CHAPTER 7

Cities and the Environment

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Abstract

This chapter surveys recent literature examining the relationship between environmental amenities and urban growth. In this survey, we focus on the role of both exogenous attributes such as climate and coastal access and endogenous attributes such as local air pollution and green space. A city's greenness is a function of its natural beauty and is an emergent property of the types of households and firms that locate within its borders and the types of local and national regulations enacted by voters.

We explore four main issues related to sustainability and environmental quality in cities. First, we introduce a household locational choice model to highlight the role that environmental amenities play in shaping where households locate within a city. We then analyze how ongoing suburbanization affects the carbon footprint of cities. Third, we explore how the system of cities is affected by urban environmental amenity dynamics and we explore the causes of these dynamics. Fourth, we review the recent literature on the private costs and benefits of investing in “green” buildings. Throughout this survey, we pay careful attention to empirical research approaches and highlight what are open research questions. While much of the literature focuses on cities in the developed world, we anticipate that similar issues will be of increased interest in developing nation's cities.

Keywords

Urban economics, Cities, Environment, Carbon policy, Equilibrium sorting, Climate change, Green infrastructure

JEL Classification Codes

H4, Q5, O3, R1

7.1. INTRODUCTION

Both within cities and across cities, nonmarket amenities are an important determinant of where people choose to live and work. While we now spend more time online as we shop on Amazon, socialize on Facebook and Twitter, stream movies from Netflix, and telecommute from home, our physical location continues to define what place-based attributes we enjoy and the environmental conditions to which we are exposed.

Certain locational attributes such as rivers and ocean ports that were once key determinants of local productivity now play a central role as amenities offering unique views as well as recreational and climate amenities. Today, the Ritz-Carlton in Battery Park on the south tip of Manhattan is selling apartments for over $1300 a square foot. This price premium reflects the desirability of waterfront real estate in modern Manhattan. A majority of the US population and income are clustered in counties within 80 km of a coast or the Great Lakes (Rappaport and Sachs, 2003). This concentration of economic activity along the coasts and major rivers is a function of both the historical persistence of early settlement patterns and the key role that transportation access played in determining the locations of early waves of industrial activity (Bleakley and Lin, 2012).

The persistence of these coastal patterns today is in no small part supported by the environmental amenities conveyed by proximity to rivers and coasts and the climate amenities enjoyed by those living on or near the coast. In coastal cities such as Los Angeles, richer people consistently live close to the beach, and thus, there has been less suburbanization of income than in noncoastal metropolitan areas (Lee and Lin, 2013).

Today, nonmarket amenities such as clean air, green spaces, temperate climate, and safe streets help fuel the modern consumer city (Glaeser et al., 2000; Rappaport, 2009). Consumer preferences for these amenities draw wealthier individuals to attractive locations, a trend that is reinforced by employers (much freer of resource- and transportation-related locational constraints than were their predecessors) who choose to locate in high-amenity locations as a way to be more attractive to potential employees. At the same time that cities such as London and San Francisco are experiencing sharp increases in their home prices, there are other cities such as Las Vegas and Phoenix whose population levels continue to grow. Even though these places are not blessed with naturally high levels of amenities, millions of people are expressing a desire to live in such cities. Home prices and wages adjust in the spatial equilibrium and the diverse population and firms sort across space. While some middle-class households will be disappointed that they cannot afford coastal housing, there will be other households with a taste for large new housing who are quite willing to live in an affordable city such as Las Vegas.

At any point in time, a geographic area's environmental attributes are a function of exogenous geography and determined by the (intended and unintended) choices made by the set of households, voters, and industries that cluster within the city. Households and firms trade off the private benefits of a specific location's attributes versus what they must pay in rents to locate there. Given that higher-quality neighborhoods and cities will require a rent premium means that such areas self-select a subset of households and firms to locate there. Expensive high-amenity areas such as Berkeley, California, and Portland, Oregon, attract highly educated individuals. The Tiebout sorting of like-minded progressive environmentalists attracts local firms who cater to such consumers (i.e., organic farmers' markets). The net effect is that green cities emerge due to both selection and treatment effects. Cities such as San Francisco feature few dirty heavy industries. Instead, the "golden goose" for these high-quality-of-life cities tends to be high-tech companies who, in turn, employ workers who demand high-quality local amenities. Such worker/voters support local leaders who enact policies that further enhance local quality of life, and this process feeds on itself as a type of social multiplier effect (Sieg et al., 2004; Bayer et al., 2007).

This causal link between exogenous amenities (i.e., San Francisco's unique coastal beauty) and endogenous amenities (San Francisco becoming a center of green living) is one of the main themes of this chapter. These synergies pose a challenge for empirical research seeking to measure the marginal willingness to pay for individual local public goods such as air quality improvements. As one local public good improves (perhaps due to local deindustrialization), this will induce a resorting of heterogeneous households and firms such that several aspects of local quality of life will be affected (Kuminoff et al., 2013). Our survey investigates different approaches for addressing this issue.

We explore four main issues related to sustainability and environmental quality in cities. First, we introduce a household locational choice model to highlight the role that environmental amenities play in shaping where households locate within a city. We discuss how the four major recent changes in the US cities, improvements in air quality, rising demand for open space, brownfield remediation, and improvements in center city quality of life influence where and how densely different income groups live within metro areas. Second, we analyze how ongoing suburbanization affects the carbon footprint of cities. Whether this association between suburbanization and carbon production represents a causal effect remains an open question. We discuss various identification strategies for convincingly answering this question.

Third, we explore the causes and consequences of urban environmental amenity dynamics. A city's production of pollution depends on its demographics, industrial structure shifts, and the local and national policies that are adopted. As local public goods shift over time (i.e., Pittsburgh's air quality improves), we seek to understand how such amenity dynamics affect the cross city spatial equilibrium. Unlike standard hedonic analyses, we discuss the cross city sorting of both households and firms and the role that environmental amenities play in this locational decision. We explore how new local and federal policies (i.e., local zoning and differential enforcement of the Clean Air Act) affect the spatial equilibrium, and we study how the emerging new risk of climate change and the resulting increase in summer temperature and sea level rise for coastal cities affects the system of cities. Any change in local public goods introduces distributional effects. We explore the economic incidence of changes in quality of life in different cities and their implications for the well-being of rich, middle-class, and poor urbanites.

While much of the empirical quality of life literature has focused on the United States, we argue that these same issues arise in developing countries as economic development increases the demand for nonmarket amenities. This section ends by discussing open research questions set in the developing world.

Finally, we review the recent literature on the private costs and benefits of investing in "green buildings." In the developing world today, billions of people are moving to cities. Such cities are constructing new residential and commercial real estate that will last for decades. Given that buildings are major consumers of electricity, it is important to understand how urban real estate developers, investors, and real estate tenants demand electricity because these decisions have key implications for greenhouse gas production and thus the severity of future climate change.

7.2. INCORPORATING LOCAL AND GLOBAL ENVIRONMENTAL EXTERNALITIES INTO LOCATIONAL EQUILIBRIUM MODELS

In this section, we present an equilibrium locational choice model to study the role that location-specific environmental amenities play in determining who lives in a given area. The model melds ideas from earlier work including Ellickson (1971), Stull (1974), Epple and Platt (1998), Epple and Sieg (1999), Sieg et al. (2004), and Banzhaf and Walsh (2008).

Assume there exists a continuum of households of measure N that are characterized by their income y, the distribution of which is given by $f(y)$, which has continuous support over the interval $[yl, yh]$. In cases where income heterogeneity is of second-order concern, we will often assume that $[yl, yh] = \overline{Y}$ such that all households share the same income level. Location choices are discretized and each household must choose to live in one of J discrete locations within the metropolitan area,[1] indexed by $j \in \{1, \ldots, J\}$. Conditional on location choice, households then choose their optimal level of land to consume.[2]

Household preferences are represented by the indirect utility function $V(y,P_j,Z_j)$, where P_j is the price of a unit of housing at location j and $Z_j = [Z_1, \ldots, Z_k]$ is a vector of amenities available uniquely to households that choose to live at location j. This vector consists of local public goods that are and are not related to the environment. It includes exogenous environmental locational attributes such as distance to beaches and climate and endogenous environmental amenities such as pollution and protected open space. The elements of Z also include access to employment opportunities and nonenvironmental amenities such as crime and school quality.[3] Finally, each location within the metropolitan area is characterized by a continuous housing supply function $S_j(P)$.[4] This is a

[1] Note that in some models, locations are modeled as continuously varying along certain amenity attributes, the canonical example of this approach being the basic monocentric city model that describes continuously varying locations in terms of their distance from the central business district.

[2] Alternatively, one could assume that land is used as one input in the production of housing with, for instance, a constant returns to scale technology. However, while tractable, this approach adds an extra notational burden without changing the general intuition that the model provides relative to the role of prices and incomes in determining population density.

[3] The specification of $V(.)$ also implicitly assumes the inclusion of a numeraire whose price is normalized to 1. For tractability, $V(.)$ is assumed to be continuous with bounded first derivatives that satisfy $V_y > 0$, $V_Z > 0$, and $V_P < 0$. For simplicity, we assume that indirect utility function is specified such that the associated land demand function is independent of amenity levels Z and is given by $D(P,y)$, which is also continuous with bounded first derivatives $D_y > 0$ and $D_P < 0$. Demand is assumed to be strictly positive and bounded from above.

[4] The supply function describes what portion of a location's available land L_j will be committed to residential use at a given price. We assume that there exist residual competing demands for land at each location and that there is one special competing use (i.e., agricultural production) for which there is completely elastic demand for land at any price at or below the reservation price $\overline{P}_A$. Thus, the supply of land for residential use at a given location is equal to zero for any price at or below $\overline{P}_A$. At prices above $\overline{P}_A$, residential land supply is increasing to an upper bound of L_j.

very general specification, which embeds the basic monocentric city model, theoretical sorting models such as those considered by Epple and Platt (1998) and Banzhaf and Walsh (2008), and the empirical framework pioneered by Epple and Sieg (1999).

In equilibrium, the sorting of income types across locations will depend on the income elasticities for land and locational amenities. Equilibrium in the model is defined by a vector of allocation functions $\phi_j(y)$, which identify the proportion of each income-type living in each location and a vector of J location-specific housing prices, which satisfy the locational equilibrium conditions:

$$V\left(y, P_j, Z_j\right) \geq V(y, P_k, Z_k) \forall k, y \forall j, \text{ where } \phi_j(y) > 0 \tag{i}$$

$$N \int_{y_l}^{y_h} D\left(P_j, y\right) \phi_j(y) f(y) \mathrm{d}y = S_j\left(P_j\right) \forall j \tag{ii}$$

$$\sum_{j=1}^{J} \phi_j(y) = 1 \forall y \tag{iii}$$

Condition i requires that in equilibrium, no household would be strictly better of choosing a different location. Condition ii requires that the housing market clear in each location. And condition iii requires that each household is assigned to a specific location.[5]

As specified, the model is still quite general. Further simplicity can be gained by assuming that the vector of amenities Z_j can be collapsed into an index such that $V\left(y, P_j, Z_j\right) = V\left(y, P_j, G\left(Z_j\right)\right)$ and $\frac{\partial V}{\partial G} > 0 \forall y$. Under this assumption, locations are vertically differentiated with all households agreeing on the relative ranking of "quality" across locations. This assumption when combined with equilibrium condition i requires that housing prices be strictly increasing in the amenity index G.[6]

[5] Note that the discreteness of locations can be easily relaxed by instead indexing location by a continuous variable j, that is, distance to the CBD, and then adjusting conditions ii and iii as follows. First, the functions that are indexed by j become functions of j (i.e., $\phi_j(y)$ becomes $\phi(y,j)$). Second, in condition ii, $S_j(P_j)$ must be replaced by $s_j(P_j)l(j)$, where $s_j(P_j)$ is the supply of housing per unit land at continuous location j and $l(j)$ is the amount of land per unit of j available at location j (if the "city" is a one unit wide strip of land emanating out of the CBD and j indexes distance from the CBD, then this collapses to $s_j(P_j)$). Finally, in condition iii, the sum is replaced by an integral over the entire support of j, $\int_{j \in 0}^{\infty} \phi(y,j) \mathrm{d}j = 1$.

[6] To offer stronger predictions about the sorting of individuals by income, the model as presented here limits household heterogeneity to the single dimension of income. Epple and Platt (1998) incorporated heterogeneity in tastes for the overall public good level G into a similar model. They showed that under a modified single-crossing concept that considers both a taste parameter and income, stratification occurs with all individuals of a given taste level sorting by income and all individuals with a given level of income sorting based on the strength of their preferences for public goods. Empirical models have generalized this framework to incorporate heterogeneity in tastes for specific attributes and specific locations by incorporating random coefficients on the elements of the G-index and adding an idiosyncratic location parameter, which is typically assumed to have a logit distribution. These analyses then build on the canonical random utility framework developed by Berry et al. (1995). For an overview of this literature, see Kuminoff et al. (2013).

As specified, the model is still too general to make predictions regarding income sorting. In general, sorting will depend on the relationship between income and the marginal (indirect) utilities of G and P (V_G and V_P). To facilitate a characterization of the equilibrium sorting of households across communities, we require further restrictions on preferences. A common assumption made in these models is that preferences satisfy the "single-crossing" property. This condition requires that the slope of an indirect indifference curve in the (G, P) plane, $-\frac{V_G}{V_P}$, be monotonic in income. Intuitively, this assumption implies that willingness to pay for the amenity bundle is either increasing $\left(\text{when } \frac{\partial - \frac{V_G}{V_P}}{\partial y} > 0\right)$ or decreasing $\left(\text{when } \frac{\partial - \frac{V_G}{V_P}}{\partial y} < 0\right)$ in income.

