predicting that this area's mean temperature will rise to 90°F by the late twenty-first century.

Climate change will have a differential impact on major-city quality of life. Table 2 highlights that all of the cities in Southern California are expected to suffer a sharp climate amenity loss due to climate change. In contrast, cities in Florida will experience an improvement in their climate bundle as winter temperatures increase (an amenity) and summer average temperatures rise relatively little. Only three major U.S. metropolitan areas are expected to experience an improvement in their climate bundle due to climate change. Relative real estate prices will adjust to reflect these underlying changes in climate amenities. These effects could be quite large. The average home price in the year 2000 for Los Angeles County was \$286,632.8. Thus, the predicted amenity decline of \$128,773 reported in Table 2 represents more than a 50% decline! The climate models are predicting that Los Angeles will have a similar climate amenity bundle as Jacksonville, Florida, by the year 2070.

Climate is just one dimension of risks that cities face owing to climate change. Warmer summer temperatures will raise urban ozone smog levels, and this will reverse some of the recent gains in big-city smog progress (<http://www.epa.gov/airtrends>). Cities also differ with respect to whether they are located on a coast and thus at risk for flooding. All over the United States, people are moving to the coasts (Rapaport & Sachs 2003). As population increases in coastal areas, resulting in more construction, are assets at risk? Pielke and coauthors (Pielke & Downton 2000, Pielke et al. 2008) have documented that population locational trends have increased the risk that more people and capital will be destroyed by floods and hurricanes.

Data indicate that certain coastal cities now face increased risk of flooding due to climate change—think of New Orleans, Louisiana. But are these low-probability events salient enough and large enough to be capitalized into the cross-city hedonic wage and real

estate gradients? Risk perception plays a key role in determining the incidence of the amenity dynamics induced by climate change. If safer, more pleasant cities do not command a real estate premium, then land owners in such cities are not enjoying the rents from this dimension of city quality. Conversely, if at-risk cities feature a sharp capitalization effect, then this could affect population sorting. Such cities may be more likely to attract the poor as well as risk lovers.

Experience has shown that government interventions can help cities self-protect against shocks posed by climate change. Although government cannot change the weather, engineering investments such as improved levees help to reduce the risks posed by storms. In the presence of Knightian uncertainty, how do we estimate the expected present discounted value of the benefits we gain from making such engineering investments versus delaying such an investment? Weitzman (2009) sketched some alarming right-tail, low-probability events associated with climate change.

Government investment in city protection can have important implications for the spatial distribution of investment and human capital across a nation. Kousky et al. (2006) offered a useful framework. They modeled the noncooperative investments of the private sector and a government that both recognize that their investments are complementary. For example, suppose that the private sector must decide whether to make an irreversible investment in a new hotel. The government must decide whether to invest in sea walls that reduce the probability of climate change-induced flood. If the private investor believes that the government will build the sea wall, then the expected benefits of building the hotel increase. Symmetrically, if the government believes that the hotel will be built, then its incentive to build the sea wall also increases as more physical assets are now in need of protection. This scenario presents an implicit moral hazard problem. If people and capital that would have self-protected and located in a “safe city” such as St. Louis, Missouri, now locate in New Orleans because they trust that government will invest and protect them, then the government’s activism will crowd out self-protection and more people will be at risk from the climate change shock. If the sea walls have a positive probability of crumbling due to Mother Nature’s blows, then the *ex post* costs of government activism can be large.

In terms of political economy, politicians based in at-risk areas (e.g., New Orleans) such as mayors and congressional representatives have strong incentives to attract resources to build up their city (Glaeser & Gottlieb 2008). They will lobby for federal financing of local public goods such as sea walls. Indeed, major public transit infrastructure projects such as urban subway systems receive subsidies of up to 80%. The Boston Big Dig is a famous example. But do such investments encourage efficiency or do they breed moral hazard effects as more people move to coastal areas because they feel safe as a result of government investments? If significant federal resources are used to provide local public goods for specific cities, then this will be a redistribution from tax payers in safe cities to tax payers in at-risk areas. This raises efficiency and equity issues.

An interesting, but potentially costly, game of “chicken” could arise. Suppose that cities such as New Orleans want improved sea walls but they want the federal government to pay for them. These cities have an incentive to delay constructing such capital-intensive projects. If they delay, then can pass the costs on to the federal government. Thus, in the short run, they face more climate risk because they are not prepared should disaster strike. An alternative financing approach would be to tax local land owners. In an economy with low cross-city migration costs, urban land owners bear the incidence of improvements in public goods.