Focusing on the increasing case, single crossing guarantees that equilibrium can be characterized by an ordering of locations that is increasing in both P and G. For each pair of "neighboring" locations (as sorted by this ranking), there will exist a set of boundary households (uniquely identified by income level) that are indifferent between the two locations. Households whose income is below the boundary location will prefer the lower-ordered location, and those whose income is above the boundary income will prefer the higher-ordered location. This leads to perfect income stratification of households across locations based on their level of the amenity index.

The basic model as specified has implications for how spatial heterogeneity in locational attributes affects the spatial distribution of households and the income distribution across the city. To illustrate the basic machinery of the model, consider the case where households care about just two locational amenities, access to employment locations and environmental quality. Suppose, for instance, that employment is at a single factory located at the CBD and that the factory's pollution mostly lands on residential areas closer to the city center, while areas further from the city center are exposed to less of the factory's pollution. This differential pollution exposure implies that residential locations vary in two dimensions (commute times and environmental quality), both of which are a function of distance to the CBD and under our index assumption work through the G function. Prices will now increase with distance to the CBD x if

$$\frac{\mathrm{d}G}{\mathrm{d}x} = \frac{\partial G}{\partial \text{Commute costs}} \frac{\mathrm{d}\text{Commute costs}}{\mathrm{d}x} + \frac{\partial G}{\partial \text{Pollution}} \frac{\mathrm{d}\text{Pollution}}{\mathrm{d}x} > 0 \tag{7.1}$$

In a continuous expression of the problem, the actual rent gradient at a given distance from the CBD is given by

$$\frac{\mathrm{d}P}{\mathrm{d}x} = -\frac{V_g}{V_P} \frac{\mathrm{d}G}{\mathrm{d}x} \tag{7.2}$$

where V_g and V_P are evaluated at the income of individuals who choose to live distance x from the CBD.

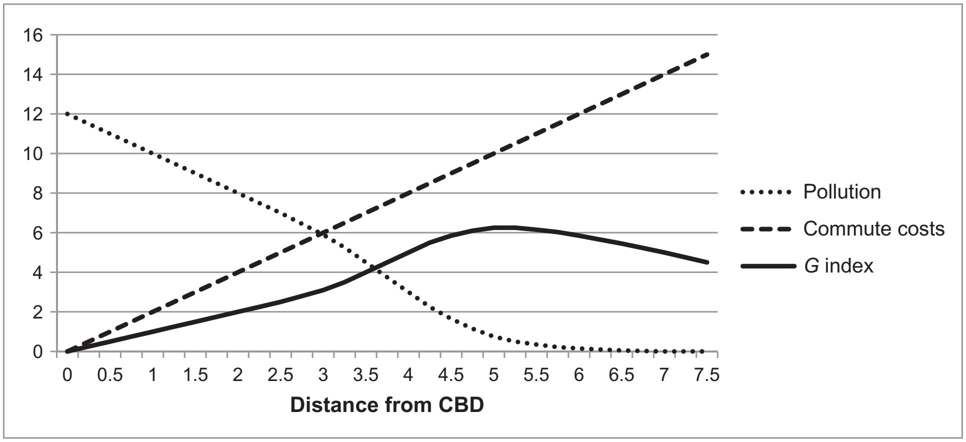

Figure 7.1 The distribution of amenities within a city.

If we assume that pollution levels drop relatively quickly beyond some specified distance from the CBD, then the overall amenity index and its two component parts will be as presented in Figure 7.1, with the most desirable location being just beyond 5 miles from the CBD.[7] Our model also predicts that prices will be highest in this location and that the richest individuals in the community will locate at this point, with incomes dropping as we move either into the CBD or toward the urban fringe and the lowest-income individuals locating at the CBD. Predictions regarding population density are more nuanced. In equilibrium, prices will be highest at locations where amenity levels (G-index) are highest. *Ceteris paribus*, higher prices lead to lower lot sizes. Thus, at the intensive margin and working through the price channel, higher levels of environmental quality (and amenities in general) serve to increase the density of development. However, at the extensive margin, high-income households tend to sort into the high-amenity locations. *Ceteris paribus*, these high-income households will demand relatively larger residential lots. Thus, there is an income channel through which environmental amenities can effectuate lower housing densities.

This dichotomy between price and income effects is particularly important for understanding the potential impact of zoning restrictions on density. In high-amenity locations, high potential rents create a strong incentive for developers to build up (generate more square footage of living space per unit of land input). By magnifying the relative importance of the price effect, the potential for building up increases the probability that the net

[7] If the city center is a major employment center, then this will create a pollution “hot spot” downtown as pollution will be created as a by-product of transportation, industrial activity, and individual choices such as litter and smoking.

effect of amenities will be to increase density. However, it is precisely these high-environmental-amenity locations that tend to experience restrictive zoning regulations designed to prevent dense development.

The shape of the income distribution also plays an important role in determining the relative density outcomes in high G locations. If there is limited income heterogeneity, then the income sorting channel will be attenuated and price effects will dominate, leading to densification around high-amenity locations. Conversely, in the face of large degrees of income heterogeneity, if the superrich have a high willingness to pay for large homes in high-amenity areas, then we would expect to see large lots and relatively low-density development in high-amenity areas—as the income sorting channel dominates the price channel.

7.2.1 Emerging within city environmental trends

We now examine several environmental dynamics playing out across urban areas and explore how these supply-side changes affect the spatial distribution of economic activity within cities. An overarching recent trend in the urban environment is the improvement in central city quality of life on both environmental and nonenvironmental dimensions. This trend has important implications for the long-run suburbanization trend. We first consider the literature on three specific environmental components of this change (air quality, open space, and brownfield cleanup) before returning to the issue of central city quality of life in general.

7.2.1.1 Improving air quality

The stylized example presented in Figure 7.1 highlights the potential role that air pollution could play in shaping the spatial structure of cities. Historically, the combination of urbanization, industrialization, and heavy reliance on coal in both manufacturing and residential uses led to extreme pollution problems (Barreca et al., 2014). The "London Fog" made news in the United States as early as 1879 (Stradling and Thorsheim, 1999). Eighty years later, the Great Smog of 1952 was responsible for the death of as many as 12,000 Londoners (Clay and Troesken, 2010). Thus, local air pollution has been a major component of the spatial amenity landscape. Perhaps, nowhere are the trade-offs between commute time and air pollution better illustrated than in the East End neighborhoods of late nineteenth-century Pittsburgh. By the late 1800s, the city's industrial success had led to such severe air pollution problems that it was famously referred to by James Parton as "hell with the lid taken off" (Tarr, 2003). The air pollution created a situation where "society was forced to flee to the freer air of the East End" (Nevin, 1888). This environmental haven, separated from the mill-laden rivers by surrounding hillsides, became the location of choice for both the city's elite and the nation's elite. By 1900, residents of this neighborhood, located five miles from downtown Pittsburgh, controlled as much as 60% of America's productive assets (Skrabec, 2010).

Over the last few decades, there has been a sharp reduction in the US urban air pollution. Smith (2012) documented that the US air pollution (as measured by ambient PM10) has fallen by roughly 50% between the early 1960s and 2008. Similar progress is documented in Germany and Spain. In spite of these improvements, there continues to be strong empirical support for the role that air pollution variation plays in determining the spatial structure within cities. A voluminous set of hedonic studies demonstrate that air quality capitalizes into housing prices suggesting that it belongs in the locational equilibrium model's amenity vector.[8] Further, direct reduced form evidence regarding the role of air pollution in household location decisions is provided by Banzhaf and Walsh (2008). These authors first showed that the locational equilibrium model in general predicts increases in both density and income when amenity levels increase at a single location. They then tested these density and income predictions *vis-à-vis* air pollution by evaluating the impact of changes in the scale and existence of sources of toxic air pollution that occurred in California between 1990 and 2000.

Their work broadly supports both the density and the income predictions of the model. On density, they found that removing exposure to polluting facilities increased population density on the order of 5%, while adding new exposure led to a drop in population density of similar magnitudes. This density result is likely driven by two related factors. First, working through the price channel, reductions in pollution provide incentives for developers to develop more intensely and households to consume less square footage. Second, removal of polluting facilities provides an opportunity to redevelop the land into residential use. This process is reenforced by the newly increased land prices. In terms of the spatial distribution of households of various income levels, new exposure to toxic air pollution was associated with a drop in a neighborhood's average annual household income of $1000 or more. Conversely, the loss of exposure to polluting facilities was estimated to lead to concomitant increases in income.

While this research provides reduced form evidence of the potential importance of air pollution in the locational equilibrium framework, such studies do not explicitly model how different households respond to exogenous changes in air pollution. A recent residential sorting literature has sought to test how the spatial distribution of households within a city is affected by regulation-induced changes in the spatial distribution of pollution. Do richer people now move to areas that have experienced a quality of life improvement? A handful of studies have attempted to estimate locational equilibrium models of household location that directly incorporate spatial heterogeneity in air quality.

[8] Smith and Huang (1995) summarized 37 studies that used hedonic property analysis to evaluate the housing price effects of air pollution. Zabel and Kiel (2000) and Kim et al. (2003) presented additional hedonic studies of air pollution valuation.

The first such efforts are reported in Sieg et al. (2004). These authors estimated a locational equilibrium model for the greater Los Angeles metropolitan area that incorporates spatial heterogeneity in ozone concentrations. They then used the estimated model to compute a counterfactual equilibrium, which describes the predicted sorting of households of different income levels across 92 different neighborhoods located in five different Southern California counties, under the assumption that ozone levels were what they would have been (as estimated by the Environmental Protection Agency) if the Clean Air Act Amendments of 1990 (CAAA) had never occurred.

To highlight the potential importance of accounting for equilibrium sorting when evaluating nonmarginal changes in locational amenities. Table 7.1 reproduces Sieg et al.'s estimates of the county-level impacts of the CAAA. Consider, for instance, the average household that would have located in Los Angeles County in a baseline no-CAAA state of the world. The first three columns of the table report the impact of the CAAA on ozone levels, prices, and the *G*-index in their baseline county (Los Angeles). On average, implementation of the CAAA was predicted to provide a 9.40% improvement in Los Angeles County's ozone pollution and drop average housing prices by 0.20% (as we discuss below, this price drop arises from the fact that Los Angeles County saw small improvements in air quality relative to overall regional improvements). The 9.40% ozone improvement was associated with an overall 2.30% increase in average *G*-index levels. However, in assessing the impact of the CAAA on individual households, it is necessary to account for the fact that households move when the spatial distribution of amenities changes. The last two columns of the table account for these movements and report the change in price and *G*-index predicted to be actually experienced by households in the post-CAAA locational equilibrium as opposed to the baseline no-CAAA equilibrium (i.e., accounting for the relocation of those households who choose different locations under the two different two locational equilibriums). In general, under the post-CAAA equilibrium, households tended to sort out of their initial Los Angeles County neighborhoods and into neighborhoods that saw slightly smaller amenity increases (2.00% vs. 2.30%) and slightly larger price decreases (−0.60% vs. −0.20%). In some instances, the impact of sorting can be quite large. For instance, this analysis predicts that, on average, individuals who

Table 7.1 Sieg et al. (2004) results

	Initial location			Postsorting	
County	**Pct. Δozone (improvement) (%)**	**Pct. Δprice (%)**	**Pct. Δ*G* index (%)**	**Pct. Δprice (%)**	**Pct. Δ*G* index (%)**
Los Angeles	9.40	−0.20	2.30	−0.60	2.00
Ventura	9.40	−2.60	0.40	−1.20	1.60
Orange	10.60	−1.60	1.10	1.00	1.50
San Bernardino	14.30	2.90	5.40	2.80	5.30
Riverside	18.30	5.90	7.60	6.30	8.00

initially live in Ventura County will experience a public good change that is actually four times as large as that experienced at the average household location in Ventura County.

These differences can be extremely important when considering the distribution of welfare from a given policy. For instance, in this example, the partial equilibrium estimate of the average Ventura County household's willingness to pay for these air quality improvements is only $21 per year, while the general equilibrium estimate, which accounts for relocation, is $539 per year. Table 7.1 also highlights the importance of relative improvements in evaluating the price effects of environmental improvements. While all counties experienced overall air quality improvements, because those that experienced lower levels of improvement became relatively less attractive, they actually are predicted to experience price decreases in the new equilibrium.[9] It is important to note that this research assumed that Los Angeles was a closed economy and that the improvement in local air quality did not accelerate population growth of the region as a whole. Future research might examine intrametropolitan area and intermetropolitan area choice within a unified framework. In an open economy, it is likely to be the case that even those areas with the lowest relative gains in air quality will still experience accelerated economic growth.

Two additional recent studies have also incorporated air pollution in a locational equilibrium model. Tra (2010) utilized a random utility model (RUM) approach, which incorporates horizontal differentiation to analyze the impact of air pollution changes in the LA metro area. The RUM framework uses a random coefficients framework that allows individual households to place different weights on the various elements of the amenity index and incorporates idiosyncratic tastes for specific locations. Tra's results are generally consistent with those of Sieg et al. Bayer et al. (2011) incorporated ozone pollution along with crime rates and racial composition into a dynamic version of the random utility approach, which they estimated using data from the San Francisco Bay area. They find that on average, households would be willing to pay $295 for a 10% decrease in the number of days that ozone levels exceeded the state's hourly standard.

Applying such a structural approach to studying the valuation of air pollution in cities in the developing world would be quite valuable. In the developing world, cities in China and India feature extremely high levels of air pollution, and within these cities, there is substantial variation in air pollution. Zheng and Kahn (2008) estimated hedonic real estate price regressions using the price per square foot of new residential apartments built across Beijing from 2004 to 2006. Controlling for a large number of attributes of the apartment and the neighborhood, they estimated that a one microgram per cubic meter increase in PM10 is associated with a 0.5% reduction in local home prices.

[9] While not reported in the Sieg et al. (2004) paper, these relative changes in amenity level can also expected to be associated with changes in the distribution of income groups across the counties, with the average income of households in the counties that experienced the largest improvements increasing.

One potentially fruitful area for future research is on the spatial distribution of air pollution within cities. Today, regulators are paying greater attention to small particulates such as PM2.5. Atmospheric chemistry studies have documented that "hot spots" exist close to major highways in cities such as Los Angeles (see Hu et al., 2009). If government regulations reduce such pollution, an important economic incidence issue arises. As particulate problems fall near freeways, will renters in the area benefit or will they be priced out of their previously affordable neighborhoods? If richer people move in, will the type of gentrification documented by Sieg et al. (2004) repeat itself so that the main winner from the local public good improvement are the local land owners?

Some cities continue to have rent control and rent stabilization programs. For example, there are 15 cities in California who have rent control and these include Los Angeles and San Francisco.[10] Incumbents in such programs are less likely to be priced out of gentrifying neighborhoods. In addition, developers in major cities are often asked to set aside a given fraction such as 20% of units in new residential towers to be sold to lower-income households. In this sense, activist local government housing policy interacts with environmental dynamics such that a subset of lower-income households enjoy the gains of local amenity improvements without facing sharp increases in rents.

7.2.1.2 Preservation of open space

Throughout the United States, many local governments have introduced publicly financed efforts to purchase open space development rights. The intent of such legislation is to preserve land for recreational and aesthetic purposes (Kotchen and Powers, 2006; Banzhaf et al., 2010). Such land set-asides affect the spatial patterns of economic development within a metropolitan area.

Several researchers have considered the role that open space protection can play in determining urban spatial structure. Most of this work has been theoretical in nature and largely builds directly on monocentric city formalizations of locational equilibrium. Wu and Plantinga (2003) incorporated open space into a monocentric city model and found that land protection at the urban fringe can lead to "leap frog" development as open space amenities increase the desirability of land on the far side of the newly protected open space from the city center. Turner (2005) considered open space in a dynamic version of the model that incorporates both urban and suburban locations. He found that in the presence of open space amenities, more remote areas are developed before more central areas. Following on arguments made by Brueckner (2000) about potential market failures in the provision of open space, Bento et al. (2006) developed a computational monocentric city model that incorporates the amenity value of open space at the urban fringe. Under this formulation, the market can lead to inefficiently

[10] http://www.dca.ca.gov/publications/landlordbook/appendix2.shtml.

large urban areas as private developers fail to account for the decrease in utility experienced by extant city dwellers due to increased distance to open space at the fringe.

On the empirical front, two papers have considered the issue of open space protection and/or land regulation in a locational equilibrium framework. Walsh (2007) extended the empirical approach developed by Epple and Sieg (1999) to structurally estimate a locational equilibrium model of open space and housing markets in Wake County, North Carolina. The model incorporates multiple employment centers and two types of open space, publicly owned and privately held. Simulated versions of the model are used to undertake counterfactual exercises that incorporate the endogenous nature of privately held open space—modeled essentially as a residual land use. A key finding from this work is that public protection of open space in a given location can lead to an overall decrease in a neighborhood's overall (public + private) provision of open space due to the acceleration of the conversion of privately held open space, which is attracted by the amenity created by the new public land.

A second notable empirical analysis is the work of Cheshire and Sheppard (2006). They used hedonic methods to estimate implicit prices for "amenities produced by the planning system" and then embedded these estimates in a modified monocentric city model that is calibrated to data for the city of Reading in the United Kingdom. The fitted model is then used to calculate the gross monetized value of planning by calculating the change in household expenditure functions needed to hold utility constant under no planning counterfactual outcome—assuming that without planning laws, there would be no open space and that all industrial activity would be equally distributed across the landscape. Working within the framework of the traditional urban model allows Cheshire and Sheppard to implicitly incorporate general equilibrium adjustments in their analysis. Their results suggest that there is a net loss from planning activities that may be as high as 3.9% of annual incomes—with the largest positive benefits from these activities being associated with the provision of accessible open space.

In related work, Turner et al. (2014) use an innovative reduced form approach to evaluate the impact of land use regulation on the price of undeveloped land. They distinguish between three different channels: "own lot" effects, which measure the price effect associated with restrictions that regulations place on the lot itself; "external effects," which capture the price impacts that derive from restrictions on proximate land uses; and supply effects, which stem from the impact that land use regulations have on equilibrium prices through their attenuating effect on the supply of developed land. They find that a one standard deviation increase in land use regulation decreases land value by about one-third. They attribute the bulk of this effect to own and external lot effects with a 2–3% decrease in developable area contributing the residual.

Finally, we note that a large hedonic literature provides support for the claim that access to open space amenities will lead to higher housing prices. McConnell and Walls (2005) reviewed approximately 40 published articles that use hedonic methods to assess the capitalization of open space into housing prices. They document capitalization of a wide variety of open space amenities including general open space, parks, and natural areas; greenbelts; wetlands; urban/suburban forest preserves; and agricultural lands.

7.2.1.3 Superfund, brownfield, and industrial site remediation

The legacy of more than a century of manufacturing activity is that many US cities feature large numbers of past industrial sites. These areas suffer from toxic releases and severe localized damage to the land and nearby water (Sigman, 2001). The most toxic of these sites have been placed on the National Priorities List (NPL) and have been targeted for cleanup by the Environmental Protection Agency through the Federal Superfund program. In 1982, an initial 400 sites were place on the NPL. Today, there are more than 1300 sites on the NPL (US GAO, 2013). These sites are however only the tip of the iceberg. The US Government Accountability Office estimates that there are additionally between 450,000 and 1 million brownfield sites in the United States. While not as toxic as NPL sites, redevelopment or reuse of these sites is complicated by the presence or potential presence of hazardous wastes and can sit abandoned or unused (US GAO, 2005). A large literature documents that property values are negatively impacted by proximity to NPL sites (see Kiel, 1995; Kiel and Williams, 2007).[11]

As noxious industrial sites are cleaned up, what happens to urban form and the spatial distribution of real estate prices? Two recent studies are of particular interest. Greenstone and Gallagher (2008) examined how tract-level median household values respond to the cleanup of NPL sites. They compared housing price growth in areas surrounding the first 400 hazardous waste sites added to the NPL and thus slated for Superfund cleanup to housing price changes in the areas surrounding the 290 sites that narrowly missed qualifying for the NPL. Greenstone and Gallagher (2008) implemented an instrumental variable approach that embeds a type of regression discontinuity design. The discontinuity arises from the fact that, while all 690 of these sites were scored with an index number representing their level of priority for cleanup, EPA subsequently set an arbitrary score cutoff for listing based on the agency's projection that it could afford to clean 400 sites. Their main outcome equation relates changes in census tract home prices over time to whether the site was designated as an NPL site:

$$\Delta \text{Median census tract home price} = \alpha * X + \beta * \text{NPL site} + \varepsilon \tag{7.3}$$

Greenstone and Gallagher (2008) instrumented for the NPL site listing dummy using a dummy that equals one if the site's hazardous ranking score exceeded 28.5 at the baseline.

Based on this research design, Greenstone and Gallagher (2008) concluded that Superfund listing has little to no effect on local median housing value changes. More

[11] A summary of these findings can be found in Sigman and Stafford (2011).

recently, Gamper-Rabindran and Timmins (2013) revisited the Greenstone and Gallagher results and found a positive impact of cleanup on prices. The main reason for this difference in findings is that, while Greenstone and Gallagher evaluated the impact of a site being listed for cleanup, Gamper-Rabindran and Timmins focused on the deletion from the NPL, which occurs after cleanup is actually completed. Thus, Greenstone and Gallagher were measuring the impact of providing information that a site has been designated as an NPL site and may be cleaned up in the future, while Gamper-Rabindran and Timmins were measuring the impact of the actual cleanup. As of August 2014, there were 1318 sites listed as NPL sites and 383 deleted sites on the Superfund list.[12] These data suggest that not all listed sites are cleaned up and this raises an expectation issue, namely, if and when in the future will the cleanup actually occur. Home buyers are likely to have different expectations over these random variables and this will affect their bidding for housing near such sites.

Gamper-Rabindran and Timmins also documented that the use of tract-level data can mask important within-tract variation in exposure. They showed that a cleanup has a larger effect in the lower portions of the within-tract housing price distribution and used house-level data to show that cheaper houses within an exposed census tract tend to be located closer to the NPL site.

Less toxic brownfield sites have also been studied. Three recent studies are of particular note. Currie et al. (forthcoming) geocoded housing sales data from five states (Texas, New Jersey, Pennsylvania, Michigan, and Florida) covering the years 1998–2005. They used data from the Toxics Release Inventory to identify facilities that release toxic emissions and they used microdata from the Longitudinal Business Database to identify the births and deaths of these toxic plants. Their paper measures the housing market and health impacts of 1600 openings and closings of industrial plants that emit toxic pollutants. They found that housing values within one mile decrease by 1.5% when plants open and increase by 1.5% when plants close.

Second, Taylor et al. (2012) studied 105 sites in the Minneapolis metropolitan area, the majority of which are located in the urban core. A major innovation of this work is that they studied the difference between clean industrial sites and toxic sites and noted the high level of spatial correlation between specific contaminated sites and commercial and industrial sites in general. They argued that it is important to control for this potentially confounding factor. They documented that proximity to clean commercial sites (within 0.3 miles) lowers property values by roughly 4.5–5.5%. Environmental contamination increases the negative impacts by approximately 2.5–3.0%. They found that once the site is remediated, the contamination effect disappears.

Third, Haninger et al. (2014) evaluate the US EPA's Brownfields Program, which awards grants for the redevelopment of brownfields. They utilize a variety of

[12] See http://www.epa.gov/superfund/sites/npl/.

identification strategies to evaluate a set of 327 brownfield sites that were nominated for cleanup—197 of which were awarded grants for cleanup and 130 were not. They nonparametrically identify a treatment threshold of 2040 m. Estimates of the price effect from cleanup range from 5% to 32%.

A review of the recent literature argues for the presence of price effects associated with close proximity to brownfields and polluted sites. These price effects suggest households are sorting in response to these disamenities. However, from the perspective of the locational equilibrium framework, one would also like to see more direct tests of sorting behavior. A summary of the extant literature is provided in Banzhaf and McCormick (2006) and Noonan (2005). The majority of this literature, going back to United Church of Christ (1987), documents correlations between hazardous facilities and the presence of low-income/minority groups.

However, few of these studies explore the sorting behavior of individuals—instead viewing siting decisions from an environmental justice perspective that focuses on correlations between race/disadvantaged status and pollution. The handful of studies that have looked at demographic changes related to citing or removal of toxic waste facilities have found mixed results.[13] It remains an open question of whether urban political leaders choose to locate noxious facilities in minority residential communities or whether poor and minority households choose to live close to such facilities because of the housing price discount.

The recent hedonic research documenting the price appreciation in localized areas where noxious sites are cleaned highlights that gentrification will take place in those neighborhoods. The economic incidence is such that land owners in those areas will gain the most. Such hedonic studies do not recover welfare estimates nor do they document changes in population density over time. As a noxious site located in prime piece of center city real estate is remediated, it is possible that the population density in the area will increase. In this sense, the reclamation of center city land can contribute to the center city resurgence documented in many US cities.

7.2.2 Improving quality of life in the center city

In recent years, there have been sharp improvements in center city quality of life brought about by several synergistic trends including declines in center city crime (Schwartz et al., 2003; Levitt, 2004), improvements in urban air pollution (discussed above; see Kahn and Schwartz, 2008; Wolff, 2014), multibillion dollar investments in rail transit systems that transport people to the city center (Baum-Snow and Kahn, 2005; Kahn, 2007), major investments in cleaning the nation's downtown rivers and waterways (Olmstead, 2010), and building of bike lanes and urban parks such as the Rose Kennedy Greenway (Tajima, 2003).

[13] See, for instance, Been (1994), Been and Gupta (1997), Wolverton (2009), and Cameron and McConnaha (2006).

At the same time, there have been emerging demographic trends such as more women working in the labor force and thus delaying marriage and having fewer children (Goldin, 2006). Such households have less of a need to live in the school-focused suburbs. At the industrial level with manufacturing shrinking in its employment share, more people are working in the high-tech service sector and many of these industries gain from downtown locations. Such industries disproportionately hire highly educated people (Moretti, 2012). All of these trends further strengthen the central business district.

Downtown environmental progress is likely to have played a key role in causing the center city revival. While it is very difficult to parse out the individual effects of specific factors, together, these trends have strengthened center cities and have encouraged private developers to make multibillion dollar investments in new downtown real estate projects. The net effect of these investments is to lead more and more people (especially young adults and older adults whose kids are out of the house) to be willing to live downtown. In high-amenity center cities such as New York City and Paris, the rich have chosen to live in the center city (Brueckner et al., 1999; Brueckner and Rosenthal, 2009).

This center city resurgence has been studied in detail (Glaeser and Shapiro, 2003; Glaeser and Gottlieb, 2006) and seems likely to continue. More and more mayors are prioritizing reinventing their downtowns with a focus on beauty and promoting tourism around their waterfronts (see Carlino and Saiz, 2008). Examples range from Pittsburgh, to Chicago, to Shanghai, to Seoul. As center city quality of life improves, center city property values rise. Compare Manhattan's real estate prices in the bleak 1970s versus in Mayor Mike Bloomberg's Manhattan of 2012. By raising center city property values, property tax revenue rises and urban leaders can finance more of their pet projects. It is no accident that New York City mayors focused on enforcing dog poop laws, providing bike lanes, and enforcing antismoking ordinances. At a time when crime is falling sharply, time outdoors is a complementary activity to clean air and safe streets.

As urban quality of life in center cities has improved, it has triggered gentrification in the center cities, and this in turn triggers private sector investments in upgrading buildings and offering better restaurants and retail shopping (Waldfogel, 2008). The geographic patterns of upscale supermarkets with organic offerings, such as Whole Foods, are not surprising (see Meltzer and Schuetz, 2012).