Cities that could suffer from the effects of climate change can use public policies and market incentives to reduce *ex ante* risk taking and reduce the costs of adaptation. Cities can use zoning laws to discourage high-density development in at-risk areas. If property insurance prices reflect actuarial risk, then this would discourage building in flood zones and fire zones. Climate change is likely to increase the frequency and severity of such events. Insurance is a regulated market. Whereas economists may support price discrimination such that at-risk areas feature higher insurance premiums, citizens may complain that this is “price gouging.” The government may have to provide insurance policies to the public if for private firms think that they cannot earn profits in the face of potential regulation (Ross et al. 2007). If governments do not allow the insurance industry to engage in price discrimination, then the *ex post* costs of adaptation will be higher.

An important open question concerns how the population forms subjective expectations over the likelihood of low-probability “bad states of nature.” For example, if coastal residents believe that horrific floods never take place, then they will take no precautions against such events. If urbanites form rational expectations regarding the likelihood of future disasters, then real estate prices will be low in areas that face greater risk. This would induce sorting such that risk lovers and the poor would live in the at-risk areas. However, if the public is unaware of the actuarial risk, then the government has a paternalistic justification for investing in public self-protection. An open issue is whether voters will view such investments positively, or if they need to experience additional salient events such as a Hurricane Katrina before they are willing to support costly self-protection investment? The answer partially hinges on whether voters believe climate scientists. If the public views these scientists as alarmists who have been wrong about past predictions, then the government may respond by underinvesting in public self-protection and the public will also underinvest in private self-protection as they underestimate the true threat posed by climate change.

5. ADAPTATION IN CITIES IN DEVELOPING NATIONS

Cities in least developed countries face two additional adaptation challenges. One is the rural to urban migration accelerated by climate change. The other is the increased risks of disease, pollution exposure, and natural disaster faced by informal urban squatters. The following sections sketch the likely consequences of these patterns and suggest a research agenda.

5.1. Rural to Urban Migration

In developing nations, many more people live in rural areas. Many of these people may move to nearby cities if the income they earn from farming declines owing to climate change. Barrios et al. (2006) report that climatic change, as proxied by rainfall, has affected urbanization in Sub-Saharan Africa but not elsewhere in the developing world. Decolonization, which has removed legislation prohibiting the free internal movement of native Africans, has further strengthened this link. In a Harris-Todaro expected utility framework, climate change provides a push from farming areas as previously profitable areas experience a reduction in profitability. An active agricultural economics literature has examined how farmer profitability varies as a function of climate (see the work of Mendelsohn & Dinar 1999). One optimistic claim is that farmers currently suffer less from climate variability than they did in the past. The simplest static expected-income

calculation comparison would yield a locational decision rule stating that a farmer should move to the city given the following:

$$\text{Profits farming} \leq (\text{probability find job}) * \text{urban wage} - \text{migration cost} - \text{urban rent} \quad (3)$$

In the short term, climate change will lower farming profits, thereby encouraging urbanization. In the medium term, such migration may have general equilibrium effects. As farmers urbanize, equilibrium urban wages will decline and urban rents will increase. These changes in factor prices will slow migration.

5.2. Risks to Urban Poor

Climate change also poses a set of risks to the urban poor. Heat waves, exposure to high levels of urban smog, and climate-related events such as floods and mudslides all threaten this vulnerable group.⁶ In the developing world, city governments are not providing high-quality services. Comparative research has documented that governance quality is worse in poorer nations (La Porta et al. 1999). If local governments do not have the revenue to provide basic services such as clean water and sanitation for a growing urban population, then climate change-induced “environmental refugees” can help to unintentionally trigger local urban quality of life challenges. In such nations, the urban poor face the greatest risks from climate change-induced events such as heat waves and flooding. Relative to richer households, they have less access to medical services and household durables to offset climate exposure (e.g., air conditioning, refrigeration). Facing the land price gradient, the poor choose to live in the lowest quality, least desirable parts of the city where rents are low. The inability of the poor to defend themselves from climate change matters because local governments in developing countries are least likely to have financial resources to provide public goods to protect the local population. Such governments are also likely to be unresponsive to the needs of informal squatters who are unlikely to vote.