Whether this demand for downtown living leads millions of more people to live downtown depends on the elasticity of downtown housing supply. Such studies as Glaeser et al. (2006) and in this handbook Gyourko and Molloy (2015) highlight the challenges in building more housing downtown. Kahn (2011) used data from cities across California and argued that more liberal cities are less likely to issue new housing permits. In their study of Massachusetts cities, Glaeser and Ward (2009) concluded that cities with more manufacturing and more minorities in 1940 are also associated with smaller minimum lot sizes. If environmental quality rises in the center city but the housing supply is highly inelastic, then such demand will simply translate into higher downtown prices and the rich living downtown. This proposition merits more research in urbanizing nations around the world. Brueckner and Sridhar (2012) documented that building height limits in India's cities are contributing to suburban growth. They documented that cities with higher floor to area ratios are more compact.

7.3. GLOBAL EXTERNALITIES EXACERBATED BY THE INTRAMETRO AREA LOCATIONAL CHOICE OF HOUSEHOLDS AND FIRMS

The equilibrium sorting and hedonic models discussed above focus on the demand for location-specific attributes such as air pollution, a short commute, or good school access. Households have the right incentives to trade off such attributes against the market price they must pay for homes located in such communities. However, equilibrium sorting models typically ignore how a specific household's locational choice has consequences for pollution production. For example, if a household chooses to live close to public transit, such a household may be more likely to use public transit more and drive less (Baum-Snow and Kahn, 2005). In aggregate, such locational choices reduce a city's carbon footprint and help to reduce climate change risk even though each individual household is small in terms of total greenhouse gas production.

Unlike localized environmental goods, changes in greenhouse gas emissions associated with expanded urban footprints do not have any direct effect on the relative attractiveness of different urban locations, so this type of extension to the model essentially boils down to a measurement challenge in which researchers attempt to measure the impact of different spatial structures on greenhouse gas emissions.

A standard claim in the popular media is that suburbanization has a large causal effect on increasing driving and household electricity consumption. Such a result emerges from the standard monocentric model. Suburban homes are far from the CBD's jobs and far from public transit. This leads such households to drive more miles. Since land prices fall with respect to distance from the city center, suburbanites live in larger homes that use more electricity for basic home functions such as air-conditioning and leisure. Such suburban households live further from public transit and are more likely to work in the suburbs. Together, these facts suggest that they will drive more and consume more electricity than if they lived in the center city. These activities will contribute to extra greenhouse gas production if the vehicle is fueled using gasoline and if the home's electricity is generated by coal and natural gas.

From a welfare and policy perspective, this discussion hinges on a failure to price the externalities associated with energy consumption and production. For example, Parry and Small (2005) estimated that internalizing gasoline consumption externalities in the

United States would require a $1 increase in the gasoline tax.[14] In the presence of such as tax, suburbanites would be more likely to buy more fuel-efficient vehicles, and the carbon externality associated with suburbanization would diminish. This example highlights that the social costs of suburbanization literature are really focused on a second-best world in which households and firms are spreading out without facing the social costs of their actions. A critical implication is that any empirical research focused on the externality consequences of suburbanization must account for the dynamics of the carbon-pricing regime faced by key decision makers.

The greenhouse gas implications of the suburbanization trend depend on the technologies used for generating suburban household electricity demand and for fueling private vehicles. Today, with coal and natural gas providing most of our power and the bulk of private vehicles still being run on gasoline, there is a large carbon impact. In the future, if more households have solar panels fueling electric vehicles, then the carbon consequences of the suburbanization of US homes and jobs could be sharply reduced. In the absence of carbon pricing in the United States, it remains an open question how quickly the research frontier will advance so that the widespread diffusion of solar homes and electric cars takes place.

7.3.1 Measuring the causal effect of suburbanization on household energy consumption

The typical research design seeking to test the hypothesis that suburbanization causes greater household GHG emissions is based on running an OLS regression model of Equation (7.4). In such an equation, the key explanatory variables are such observables as the household's distance from the city center and the population density in the area where the household lives:

$$\mathrm{GHG}_{ijk} = \sum_{q} \gamma_q X_i^q + \sum_{a} \theta_a V_j^a + \sum_{c} \beta_c Z_k^c + \varepsilon_k \tag{7.4}$$

In this regression, the dependent variable is the level of annual household GHG emissions produced by household i living in metropolitan area j in tract k. This variable can be formed with data on the household's annual gasoline consumption and information on the household's annual home fossil fuel consumption such as on natural gas and oil and information on the home's annual electricity consumption and the local electric utility's carbon emissions factor (see Glaeser and Kahn, 2010). X_i^q refers to the value of individual characteristic q for household i. It can include standard household attributes such as the household's income, the head's age, and the household's size. Z_k^c refers to the value of characteristic c in tract k. For example, this may include a household's census tract's population density and the tract centroid's distance to

[14] Davis (2011) and Muller et al. (2011) quantified the externalities associated with coal-fired power plants.

the central business district. The final set of variables, denoted by V_j^a, refers to attribute a of MSA j.

OLS estimates of this equation raise the issue of self-selection.[15] Since households are not randomly assigned to live in neighborhoods, valid concerns can be raised about whether a select subset of people choose to live in the suburbs versus the center city. At the start of this section, we presented a residential locational choice model. That model did not explicitly include an intensive margin of how much do people travel once they choose a location within a metro area. Suppose that households who enjoy driving are more likely to locate in the suburbs further from jobs and shopping centers. The econometrician who ignores this self-selection will be likely to recover biased estimates based on Equation (7.4) because the distance variable is correlated with unobserved attributes of the household. Researchers who rely on OLS have to argue that other factors such as local school quality and housing demand are the key determinants of locational choice and that these choices are independent of the transportation use.

Does living at high density close to the city center induce individuals to consume less energy (i.e., a "treatment effect")? Or instead, has a select subgroup of the population chosen to live in center cities? This selection effect may be due to unobserved population heterogeneity such that there are people who are predisposed to living the "low-carbon" lifestyle and thus have less demand for residential space and prefer using public transit and walking to driving.[16]

Applied economists have recognized this challenge and have tried to make progress using a longitudinal research design. Many urbanists have claimed that people walk and exercise more when they live in center cities. Eid et al. (2008) used a geocoded version of the National Longitudinal Survey of Youth 1979. These data track each individual's residential address, weight, and other personal characteristics over time. They reported that 79% of these people move address at least once during their 6-year study period. By first differencing their data, they removed individual fixed effects and focused on measuring the association between local neighborhood attributes and a person's body mass index (BMI). This association can be measured because some households move from the center

[15] Several recent studies have attempted to quantify geography-related variation in carbon intensities. Glaeser and Kahn (2010), Holian and Kahn (2013), and Lee and Lee (2014) provided estimates of the relationship between urban population density and the total greenhouse gas emissions from transportation. Zheng et al. (2011) quantified the carbon footprint effects across China's cities. VandeWeghe and Kennedy (2007) compared per capita auto- and building-related GHG emissions across census tracts within greater Toronto, Canada. Between the most carbon-intensive (typically suburban) and the least carbon-intensive (typically urban) tracts, they found that GHG emissions vary by more than a factor of 4.

[16] The causes of such environmentalism remain an open research question. The peer effect literature and research on parental transmission of culture and values offer possible pathways for examining this issue (Becker, 1976; Bowles, 1998; Iannaccone, 1998).

city to the suburbs and vice versa.[17] They test and reject the hypothesis that suburbanization contributes to rising obesity levels.

A randomized field experiment design would offer a cleaner way to disentangle selection from treatment effects. Suppose that public housing is scattered across different neighborhoods in a city. Those households who sign up for a public housing lottery would be randomly assigned to their place of residence. A researcher focusing on this subpopulation could study the transportation patterns of these individuals to establish the causal effect of urban form on car use. The researcher would face the challenge of establishing whether results based on this subpopulation are likely to generalize to other subsets of the population.[18]

The bottom line in terms of this area of research is that while a handful of papers have been written that highlight potential strategies for identifying the causal link between urban structure and household energy consumption, this issue remains an open question and merits future work both in developed and in developing nations' cities.

7.3.2 Suburbanization and carbon politics

Households who live a high-carbon lifestyle are likely to be aware of this fact and thus to oppose policies such as carbon taxes that would raise electricity and gasoline prices. For example, Cragg et al. (2013) documented that US congressional representative voting on the American Clean Energy and Security Act in 2009 was positively correlated with their district's per capita carbon emissions. Holian and Kahn (2014) document that California voters who live in the suburbs are less likely to support the state's landmark AB32 legislation. California's AB32 commits California to major greenhouse gas reductions by the year 2020 and 2050. It includes new regulations including a cap-and-trade program for carbon dioxide.[19] In the year 2010, California voters had the opportunity to repeal AB32 by voting in favor of Proposition 23. These voting data provide researchers with the opportunity to studying geographic patterns in the precinct level data. Holian and Kahn (2014) document that suburban geographic areas were more likely to vote against cap and trade even after controlling for the fact that more liberal voters live in the center city. This finding is of interest because it highlights that suburbanites are self-interested

[17] The authors do not model why people are moving across geographic areas, and thus, they are implicitly assuming that the migration decision's determinants are not correlated with unobserved determinants of BMI changes.

[18] As an example, the "Move to Opportunity" (MTO) program of the US Department of Housing and Urban Development (HUD) introduced a randomized lottery in which low-income households who "won" the lottery receive vouchers to move to low-poverty areas. The survey data include household vehicle access. This experimental design would allow researchers to study whether the probability that a household owns a vehicle increases when it moves to areas further from public transit and further from the city center. The natural control group in this case is other MTO-eligible families who did not win the lottery (Ludwig et al., 2011).

[19] http://www.arb.ca.gov/cc/ab32/ab32.htm.

voters who believe that their operating expenses will rise in the presence of a carbon tax. Center city voters recognize that they live in smaller apartments and drive less and use public transit more. The aggregate effect of these choices is that they face a lower carbon bill if a carbon tax is enacted. The voting patterns support this spatial hypothesis.

A majority of US metropolitan area jobs are located in the suburbs. Glaeser and Kahn (2001) used geocoded zip code-level employment data to document the empirical distribution of jobs across cities and industries. As road networks have improved and center city land has increased in price, jobs have suburbanized. Improvements in information technology have allowed firms to fragment so that they reduce their demand for downtown real estate and only retain workers who require face-to-face interaction with other firms to remain there (Rossi-Hansberg and Sarte, 2009).

Households who live and work in the suburbs are unlikely to use public transit. Aware of this fact, they are less likely to support public policies that improve public transit or to use this public transit. This fact helps to explain how over 16 major cities have made major investments in rail transit systems over the last few decades, but only Boston and Washington DC have seen significant ridership of these systems (Baum-Snow and Kahn, 2005).

Throughout the urbanizing world, people are decentralizing as new roads are built and as household income rises. While environmental economists have stressed that the introduction of a carbon tax is likely to offer greater long-run benefits relative to its upfront costs, this group of researchers has tended to ignore the spatial distribution of voters and its implications for the economic incidence of new taxes. Whether the worldwide suburbanization trend affects the likelihood of a global carbon treaty would appear to be an important future research topic.

7.4. ENVIRONMENTAL AMENITIES IN A SYSTEM OF CITIES

In this section, we survey ongoing research examining how environmental amenities shape cross city competition for workers and firms. We examine the causes of differential environmental improvements in some cities (the evolving supply of pollution), and we seek to understand its consequences for the sorting of heterogeneous workers (who differ with respect to human capital) and the types of firms who hire them (i.e., Facebook vs. service firms).

An enormous cross-sectional cross city compensating differentials literature has used the core Rosen/Roback modeling structure to estimate hedonic wage and real estate impacts of nonmarket goods (for a general survey, see Gyourko et al., 1999). The classic Rosen/Roback model of cross city quality of life implicitly assumes that spatially tied attributes are exogenously determined and fixed over time. The leading papers in the cross city nonmarket quality of life literature have been static studies seeking to estimate the cross-sectional hedonic equilibrium at a point in time (Graves and Linneman, 1979; Blomquist et al., 1988; Gyourko and Tracy, 1991; Albouy, 2008). Such estimates are quite useful for learning about the marginal migrant's implicit price index for nonmarket goods and can be used to construct a Laspeyres price index for necessary expenditure to consume a fixed nonmarket local amenity bundle such as climate attributes (Cragg and Kahn, 1999; Costa and Kahn, 2003). This approach is less informative in the case where households face migration costs in moving across cities and when there is significant heterogeneity with respect to the preferences for local public goods. In this case, the hedonic gradient represents the marginal mobile person's willingness to trade off money for local public goods, and such estimates may reveal little about the preferences of those far from the margin (Bayer et al., 2009).[20]

7.4.1 A cross city household locational choice model

This section modifies the locational equilibrium model presented in Section 7.3 to motivate the discussion below of environmental quality and cross city sorting by heterogeneous households and firms. As presented here, the model is a modification of Bayer et al. (2009) cross city locational choice model. At a point in time, a household is located in a specific metropolitan area $j \in J$ and must choose whether to stay in its current location or move to another location. Households differ with respect to their human capital endowments and can foresee both the incomes and housing prices available to them at all potential locations. Households recognize that if they move, they will incur moving costs (which are heterogeneous; we discuss them below) but that it will enjoy a vector of location-specific attributes G. As with the intracity model presented above, some of these attributes are environmental attributes such as climate, proximity to coasts, and local environmental quality. Finally, we assume that each household has an idiosyncratic preference shock (error term) associated with each possible location ϵ_{ij}. For simplicity, we assume a linear indirect utility function, and thus, the utility that household i that initially is located in community j will receive if it chooses to locate in community k is given by Equation (7.5):

$$V_i^{jk} = \beta * \text{Income}_{ik} - \gamma * \text{Price}_k + \Gamma(D_i, \nu_i) * G_k - \delta * \text{Moving costs}_i^{jk} + \epsilon_{ik} \tag{7.5}$$