International research continues to investigate which cities are the “hot spots” of climate risk. A recent OECD study of 130 cities states that merely 10 cities in the world today account for half of the total world exposure to coastal flooding. These cities include the following: Kolkata and Mumbai in India; Dhaka, Bangladesh; Guangzhou, China; Ho Chi Minh City, Vietnam; Shanghai, China; Bangkok, Thailand; Rangoon (Myanmar), Burma; Miami, Florida, United States; and Hai Phong, Vietnam (Nicholls et al. 2008). Future research should examine whether these cities are investing in self-protection (e.g., sea walls) against flooding or are taking proactive steps to move the population away from areas at the highest risk from flooding.

6. CONCLUSION

Relatively little economic research has focused on cities and climate change. This paper argues that the role of cities in causing climate change and the impact that climate change will have on different types of cities represent first-order issues at the intersection of

⁶In recent work, I have documented that richer nations suffer fewer deaths from natural disasters than do poorer nations (see Kahn 2005). I argued that income is associated with a higher quality capital stock, better functioning government, and greater medical resources to treat those affected by natural disasters.

environmental and urban economics. After all, urban growth fuels income growth. As people around the world achieve the “American Dream,” an unintended consequence is increased per-capita GHG production. Such scale effects unleashed by capitalism suggest that city growth is causing climate change. But, city growth also helps to slow population growth and accelerate technological innovation and diffusion. In a world without explicit carbon pricing, the net effect of urbanization is GHG growth. This paper offers a set of conjectures for how cities will be affected by the introduction of carbon pricing. The investigation of such incentive pricing in both developed and least-developed cities represents an important topic for future research.

This paper also examines how city quality of life will be affected by climate change. Adaptation to climate change can take place at the individual, city, and national level. Strategic interactions among these three sectors merit future research. Under plausible scenarios, government *ex ante* investments in self-protection (i.e., sea walls) will crowd out self-protection of private individuals and firms.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

- Auffhammer M, Carson RT. 2008. Forecasting the path of China’s CO2 emissions using province-level information. *J. Environ. Econ. Manag.* 55:229–47
- Audretsch D, Feldman MP. 2004. Knowledge spillovers and the geography of innovation. Vol. 4. In *Handbook of Urban and Regional Economics*, ed. JV Henderson, JF Thisse, 4:2713–39. Amsterdam: Elsevier
- Barrios S, Bertinelli L, Strobl E. 2006. Climatic change and rural-urban migration: the case of Sub-Saharan Africa. *J. Urban Econ.* 60:357–71
- Blomquist G, Berger M, Hoen J. 1988. New estimates of quality of life in urban areas. *Am. Econ. Rev.* 78:89–107
- Cragg M, Kahn ME. 2009. *Carbon geography: the political economy of congressional support for legislation intended to mitigate greenhouse gas production*. Work. Pap. 13178, NBER
- Deschenes O, Greenstone M. 2007a. *Climate change, mortality and adaptation: evidence from annual fluctuations in weather in the US*. Work. Pap. 13178, NBER
- Deschenes O, Greenstone M. 2007b. The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *Am. Econ. Rev.* 97(1):354–85
- Diamond J. What’s your consumption factor? *New York Times*. Jan. 2: Op-Ed. http://www.nytimes.com/2008/01/02/opinion/02diamond.html?_r=1&oref=slogin&pagewanted=print January 2, 2008
- Duranton G, Puga D. 2001. Nursery cities: urban diversity, process innovation, and the life cycle of products. *Am. Econ. Rev.* 91(5):1454–77
- Ellerman AD, Buchner BK. 2007. The European Union emissions trading scheme: origins, allocation, and early results. *Rev. Environ. Econ. Policy* 1(1):66–87
- Gately D, Huntington HG. 2001. *The asymmetric effects of changes in price and income on energy and oil demand*. Work. Pap., Stanford Univ. <http://www.stanford.edu/group/EMF/publications/doc/OP50.pdf>
- Glaeser E, Kahn ME. 2008. *The greenness of cities: carbon dioxide emissions and urban development*. Work. Pap. 14238, NBER