In Equation (7.5), moving costs are zero if $j = k$. $\Gamma(.)$ captures both systematic heterogeneity in taste for amenities (based on a vector of demographic characteristics, D_i) and

[20] For example, suppose that a Chicago resident who currently earns \$100,000 could earn \$140,000 if he moves to San Francisco. Suppose that housing units are all the same size and that this Chicago resident currently pays \$20,000 in rent but would pay \$120,000 for a housing unit in San Francisco. Abstracting from federal and local taxes, this person sacrifices \$60,000 in private consumption if he moves from Chicago to San Francisco. If we observe this person make this move, then a lower bound on his willingness to pay for San Francisco's amenities over Chicago's amenities is \$60,000. Note that this example assumes that migration costs are zero and abstracts from potential adjustments in the level of housing consumption. Suppose that due to family reasons, this person would face a \$250,000 migration cost for leaving Chicago. An econometrician who does not observe this cost would see the person remain in Chicago and would infer that this person does not value San Francisco's amenities.

a random coefficients component driven by the idiosyncratic shock ν_i. Inclusion of D_i in the Γ function allows the model to reflect the fact that, on average, demographics such as education level impact tastes for environmental quality (Kahn, 2002).[21]

Assuming a logit error term collapses the implicitly high-dimensional problem of identifying the probability of household i, initially located in j, choosing location k as its final destination into the familiar logit probability expression presented in Equation (7.6),

$$\text{Probability}_i^{jk} = \frac{e^{\beta * \text{Income}_{ik} - \gamma * \text{Price}_k + \Gamma(D_i, \nu_i) * G_k - \delta * \text{Moving costs}_i^{jk}}}{\sum_{l \in J} e^{\beta * \text{Income}_{il} - \gamma * \text{Price}_l + \Gamma(D_i, \nu_i) * G_l - \delta * \text{Moving costs}_i^{jl}}} \tag{7.6}$$

Several points regarding empirical implementation of Equation (7.6) merit discussion. First, there is a fundamental asymmetry between the decision maker and the econometrician. The econometrician must impute what this household will earn in each local labor market. While it is easy to impute the rental price of what each household will have to pay for housing in cities such as Boston and Houston, a fundamental self-selection issue arises when using the wages for college graduates who already live in Houston as an estimate of the wage a person now living in Chicago would earn if he moved to Houston. To avoid self-selection concerns, the researcher must assume either that there are no unobserved skills or that the factor price for these skills is equal across cities (Heckman and Scheinkman, 1987).

A key innovation in this model of location choice is the introduction of migration costs (also see Kennan and Walker, 2011). The introduction of migration costs means that migration is an investment and that a forward-looking migrant should also form expectations of how his or her income and the amenities of the area will evolve over time. Incorporating fixed costs is particularly important in the modern economy, where there is an aging population who has built up location-specific social capital (Glaeser et al., 2002). In this case, hedonic differences in prices may sharply understate the marginal valuation of amenities depending on who is the marginal household (Bayer et al., 2009).

Bayer et al. (2009) estimated a version of this model to recover estimates of the marginal willingness to pay for air quality improvements using data on migration while allowing for positive migration costs. They argued that standard hedonic methods will underestimate the marginal willingness to pay for clean air and other location amenities because there are inframarginal households who value such amenities but face large migration costs to moving, and thus, the hedonic gradient contains biased information about household's marginal valuations. In their application, they documented that a

[21] As presented here, preferences do not exhibit the single-crossing property discussed in Section 7.3. Incorporating income into the Γ function is one way to address this issue.

major bias arises because households are estimated to have high moving costs associated with leaving their state and/or region of birth. A majority of US citizens were born in areas with relatively high air pollution levels. Bayer et al. demonstrated that failure to account for a household's birth-related attachments to these relatively polluted areas imparts a large downward bias in estimates of the willingness to pay for clean air.

In the presence of migration costs, forward-looking households will consider both the amenities of a location today and their expectations of future amenity levels in potential destination cities (see Bishop and Murphy, 2011; Bishop, 2012). Bishop (2012) assumed that such locational attributes as crime and air pollution follow an AR(1) process and used city-specific estimates of this process to predict future amenity values. In cities where polluted areas are expected to improve over time, today's amenity value understates future progress. If, for instance, the AR(1) process is mean reverting and economic agents anticipate that relatively polluted locations will improve toward the mean over time, then the econometrician who estimates a static model and does not incorporate these dynamics will underestimate the willingness to pay for such an amenity. This bias arises because the econometrician observes people moving to locations with high levels of pollution today and therefore infers that individuals do not prioritize pollution avoidance heavily in their location decisions. When, in fact, economic decision makers are basing their decisions on the lower levels of pollution that they expect to experience in these locations over longer-run time horizons.

7.4.2 Modeling cross city differences in the local public good supply

Environmental and urban economists have not been explicit about how the G is produced and who is doing this "production." Implicit in this is the view that local public goods are either exogenous or being produced through some unintended by-product of economic activity.

In papers such as Kahn (1999) or Levitt (2004), researchers adopt a reduced form approach and model a location's local public good vector by simply regressing measures of amenities (such as air pollution or crime) on a set of observables:

$$G_{jt} = f\left(X_{jt}, Z_t\right) \tag{7.7}$$

In this equation, the G is the city's local public good vector, X is a vector of city-specific demographics and industries located within the borders, and Z is a vector of national policies that have been implemented. This reduced form equation representing the supply of local public goods, including many environmental attributes, highlights a key difference between urban economics and industrial organization.

Starting with Rosen (1974, 2002), urban economists have thought of locations as differentiated products whose attributes are in a characteristics space. In this sense, there is a close link between urban and industrial organization economics. In the modern IO literature, profit product sellers choose what to bundle into a product such as a car or an airplane ride in order to collect more revenue (Berry et al., 1995; Blonigen et al., 2013). A key difference between environmental and urban economics and industrial organization is that the suppliers of real estate do not consciously choose all of the local public goods bundled into a specific property. Instead, such local public goods as clean air and water and what industry and population locate within a geographic area and the daily activities of such economic actors at their specific location are an emergent property of regulation.

Diamond (2012) introduced a straightforward reduced form endogenous amenity modeling technique in which she assumed that endogenous city-specific amenities are an increasing function of the city's share of college graduates. The correlation between college graduates and amenities is likely to reflect both selection and treatment effects. College educated individuals are likely to be richer and thus are willing to pay more to live in nicer areas (selection). The clustering of such college educated in a small geographic area may also have a treatment effect in that their local purchasing power is likely to attract niche retail stores and restaurants (Waldfogel, 2008). This group's propensity to vote and to follow local politics may discipline local politicians to address quality of life concerns (Moretti, 2004). Given the positive correlation between education and environmentalism, this group is also likely to prioritize green issues (Kahn, 2002).

One promising area for future research relates to how local governments respond to both contemporaneously high levels of local public goods (the G vector) and expectations of future increases in public good levels. In recent work, Brueckner and Neumark (2014) argue that in those areas with better natural amenities (a high G), public sector workers earn higher wages. Their core logic is that households inelastically demand such areas and local officials can tax more (for redistribution purposes) without people moving away. In contrast in cities such as Detroit, if rich people move out of the center city, then the local government has less tax revenue to spend on local public services and such a decline in G may have selective effects on who remains in Detroit and on the probability that outsiders move to this center city.

7.4.3 Firm locational demand and local amenities

In the Roback (1982) model, there is no comparative advantage among heterogeneous firms such that different firms earn greater profits at one location versus another because firms do not differ. The cross city hedonic quality of life literature has developed independently of the empirical firm locational choice literature that explores the role of local agglomeration effects, transportation costs, and access to input markets that affects locational choice (Dumais et al., 2002; Rosenthal and Strange, 2004; Ellison et al., 2010). A second firm literature has explored how differences across space in environmental regulation, labor regulation, and energy prices affect the geography of where different industries cluster (Carlton, 1983; Henderson, 1996; Holmes, 1998; Becker and Henderson, 2000; Greenstone, 2002; Kahn and Mansur, 2013).

Today, firms such as Facebook, Google, Amazon, and Microsoft are locating in high-quality-of-life cities. Nascent agglomerations such as Santa Monica's Silicon Beach are emerging. High-tech firms face a coordination issue that they often have incentives to locate near each other. High quality-of-life areas help to solve the coordination problem and ex post help such firms who seek cross firm learning and labor pooling to retain workers in the local labor market.

For either factories or corporate headquarters, we can write down a locational choice problem where firms choose the location that maximizes their profits. Similar to the Bayer, Keohane, and Timmins model of household locational choice, the core locational choice probability model can be written as

$$\text{Probability}_i^{jk} = \frac{e^{\beta * \text{Agglomeration}_{ik} - \gamma * \text{Factor price}_{ik} - \delta * \text{Moving costs}_i^{jk}}}{\sum_{l \in J} e^{\beta * \text{Agglomeration}_{il} - \gamma * \text{Factor price}_{il} - \delta * \text{Moving costs}_i^{jl}}} \tag{7.8}$$

Further flexibility can be obtained by allowing the coefficients in Equation (7.8) to vary by industry k and firm i. Under such a specification, β, for instance, could be replaced by $B_k(C_i, \epsilon_i)$ where C_i is a vector of firm-level characteristics and ϵ_i is a firm-specific random component.

A key difference between the firm locational choice problem and the household problem is the desire of some firms to locate near other firms in the same industry or complementary industries. The firm agglomeration literature has devoted little attention to the role that place-based amenities (the G_j) play in determining where firms locate. For the subset of high-tech firms that seek high-skilled workers, they should recognize that where they locate is an investment. They must form an expectation of what will be future centers of agglomeration, and the high-quality-of-life cities such as Santa Monica can solve this coordination problem. For example, for high-tech firms, the agglomeration term in Equation (7.8) may be a function of the local public good G-index.

This discrete choice approach captures the sorting by heterogeneous firms. Those firms that are land-intensive will move to areas with cheaper land. Those that are labor-intensive will tend to avoid prounion states (Holmes, 1998). Those that are high emitters will avoid nonattainment counties under the Clean Air Act (Becker and Henderson, 2000; Greenstone, 2002). Those firms that are energy-intensive will tend to concentrate in places with low electricity prices (Kahn and Mansur, 2013). Such a probabilistic approach but can be aggregated up to predict how local state policies influence the sorting of industries across space. California is a state with high land prices and high electricity prices and is prounion. It is no surprise that California has deindustrialized over the last 40 years. This reduction in the scale of manufacturing lowers pollution levels and thus feeds back into a type of virtuous cycle as these amenity improvements can serve to increase the supply of high human capital labor that tends to migrate toward high-amenity locations.

7.4.4 The evolution of cross city differences in environmental amenities

In this section, we discuss four comparative statics with respect to how changes in the spatial distribution of urban environmental amenities affect the spatial distribution of heterogeneous households and firms, manufacturing dynamics, air quality dynamics, land use zoning, and climate amenities. Such environmental amenity dynamics affect the cross city locational choices of households and firms. We motivate the discussion with a discussion of the role environmental amenities have played in the evolution of the city of Pittsburgh's evolution from a polluted industrial center to a high-quality-of-life center of postindustrial commerce.

7.4.4.1 The case of Pittsburgh

Consider the case of Pittsburgh and the evolving role that natural resources have played in its existence over the last 250 years. European settlement in the region began in the 1740s with the establishment of an English trading post at the point of land where the confluence of the Allegheny and Monongahela Rivers form the Ohio River. Early in the region's history, it was the key role that these rivers played in transportation that gave Pittsburgh a natural advantage. The strategic importance of controlling these natural transportation corridors led first the French and then the British to establish forts at the confluence. Over the next 50 years, the city's population slowly grew up around Fort Pitt, its economy relying mainly on trading and the development of a boat building industry—both predicated on the vital role that the city's rivers played in moving people and goods to the west.

Beginning in the 1800s, Pittsburgh's natural transportation endowment was matched with a second critical natural resource endowment as an engine of growth. Throughout the 1800s and early 1900s, the cost of transporting coal was a key determinant of where iron (and later steel) production was located. The ready availability of local coal supplies combined with proximate sources of iron ore gave the Pittsburgh region a critical natural advantage in iron production and led to the region become a national leader in first iron and later steel production. By the close of the nineteenth century, these natural advantages multiplied as manufacturers realized that they could further reduce costs by eliminating the shipping of semifinished products and integrated production at the location of the coal fields. Thus, for more than 200 years (well into the second half of the twentieth century), the city of Pittsburgh was an economic juggernaut fueled by natural resource-based production advantages.[22] By the year 1950, Pittsburgh's population had peaked at 676,000. After 150 years as a center for iron and steel production, the city had the third-largest concentration of corporate headquarters in the United States—built almost completely on heavy manufacturing concerns.

[22] See Isard (1948) for a discussion of the evolving role of resource location in iron and steel production.

This economic success came with environmental and health costs. As the population density increased along the banks of the city's three rivers, residents experienced increased rates of infectious disease risk because of increasing concentrations of raw sewage being dumped in these rivers as people lived at high population density. Urban public health research has documented the urban death premium (Haines, 2001). Major investments in water treatment and sewage sharply reduced the urban mortality risk, but new threats to urban quality of life emerged. As trading and boat building gave way to iron and steel, an unintended consequence of the greatly increased scale of this dirty activity was large amounts of local pollution that damaged what could have been a beautiful city. In the words of one visitor to the city in 1846,

> *Everybody who has heard of Pittsburgh, knows that it is a city of perpetual smoke and looks as if it was built on a descent into a bottomless pit. But the locality is eminently beautiful, in the confluence of two rivers, with bold hills everywhere in the background, richly wooded and verdant.*[23]

Of course, this pollution carried health implications as well. Ongoing epidemiology research documents the health impacts of particulate matter from living in an area where coal was being burned (Barreca et al., 2013).