- Glaeser E, Kolko J, Saiz A. 2001. Consumer city. *J. Econ. Geogr.* 1(1):27–50
- Glaeser EL. 1998. Are cities dying? *J. Econ. Perspect.* 12(2):139–60
- Glaeser EL, Gottlieb J. 2006. Urban resurgence and the consumer city. *Urban Stud.* 43(8):1275–99
- Glaeser EL, Gottlieb J. 2008. *The economics of place-making policies*. Work. Pap. 14373, NBER
- Glaeser EL, Mare DC. 2001. Cities and skills. *J. Labor Econ.* 19(2):316–42
- Gyourko J, Tracy J. 1991. The structure of local public finance and the quality of life. *J. Polit. Econ.* 91(4):774–806
- Hansen J, Sato M, Kharecha P, Beerling D, Masson-Delmotte V, et al. 2008. *Target atmosphere CO₂; where should humanity aim?* Work. Pap., Columbia Univ. http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf
- Harbaugh W, Levinson A, Wilson D. 2002. Re-examining the empirical evidence for an environmental Kuznets curve. *Rev. Econ. Stat.* 84(3):541–51
- Hilton FGH, Levinson A. 1998. Factoring the environmental Kuznets curve: evidence from automotive lead emissions. *J. Environ. Econ. Manag.* 35(2):126–41
- Kahn ME. 2005. The death toll from natural disasters: the role of income, geography and institutions. *Rev. Econ. Stat.* 87(2):271–84
- Kahn ME. 2006. *Green Cities: Urban Growth and the Environment*. Washington, DC: Brook. Inst. Press
- Kousky C, Luttmer E, Zeckhauser R. 2006. Private investment and government protection. *J. Risk Uncertain.* 33(1):73–100
- Kruger J, Oates WE, Pizer WA. 2007. Decentralization in the EU emissions trading scheme and lessons for global policy. *Rev. Environ. Econ. Policy* 1(1):112–33
- La Porta R, Lopez-de-Silanes F, Shleifer A, Vishny R. 1999. The quality of government. *J. Law Econ. Organ.* 15(1):222–79
- Levitt SD. 2004. Understanding why crime fell in the 1990s: four factors that explain the decline and six that do not. *J. Econ. Perspect.* 18(1):1673–190
- Mendelsohn R, Dinar A. 1999. Climate change, agriculture, and developing countries: does adaptation matter? *World Bank Res. Obs.* 14(2):277–93
- Metcalf G. 2007. *A proposal for a U.S carbon tax swap*. Work. Pap. 2007-12, Hamilton Proj., Brook. Inst.
- Nicholls RJ, Hanson S, Herweijer C, Patmore N, Hallegatte S, et al. 2008. *Ranking port cities with high exposure and vulnerability to climate extremes: exposure estimates*. Work. Pap. 1, OECD Environ.
- Nordhaus W. 1979. *The efficient use of energy resources*, Cowles Monogr., Yale Univ. Press
- Pielke RA Jr, Downton MW. 2000. Precipitation and damaging floods: trends in the United States, 1932–97. *J. Clim.* 13(20):3625–37
- Pielke RA Jr, Gratz J, Landsea CW, Collins D, Saunders MA, Musulin R. 2008. Normalized hurricane damage in the United States: 1900–2005. *Nat. Hazards Rev.* 9(1):29–42
- Rapaport J, Sachs J. 2003. The United States as a coastal nation. *J. Econ. Growth.* 8:5–46
- Reyes JW. 2007. Environmental policy as social policy? The impact of childhood lead exposure on crime. *B.E. J. Econ. Anal. Policy* 7(1): artic. 51
- Ross C, Mills E, Hecht S. 2007. *Limiting liability in the greenhouse: insurance risk management strategies in the context of global climate change*. Res. Pap. Ser. 07-18, Sch. Law, Univ. Calif. Los Angeles
- Schmalensee R, Stoker T, Judson R. 1998. World carbon dioxide emissions: 1950–2050. *Rev. Econ. Stat.* 80(1):15–28
- Shapiro J. 2006. Smart cities: quality of life, productivity, and the growth effects of human capital. *Rev. Econ. Stat.* 88:324–35
- Stern N. 2008. The economics of climate change. *Am. Econ. Rev.* 98(2):1–37
- Sunstein C. 2007. *The complex climate change incentives of China and the United States*. Work. Pap., SSRN

- Pacala S, Socolow R. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305:968–72
- United Nations 2004. *World population prospects: the 2004 Revision Population Database*. esa.un.org/unpp
- Weitzman M. 2009. On modeling and interpreting the economics of catastrophic climate change. *Rev. Econ. Stat.* 91:1–19
- White M, Tagoe E, Stiff C, Adazu K, Smith D. 2005. Urbanization and the fertility transition in Ghana. *Popul. Res. Policy Rev.* 24:59–83