As is well known, by the early 1970s, Pittsburgh's steel economy, predicated on the natural advantages it enjoyed due to transportation and cheap coal, came crashing down as the US economy began its seismic shift away from heavy manufacturing. In the short run, the loss in manufacturing jobs was devastating to the region's economy. However, as documented by Kahn (1999) and Chay and Greenstone (2003), a silver lining of Rust Belt decline (starting in the 1970s and accelerated by the deep 1981 recession) has been a reduction of air and water pollution levels in Rust Belt cities such as Pittsburgh.

Pittsburgh of today has successfully reinvented itself, taking advantage of the reductions in industrial pollution that occurred with the loss of the steel industry to transition from a city where natural resources are used as inputs to production processes to an economy where these resources are packaged as amenities, which make the city an integral recruitment tool for the medical, high-tech institutions of higher education that now characterize the city's economy. Quoting from recruitment materials on Google's Pittsburgh recruitment website,

> *Back in the day, this was a steel town, known for its smokestacks and smelters. Today, it's a technology hotbed, a model for cities trying to transition from an industrial past to a knowledge-based future. Home to Carnegie Mellon and the University of Pittsburgh, the Burgh produces some of the finest engineering talent in the world. It's also one of the most livable places in the U.S. Don't take our word for it, though. Ask Forbes and the Economist.*

[23] Case (1846).

7.4.4.2 Air pollution

In Equation (7.7), we noted that environmental and urban economists take a reduced form approach in modeling a city's G at a point in time. In the case of air pollution, a standard accounting approach is to consider scale, composition, and technique effects. Consider the emissions generated by different industries.[24] To simplify the problem, assume there are a clean industry and a dirty industry. At a point in time, the total emissions in this city can be expressed as

$$\text{Total emissions}_{jt} = \text{output}_{cjt} * \text{emissions factor}_{ct} + \text{output}_{djt} * \text{emissions factor}_{dt} \quad (7.9)$$

where the c subscript indicates the clean industry and the d subscript stands for the dirty industry.

A growing city can experience reduced pollution if the composition of economic activity is shifting from dirty output to clean output and if the emissions factor for the dirty industry is significantly higher than for the clean industry. Kahn (1999) and Chay and Greenstone (2003) documented the particulate progress observed in the US Rust Belt as heavy steel producers reduced production in the face of heavy international competition. Kahn (2003) showed similar results for eastern European cities after the fall of communism. Similar trends are now playing out in many of China's richer coastal eastern cities (Zheng and Kahn, 2013; Zheng et al., 2014a,b). Pope et al. (1992) presented an early natural experiment documenting the particulate reductions achieved when a steel plant went on strike.

Over the last 40 years, US big cities have experienced an industrial composition shift as the share of jobs in manufacturing has decreased and the share working in the service sector has increased. There have been many causes of the deindustrialization of US major cities including high wages and the rise of international trade (Autor et al., 2013) and differential enforcement of Clean Air Act regulation (Henderson, 1996; Kahn, 1997; Becker and Henderson, 2000; Greenstone, 2002). As major cities feature fewer manufacturing jobs, this reduces the likelihood that middle-class households live in these cities.

This discussion has focused on the United States but the same issues arise in China. As center city land prices rise, the opportunity cost for having land-intensive manufacturing remain in the center cities has increased. In many Chinese cities, urban mayors are eager to reclaim manufacturing land to sell to real estate developers (see Zheng et al., 2014a,b). An open question concerns whether such developers and local governments have strong incentives to remediate the pollution damage (such as localized toxic emissions) caused by

[24] To simplify this emissions inventory discussion, we focus on the emissions from industry. We recognize that the transportation sector and the household sector are also major contributors to local air pollution. Their emissions can also be studied by examining scale, composition, and technique effects (see Kahn and Schwartz, 2008).

manufacturing. In the United States, the Superfund and Brownfields cleanups are intended to achieve this goal.

Richer coastal cities such as Shanghai are tightening environmental regulations and this provides a further incentive for manufacturing to migrate west to provinces featuring cheaper land and laxer regulation. This industrial migration from eastern to western China raises the possibility of future environmental progress in China's richer eastern cities at the same time that there is pollution degradation in China's western cities. The extent of this pollution transfer hinges on the emissions control technology built into the new factories opening in western China (Zheng et al., 2014a,b).

7.4.4.3 Land use regulation/zoning

A growing set of empirical studies have documented that coastal high-quality-of-life cities are more likely to engage in land use restrictions than the average city. Such cities as Boston, San Francisco, and New York City have been documented to engage in more land use restrictions (Glaeser et al., 2005, 2006; Glaeser and Ward, 2009; Kahn, 2011). Such local limits to growth are intended to preserve local quality of life, but by limiting housing supply in specific high-amenity areas, they are likely to drive up home prices in such areas and deflect middle-class people to other geographic areas featuring more elastic housing supply such as Phoenix. This in turn has implications for both access to local public goods and the carbon emissions of the residential sector (Mangum, 2014).

Glaeser and Kahn (2010) argued that the large difference in the air-conditioning carbon footprint between San Francisco and other cities such as Houston means that, by downsizing the amount of available housing, aggressive local land use zoning in coastal cities displaces people to higher-carbon areas. This suggests that an unintended consequence of local attempts to preserve coastal quality of life is to exacerbate the global challenge of climate change. Mangum (2014) builds on this research by developing a dynamic model of housing demand that he uses to simulate how the residential sector's production of greenhouse gas emissions is affected by various counterfactual policies. He finds that imposing stricter land use regulations in high-carbon-output cities would decrease the aggregate amount of carbon output by about 1.7% (2.7% in new construction), again mostly through decreasing the housing consumed per person and secondarily by moving population to low-carbon cities. His findings build on the research agenda presented in Gaigné et al. (2012) that stresses the importance of considering general equilibrium effects when evaluating the impact of local policies related to carbon footprints.

To quote Gaigné et al. (2012),

> *There is a wide consensus among international institutions and national governments in favor of compact (i.e. densely populated) cities as a way to improve the ecological performance of the transport system. Indeed, when both the intercity and intra-urban distributions of activities are given, a higher population density makes cities more environmentally friendly because the average commuting length is reduced. However, when we account for the possible relocation of*

activities within and between cities in response to a higher population density, the latter may cease to hold. Indeed, an increasing-density policy affects prices, wages and land rents, which in turn incentivizes firms and households to change place. This reshapes the urban system in a way that may generate a higher level of pollution. Thus, although an increase in compactness is environmentally desirable when locations are given, compactness may not be environmentally-friendly when one accounts for the general equilibrium effects generated by such a policy.

This quote highlights a tension in the applied economics literature. Most papers in the field experiments and regression discontinuity literature adopt a partial equilibrium approach as they focus on cleanly identifying a single parameter of interest. This quote highlights the importance of embedding such estimates within a general equilibrium framework.

7.4.4.4 Climate

A large amount of cross city hedonic research focuses on climate valuation. While climate may appear to be a static attribute, increased access to air-conditioning and rising household incomes have both lead to interesting dynamics with respect to the demand for climate. Based both on the geographic migration of the population over time and on hedonic pricing, one robust finding is the rising demand for warm winter areas. Hedonic research by Cragg and Kahn (1999) and Costa and Kahn (2003) documents the rising implicit price of warm winters in cross city hedonic real estate regressions. Using decennial census data, they documented that all else equal that the implicit price on winter temperature has been rising over time in hedonic real estate regressions. With the exception of coastal California and Oregon and Washington, warm winter states tend to have high summer temperatures. This bundling of "good" and "bad" amenities has been offset by the widespread penetration of air-conditioning access (Oi, 1996). Barreca et al. (2013) documented that over the twentieth century, there has been a sharp reduction in the mortality rate caused by extremely hot days, and they attribute this trend to the diffusion of air-conditioning.

As air-conditioning has become cheaper and of higher quality over time, warm winter and warm summer states have become more hospitable locations and more economic activity has moved there. The overall trends in population locational choice are presented in Figure 7.2. In the years 1900 and 2010, we report the cumulative percentage of all people in the United States as a function of average February temperature. Consider the median person. In 1900, the median American lived in a state whose February average temperature was 30 °F. In 2010, the median American lived in a state whose temperature was 37 °F. Note that we use the same temperature distribution for both years. The introduction of a cheap market product that offsets summer heat has sharply changed the spatial distribution of economic activity. This example highlights how market products influence climate demand and population locational choice. Future research might explore how the diffusion of air-conditioning in less-developed country cities affects the spatial distribution of economic activity in these nations.

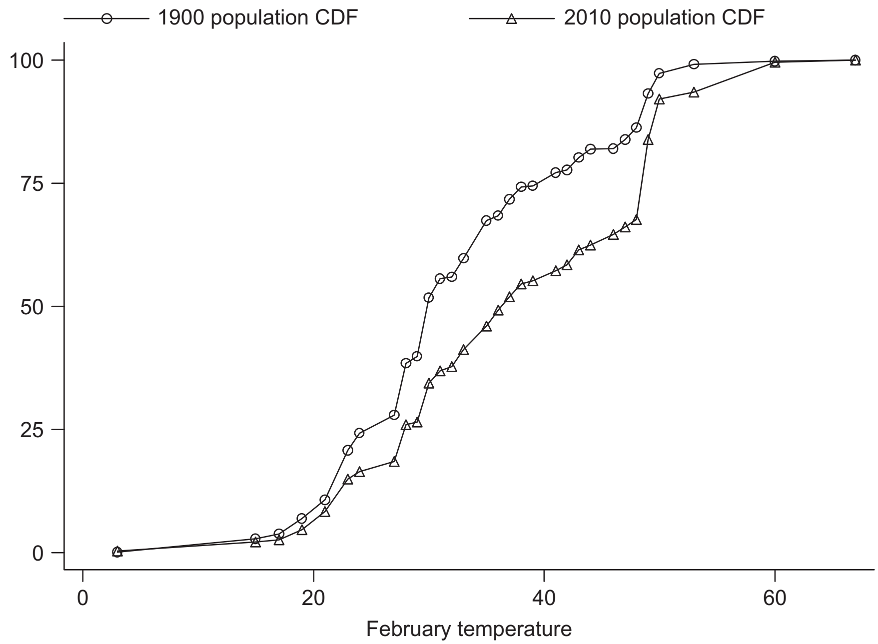

Figure 7.2 The spatial distribution of the United States population in 1900 and 2010.

7.4.4.5 Resilience to climate change shocks

While there are many unknowns about climate change's impacts on different urban areas, climate scientists do agree that mean temperature and the variance of possible outcomes regarding temperature, rainfall, and storms are likely to increase over time as global greenhouse gas emissions continue to rise. Many climate models predict significant changes in average summer and winter climate conditions. For example, in the Southwest, cities such as Las Vegas are expected to become much hotter during summer months. Albouy et al. (2013) used cross city hedonic regressions at a point in time to estimate the marginal valuations of climate. They combined these estimates with predictions from climate change models of how climate conditions are expected to change over time to predict how the climate amenity value of different cities will change due to climate change.[25] In addition to shifting mean temperature and rainfall, climate scientists have tried to be clear about their uncertainty about model accuracy and the possibility of fat tail events such as super storms. Weitzman (2009) explored the implications of "fat tails" events becoming more likely and having incredibly high costs if they do take place. This research line has not incorporated spatial features into the analysis. In this

[25] Such research implicitly assumes that there will be no future technological progress directed toward reducing the discomfort of summer heat.

section, we focus on an emerging new research agenda examining how climate change is likely to affect the spatial distribution of economic activity across diverse cities.

In an open system of cities, households and firms can migrate. This option provides a type of insurance policy as the new news about climate change's actual impacts unfold. As we discussed earlier, migration costs will inhibit such adaptation. Land prices will change in response to these shifts in migration so that the marginal household and firm are indifferent across locations (Rosen, 2002). Incumbent real estate owners will bear the incidence of new news related to how specific cities are coping with climate change (see Bunten and Kahn, 2014). Those households who face high migration costs of leaving at-risk cities (either due to their demographics or due to idiosyncratic locational capital that they have built up) will be more likely to suffer because they either are unable to move from at-risk places or will lose valuable capital in doing so.

Around the world, a large number of people and billions of dollars of real estate are located close to coastal waterways. Such coastal living offers both easy access to water amenities, beautiful views, and a temperate climate. Such coastal living puts many urbanites around the world at risk from sea level rise and natural disasters.

The impact of Hurricanes Andrew on Miami and Katrina and Sandy perhaps offers a preview of the challenges that cities will face if climate change leads to both sea level rise and more severe and intense storms. These natural disasters highlight an emerging urban research area. How will individual cities and their current urbanites be affected by climate change? Kahn (2010) argued that migration offers urbanites the option to vote with their feet if their current city's quality of life declines due to climate change. Such potential exit incentivizes urban politicians to devote effort to mitigating emerging new risks that different cities will face.

At-risk cities have a variety of strategies to protect themselves from anticipated risks. New Orleans is making enormous investments in new sea walls in response to Hurricane Katrina (Kates et al., 2006). Part of the challenge that older coastal cities face is that their existing infrastructure, such as the New York City subway, is over 100 years old and was built at a time when the emerging risks could not be imagined.

An unintended consequence of public investment in coastal armoring to fend off sea level rise is to crowd out private self-protection. More people are likely to move to a coastal city or remain there if they feel safe (Boustan et al., 2012). Kousky et al. (2006) presented a multiple equilibrium model. If an at-risk city such as New Orleans uses public funds to invest in sea walls, then private investors will be more likely to build hotels because their investment is safer. In this equilibrium, the exogenously risky city experiences economic growth because of the synergy between public and private investments. A second equilibrium in this case would be if the government does not expect that people will move to the risky city and thus the government does not build the sea walls. Anticipating that there will be no sea walls, the hotel investor does not invest in the hotel. In this "libertarian" equilibrium, less economic activity locates in the risky place. From an ex post regret standpoint, a key unknown concerns the quality of these sea walls. If private investors and migrants are overconfident about the quality of the government-provided sea walls, then a tragedy could result. This example bears a strong similarity to Peltzman's (1975) famous unintended consequence example of mandatory seat belts (a safety regulation) crowding out private effort.

For geographic areas that suffer natural disaster shocks, will their long-run growth be affected? The recent macro urban research focused on urban growth after major bombings would say "no." Davis and Weinstein (2002) studied Japan's urban population dynamics after World War II bombing and found that cities quickly converge back to their population regression line in the aftermath of a shock (i.e., bombings or natural disasters). Unlike with war bombing, coastal cities face the challenge of the future expectation that they will suffer future shocks of similar types of disasters (i.e., New Orleans will suffer from a future Hurricane Katrina). Such expectations may displace investment to less risky areas. In this sense, climate change risk may lower economic growth in risky areas while increasing investment in other less risky geographic areas that are close substitutes. Hsiang and Jina (2014) document the long-run effects of cyclones on national economic growth. They document large and persistent effects of such place-based shocks.

This section has focused on the impact of climate change on temperature and sea level rise. Another major challenge that climate scientists focus on is drought. In 2014, much of the Southwest is experiencing extreme drought. To economists, an obvious adaptation strategy is to allow water prices to rise in order to trigger both demand- and supply-side responses and to direct technological change to develop new strategies for augmenting our water supply such as water desalinization. Water regulators in the west have been slow to adopt this strategy. They often face complex objectives as they trade off several criteria including equity and efficiency (Timmins, 2002). Initial property rights disputes further inhibit the efficient allocation of water (Libecap, 2009). Whether climate change will nudge such nonprofit maximizers to more efficiently allocate a key scarce resource would be a valuable future research topic.

7.4.5 The rise of superstar green cities

Many cities are transitioning from being producer cities to becoming consumer cities (Glaeser et al., 2001). In the past, coastal cities were major hubs of production and transportation. This suggests that coastal cities and cities connected to rivers featured greater concentrations of both industrial activity and population and this scaled up pollution. In 2014, coastal and river cities in the United States now tend to have better exogenous amenities and high levels of environmental quality (the endogenous amenity). In this section, we start on the supply side to sketch some of the relevant factors responsible for the pollution progress, but then, we focus on the resulting implications for the spatial equilibrium and the economic incidence of uneven amenity improvements within a system of cities.

Today, the United States features some extremely expensive "green cities" such as San Francisco, New York City, Seattle, Portland, Boston, and Chicago, Los Angeles, and San Diego. None of these cities have a major manufacturing center. These cities all feature limited land supply both due to their topography and due to their land use regulations (Glaeser et al., 2006; Saiz, 2010; Kahn, 2011). Such "superstar cities" feature extremely high home prices and a growing share of international investors purchasing properties there to play rather than to work (Gyourko et al., 2013).

A type of social multiplier or environmental multiplier emerges. If an exogenously beautiful area such as Berkeley attracts individuals to live there, then such individuals (both through voting on public goods and taxes and through choices in private markets, i.e., tofu demand) create endogenous local attributes that may further enhance the local amenity vector (Waldfogel, 2008). This multiplier is likely to feed on itself as like-minded people increasingly move to the area.

Standard political economy logic posits that people vote their economic self-interest. This issue arises in predicting whether specific cities will support or oppose new environmental regulations such as limits on coal-fired power plants. In areas such as West Virginia, whose economy relies on coal extraction and cheap energy, workers have incentives to vote against environmental regulation. In contrast, in high-tech cities such as San Francisco, the workers are likely to already be environmentalists who are inclined to support environmental regulation, and they will anticipate that these regulations will not endanger their employment prospects. This divergence in state environmental policy leads to even more sorting by households and firms, and the net result is that coastal cities become green area hubs; this attracts workers and firms who want this lifestyle; and then, as voters, they vote for policies to further reenforce this lifestyle. Thus, it is not surprising that a red state/blue state divide on greenhouse gas policies has opened up (see Cragg et al., 2013) and that the party composition of region's congressional delegation can even affect the enforcement actions of federal regulators (Innes and Mitra, 2014). In this sense, the urban system of cities has implications for the political economy of externality mitigation legislation. We believe this connection between urban growth and economic comparative advantage and political voting outcomes is an important future research topic.

At the same time that coastal high-human-capital liberal cities such as Boston and San Francisco engage in strict zoning, there are other metropolitan areas such as Dallas offering more affordable, larger new homes. In a diverse population, people are free to Tiebout sort to pursue their own vision of the good life. Those who enjoy indoor leisure in larger homes will be more likely to choose to live in affordable Texas. In a population where people differ with respect to their tastes for local public goods, the subset of lower-income households with a strong preference for coastal big cities will be priced out of these markets. Such individuals can either live in a distant suburb of that metropolitan area or live in another city. Their loss in consumer surplus merits further research as it speaks to the cost of rising income inequality.

One way to allow more of the middle class to access these elite cities would be to build more housing in them. Critics of such upzoning have countered that cities such as Paris would stop being Paris if too much tall building construction took place. An open question in this literature relates to how much of the desirability of these superstar cities is due to their housing supply regulation? Does such regulation create such desirability by making it exclusive or by preserving the city's charm? To disentangle these effects would require a structural model of the demand and supply for endogenous city attributes. Is it the case that the demand to live in Paris increases because potential entrants know that housing supply is limited and thus that their Parisian neighbors will also be rich? In a diverse city, how do we aggregate public opinion to determine how much a city's "character" and "charm" have been diminished by new construction? Returning to Equation (7.7) where we discussed the supply of a city's local public goods, how much would a San Francisco's quality of life be diminished by introducing higher-rise buildings?

7.4.6 Cross city local public good valuation challenges and opportunities

The previous section highlighted how environmental shifts impact the system of cities through shifting the locational choice of heterogeneous households and firms. In this section, we discuss how such dynamics affect an econometrician's ability to recover marginal valuations of household willingness to pay for local environmental goods such as clean air. Researchers seek to recover the population's distribution of willingness to pay for such nonmarket environmental goods because this is a key input in conducting cost–benefit analysis of the past and future environmental regulations.

Researchers in the valuation literature use several different revealed preference techniques to infer marginal willingness to pay for local public goods. The most common technique continues to be to estimate cross-sectional hedonic wage and rental regressions with the goal of recovering what a standardized worker would earn in each local labor market and what would be the price of a standardized housing unit in each city. The hedonic literature has sought to decompose this differential into the exact observable parts of the bundle using multivariate regression analysis by estimating regressions of the form

$$\mathrm{rent}_{ijk} = \sum_q \gamma_q X_i^q + \sum_c \beta_c Z_k^c + \varepsilon_k \tag{7.10}$$

In this regression, structure controls (X) are included as well as metropolitan area level variables (Z) measuring local public goods and bads such as climate and air pollution. OLS is used to estimate these regressions at a point in time. An obvious challenge that emerges is omitted variable bias. These regressions have a "kitchen sink" feel. In this age of the field experiment, few reviewers are comfortable with the assumption that the error term in such a regression (which represents all attributes of the home observed by the renter but not observed by the econometrician) is uncorrelated with the explanatory variables.

In response to this concern, leading papers have introduced panel data approaches that incorporate fixed effects in order to sweep out geographically fixed attributes. Consider the seminal paper by Chay and Greenstone (2005) who studied the value of particulate reductions on county home prices. They exploited the fact that counties differ with respect to their assignment to attainment or nonattainment status under the Clean Air Act and the rule for assigning counties to this status has a fixed threshold (i.e., if your county's baseline pollution is less than the regulatory cutoff, then the county faces little regulation as it would be assigned to attainment status). They examined home price dynamics in counties assigned to the Clean Air Act's nonattainment status versus a control set of counties that just missed being assigned to face more severe regulation. As they documented in their first-stage regressions, air quality improved in those counties assigned to Clean Air Act treatment. They used a county's assignment to nonattainment status as an instrumental variable for changes in TSP.

For an instrumental variable to recover consistent estimates of the second stage, it must also pass an exclusion restriction:

$$\text{Second stage regression: } \Delta\text{Home price} = a + B * \Delta TSP + U \tag{7.11}$$

$$\text{First stage: } \Delta\text{TSP} = \alpha + \gamma * 1(\text{TSP in 1974} > \text{threshold TSP level}) + V \tag{7.12}$$

In Equation (7.12), 1(TSP in 1974 > threshold) is a dummy variable that equals one if a county's ambient particulate level in 1974 exceeded the threshold such that the county was assigned to nonattainment status under the Clean Air Act. The standard exclusion restriction in instrumental variable estimation requires that the error term in Equation (7.11) be uncorrelated with the instrumental variable.

Residential sorting and firm sorting in response to the exogenous amenity changes are likely to take place so that this key assumption does not hold. The error term (U) in Equation (7.11) represents all unobserved attributes of the city that are changing over time and capitalized into local home price changes. If the unobserved determinants of housing price changes (which would include the housing stock's quality, local school quality, and restaurant quality) are improving over time by more in cities assigned to high-regulation counties than in low-regulation counties, then the exclusion restriction is violated. Why might this be the case?

Implicit in the Chay and Greenstone argument is a ceteris paribus assumption that the regulation's impact on home prices solely works through its impact on ambient air quality. But throughout this survey, we have stressed that an improvement in one amenity such as clean air triggers behavioral responses by both households and firms. Recall, for instance, the work of Banzhaf and Walsh (2008), which documents household sorting in response to changes in exposure to toxic air pollution. A similar dynamic is likely to play out across US counties as counties are assigned to high and low regulation levels.

As regulation reduces air pollution in a nonattainment county, this will directly lead to air quality progress. In the medium term, it will also reduce air pollution by reducing the probability that dirty footloose manufacturing plants remain in the county. They will be more likely to move to less regulated attainment counties (Kahn, 1997; Becker and Henderson, 2000; Greenstone, 2002). The exit of such firms will reduce both air pollution and other pollution margins such as water pollution and toxic releases. As overall environmental quality improves in these counties, more educated people are more likely to move in to the county and this will tend to raise home prices because local public schools will improve, peer effects will improve, and local retail and shopping quality will improve (Waldfogel, 2008). In a nutshell, as air pollution sharply improves due to the regulation, all else is not equal.[26] The air quality regulation has indirect effects on other local amenities, and home price dynamics reflect this entire bundle's dynamics.[27]

We posit that exogenous improvements in air quality in cities such as Pittsburgh will attract richer more educated people to move to these improving cities.[28] They will move

[26] Consider a distinctive example from Falck et al. (2011). Using data from Germany's past, they documented that endogenous cultural amenities affect the spatial distribution of the highly educated. Their study is based on a natural experiment that exploits the fact that baroque opera houses were built as part of local ruler's competition for status among their peers. They estimated cross region growth regression and found that areas that were close to these opera houses attracted the high skilled to live there and this agglomeration of the skilled contributed to further local economic growth.

[27] This same issue arises in cross-sectional spatial regression discontinuity studies. Black (1999) studied real estate price variation for homes on different sides of a school attendance boundary. Such physically close homes share the same crime and pollution attributes and the same accessibility to stores and commuting options. She interpreted the difference in the average prices at the boundary to reflect the parents' willingness to pay for better schools. Implicit in such a research design is the assumption that unobservable determinants of home prices are smooth across the school boundary. But, this statistical assumption masks a strong implicit economic assumption that is unlikely to hold in cases where there is a major jump at a physical boundary in local public goods. Consider the following model of household sorting. Households differ only with respect to their income. All households gain utility from private consumption, school quality, and Jacuzzi ownership. Assume that household utility features a complementarity between school quality and owning a Jacuzzi. The econometrician observes the price of each home and the local school quality but does not observe whether the home has a Jacuzzi. In this simple example, rich people will live in the best school quality areas and will install a Jacuzzi. Their nearby poorer neighbors will live in a worse school in a home without a Jacuzzi. The econometrician conducting the regression discontinuity study will overstate the value of school quality because the jump in the school quality at the boundary *causes* the homeowner to install the Jacuzzi. The homes located in the high-school-quality district sell for a price premium because they have better schools and they have a Jacuzzi.

[28] Kahn (2007) presented another example of this type of social multiplier effect based on his analysis of the medium-term effects of new rail transit lines. In studying the impact of the fast Red Line that connects Tufts University and Harvard and MIT to downtown Boston, he documented that this subway's local impact on nearby community income and home prices grew over time. He posited that as time passed, new restaurants and retail and increased investment in the local housing supply all contributed to gentrification near the transit stops but that this process took time to unfold.

in and renovate homes (i.e., install Jacuzzis) and improve neighborhoods (perhaps, their kids are better role models at school), and these attributes are not seen by the econometrician. The net effect is that the IV design presented in Equations (7.11) and (7.12) is likely to overstate the partial effect of improvements in particulate matter on home prices because all else is not held constant. The improvement in air quality triggers a sorting of specific types of people and retail that has its own impact on home prices (see Kuminoff et al., 2013; Kuminoff and Pope, 2014). For example, if homes are now more valuable in Pittsburgh because of the air quality improvement and thus, the city collects more money in property tax revenue and offers better schools, this secondary effect will also be capitalized. This example highlights that researchers using panel methods for inferring marginal valuations for amenity improvements must distinguish between partial effects (i.e., the marginal effect of air quality improvement caused by the regulation holding all else equal) and total effects (i.e., the total change in home prices caused by the initially more stringent regulation).

This example suggests that a valuable research program for studying the value of local environmental amenities in the presence of household and firm sorting will involve the following component parts. First, researchers should identify plausibly exogenous supply-side causes of increases in environmental quality and estimate their direct effects on local environmental quality.[29] Second, in the spirit of the approaches considered in Kuminoff et al. (2013), researchers should explicitly model how heterogeneous households and firms respond to amenity improvements. Third, analysts need to investigate the process through which changes in household and firm composition impact other dimensions of local quality of life. For example, if college graduates now move to a city because its air quality improves, how much does local school quality improve because there is greater property tax revenue collected and a better local peer group? By combining these pieces of information, researchers should seek to separately identify both the direct partial equilibrium effect and the indirect equilibrium responses caused by the amenity improvement.

7.5. THE URBAN BUILDING STOCK'S ENERGY CONSUMPTION

In this section, we study how urban growth contributes to greenhouse gas production by exploring how the geography and the physical attributes of the extant urban real estate

[29] The developing world's cities offer a number of natural experiments. For example, Cesur et al. (2013) documented the spatial rollout of natural gas access across Turkey's cities. They demonstrated how this cleaner fuel substitutes for coal and thus improves local air quality and reduces infant mortality. Greenstone and Hanna (2011) documented how the phase-in of vehicle control regulations in India's cities has reduced local air pollution and infant mortality. Zheng et al. (2014a,b) documented the changing industrial patterns of China's dirty industry as it moves away from the coasts. All of these cases share the same structure such that there is a large change in the spatial distribution of pollution allowing researchers to estimate sorting models to recover estimates of the willingness to pay for environmental public goods.

stock affect aggregate electricity demand. We focus on five key links between energy economics and urban economics. First, from the standard monocentric model, buildings closer to the city center are likely to be taller and thus less likely to feature a single tenant living or working there. As we discuss below, in such cases, a split incentive problem arises. Second, due to the durability of the capital stock, older buildings are likely to be closer to the city center. Because energy regulations tend to focus on new construction, this suggests that there will be important spatial differences in energy intensity. Third, geographic areas differ with respect to climate conditions, local electricity pricing, energy efficiency regulation, and incentives for conservation. A recent literature has sought to quantify the importance of these factors. Fourth, the types of households and firms that choose to locate in a metropolitan area may influence the demand for solar homes and LEED-certified buildings. Environmental ideology, in addition to economic incentives such as minimizing operating expenses, may play a key role in determining the demand for green buildings.

7.5.1 Pollution externalities associated with electricity consumption

In 2012, residential and commercial buildings were responsible for 74% of total electricity consumption in the United States.[30] Given that electricity continues to be generated using fossil fuels (e.g., coal is the fuel source for 70% of India's power and more than 70% in China), urban real estate is a major producer of global greenhouse gas emissions. As nations such as China erect hundreds of new housing and commercial towers that will last for decades, it becomes of even greater importance to study the investment decisions in energy efficiency made by real estate developers, building owners, and their tenants. In the absence of a global carbon pricing, nations are likely to continue to rely on dirty fossil fuels such as coal and natural gas for power generation. Such cheap fossil fuels exacerbate the climate change externality.

Coal-fired power plants are major producers of a large vector of local pollutants that can cause significant harm to health and aesthetics (Davis, 2011). The economic magnitude of these localized damages hinges on how many people live downwind from these power plants and their individual willingness to pay to not be exposed to pollution. Studies based on data from the United States and from China have estimated large Pigouvian social costs associated with the use of fossil fuel-fired power plants (Zhou et al., 2006; Muller and Mendelsohn, 2007; Muller et al., 2011). In the United States today, fewer coal-fired power plants are being built and some are being shut down. The composition shift from coal- to natural gas-fired power plants should reduce both the local and the global greenhouse gas externalities associated with electricity consumption. This in turn suggests that, if major reductions can be achieved in the carbon intensity of electricity, the

[30] http://www.eia.gov/totalenergy/data/monthly/pdf/flow/primary_energy.pdf, http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.9.pdf.

Pigouvian benefits of green buildings (relative to conventional buildings) will shrink as the carbon externality from electricity consumption shrinks.

7.5.2 The building stock's energy consumption: a bottom-up approach

At any point in time, the urban real estate stock is a mixture of residential, commercial, and industrial buildings of different vintages and sizes. In the past, empirical work aimed at understanding the role of these different factors in determining energy consumption was limited by a reliance on highly aggregated data such as per capita energy consumption collected at the nation/year level. In this new big data era, researchers have increased access to highly disaggregated data from the electric utilities that supply the power. These detailed data sets provide consumption information by customer account at monthly, and sometimes even hourly, frequencies. Explaining cross-sectional and temporal variation in residential and commercial electricity consumption has become an active research topic. By merging data from the electric utilities with structural characteristics taken from local appraiser's offices or from databases such as the CoStar data, researchers can observe a building's attributes, its location, and its energy consumption. Given that buildings differ along a number of attributes, researchers are now able to decompose what portion of a building's energy consumption is due to such factors as the physical attributes of the building, its location's regulatory structure, energy prices, and local climate conditions.

It is useful to consider a simple model of a city's energy consumption. In terms of residential energy consumption, assume that there are four key factors that determine an individual household's energy consumption: characteristics of the household members themselves (number, age structure, income, and preferences), the characteristics of the structure in which they live (size, vintage, quality, efficiency investments, etc.), the climate in which the housing unit is located, and the price paid for energy. For the industrial sector, we aggregate each industrial sector to the level of a representative firm. Each industrial sector's total electricity consumption is a function of its scale of activity in a given city, baseline energy intensity, climate, and energy prices.

Under these assumptions, the total energy consumption of the residential sector for city j at time t can be written as

$$KWH_j^r = N_j * \int_{h \in H} KWH\left(\text{household}_h, \text{stucture}_h, \text{climate}_j, \text{price}_j\right) f_j(h)\mathrm{d}h \tag{7.13}$$

In the right-hand side of Equation (7.13), H represents the continuum of household types, the distribution of which in a particular city j is given by $f_j(.)$. $KWH(.)$ is a function that maps the characteristics of household members and the structure in which they live—each of which varies by household type h—along with the climate and energy price vectors experienced in city j into average energy demand. N_j is the total number of households in city j.

Similarly, we can represent the total industrial consumption in city j as

$$KWH_j^i = \sum_{i \in I} KWH\left(\text{scale}_{ij}, \text{efficiency}_{ij}, \text{climate}_j \, \text{price}_j\right) \tag{7.14}$$

where I represents the set of industries in the economy, scale_{ij} captures the scale of industry in city j, and effiency_{ij} represents the average energy efficiency of firms in industry i that are located in city j.

The total greenhouse gas emissions associated with this consumption equal the sum of each of these sector's electricity consumption and then multiplied by the city j's electric power region's emissions factor. eGRID data from the US EPA allow one to calculate the tons of carbon dioxide per megawatt of power by region by year (see http://www.epa.gov/cleanenergy/energy-resources/egrid/). A standard number is that the social cost of carbon dioxide is $35 per ton. These numbers can be used to translate electricity consumption into a bottom-line social cost of carbon dioxide estimate.[31]

This accounting algebra highlights several microeconomic channels through which a city's evolving building stock influences overall city energy consumption dynamics. For example, in the very first issue of the *Journal of Urban Economics*, Harrison and Kain (1974) called attention to the importance of durable capital as a defining characteristic of cities. Over time, newer homes tend to be larger than older homes due to overall income growth. At any point in time, a city's building stock will be a mixture of different vintages. In cities with no new construction such as Detroit, buildings built more than 40 years ago can be a large share of the total stock. In recent years, such studies as Glaeser and Gyourko (2005) and Brueckner and Rosenthal (2009) have examined the role that housing durability plays in determining a city's urban form.

From an analysis perspective, it is critical to understand, and control for, the interplay among these different channels (building stock, climate, energy prices, urban geography, etc.) when evaluating the impact of new policies. For example, if Detroit has no new housing being constructed, does it, at baseline, have a much higher electricity consumption per square foot for its average housing stock than a similar city where old homes are being scrapped and new homes are being built? If so, then, these differences must be accounted for when making cross location policy comparisons.

Over time, energy efficiency codes for new buildings have been tightened (see http://www.energycodes.gov/regulations). Given the durability of the building stock, the average energy intensity may only be affected after several years have passed. Recent research has investigated the effectiveness of past building code regulation. Jacobsen and Kotchen

[31] A second negative externality from electricity consumption is local air pollution. The eGRID data can be used to calculate the sulfur dioxide and nitrogen oxide emissions and mercury emissions associated with local power consumption. These emissions may drift far from the origin city to geographic locations downwind of the power plants (see Bayer et al., 2009). In this sense, the consumption of electricity does not necessarily have local impacts on the city because power is generated in the region not in the locale.

(2013) collected data for roughly 2000 Gainesville, Florida, homes built at different dates. They compared the energy consumption of buildings built just before and after the regulatory changes (introduced in 2001) and found that the regulation is associated with a 4% reduction in electricity consumption and a 6% reduction in natural gas.

The third term in Equations (7.13) and (7.14) is local climate conditions. Both residential real estate and commercial real estate will consume more electricity in more humid hotter summer areas. Researchers have estimated the relationship between summer cooling degree days using both cross-sectional and panel approaches (Glaeser and Kahn, 2010; Miller et al., 2008; Aroonruengsawat and Auffhammer, 2011).

The basic microeconomic model here is a Becker household production function. A household seeks comfort and higher outdoor temperature reduces comfort. Greater expenditures on air-conditioning offset the outdoor temperature. The marginal cost of reducing the indoor temperature by one degree is a function of the efficiency of the air-conditioning unit and the price of electricity. The rational household sets the thermostat so that the marginal benefits of temperature reduction just equal the marginal cost of temperature reduction. In cooler cities such as San Francisco, such comfort can be produced using fewer market inputs, and in fact, many households do not own a central air conditioner. The widespread diffusion of air-conditioning over the twentieth century has allowed US households to enjoy the winter warmth of cities such as Las Vegas and Phoenix without suffering from the summer heat (Oi, 1996; Barreca et al., 2013). In this sense, market products can offset parts of a tied spatial local bundle. California is one of the rare locations in the world to feature temperate winters and summers.

7.5.3 Weak price incentives for conservation

For a typical single-family homeowner, their annual electricity bill is typically around \$1200 per year.[32] The marginal cost in terms of effort of achieving a 15% reduction in electricity consumption might exceed the cost savings given current electricity prices. Wolak (2011) presented a bounded rationality model featuring a cost of action such that residential homeowners are only willing to take costly actions (i.e., turning off the lights) if the financial savings in lower electricity bills covers the cost of taking such an action. His analysis suggests in areas with higher electricity prices that the residential sector will be more energy-efficient because there is "more money on the table." In addition to the impact of the price levels per se, households are confronted with a complicated electricity bill structure. Many electric utilities charge households on an increasing block tariff structure such that the price schedule resembles a staircase with a rising marginal price that jumps when consumption exceeds specific thresholds. For example, in Southern California, electricity consumers face a rate schedule with five steps with the highest price being over 30 cents/kWh. Ito (2014) employs a regression discontinuity design and

[32] http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf.

demonstrates that Southern California electricity consumers respond to average prices not marginal prices. A notable feature of his research design is that he compares the consumption of nearby homes that are located in adjacent electric utility districts. This means that there is within neighbor variation in the price of electricity. Ito exploits this and estimates an average price elasticity of consumption of roughly -0.12. This suggests that residential consumers are not very price-responsive. Recognizing this fact, utilities have sought innovative tools for encouraging conservation. Some have appealed to public conservation campaigns. Reiss and White (2008) presented evidence that these can be effective in the short run. A more novel approach is to distribute Home Energy Reports, which are customized reports educating households on how their consumption of electricity compares to their neighbors. Such peer pressure has been claimed to be an effective social incentive for encouraging conservation. Allcott (2011a,b) evaluation of these reports' impact indicates that they reduce consumption by 2%. These various research designs highlight that there is still the open question of how to make energy efficiency a more salient feature for households to consider. Higher electricity prices would clearly provide an incentive for households to invest more effort studying this issue. International evidence would be valuable here.

New technologies such as smart meters allow households to observe their electricity consumption every 15 min and to see how different devices in the home use different amounts of electricity. In the past, households received a bundled monthly bill telling them their aggregate consumption and total expenditure. With the falling cost of installing smart meters, the cost for electricity consumers of being educated about how different actions such as turning on the lights or running the air conditioner is falling. Such educated consumers should be more sophisticated shoppers for durables that reduce their operating costs and in aggregate improve overall energy efficiency. Field experiments, perhaps randomizing who receives a smart meter, testing this claim would be very useful.

7.5.4 The commercial real estate sector

In many cities, the commercial real estate sector (i.e., office buildings, malls, stores, and restaurants) represents a large share of the total real estate stock, but there has been surprisingly little research on this sector's economic behavior. Until recently, the lack of data has slowed research. The DOE's Commercial Buildings Energy Consumption Survey (CBECS) was last conducted in 2003. In some cases, research partnerships with electric utilities and with private major companies have allowed researchers access to unique microdata that have allowed for progress.

Kahn et al. (2014) partner with a major western electric utility who provided billing account data for every commercial account in their service area. This research team matched these data to the CoStar data. CoStar sells data for buildings that have transacted in the previous 10 years. By matching the two data sets, the researchers observed each building's monthly electricity consumption and had access to a large set of building attributes including its real estate quality, size, year built, and the tenant roster. They used these data to estimate regressions such as those reported in Equation (7.15):

$$\ln y_i = \gamma \cdot \mathrm{X}_i + \sum_{n=1}^{k} \varphi_p \cdot T_i^n + \varepsilon_i \tag{7.15}$$

In this equation, the dependent variable y_i is the natural logarithm of average daily electricity consumption per square foot. X_i is a vector of the structural characteristics of building i, including building size, vintage, and quality. To control for the impact of occupants on building energy consumption, we also include T_i, a vector of variables measuring the percentage of the building that is occupied by each industry n, based on their SIC classification. ε_i is an error term, assumed to be i.i.d.

Kahn et al. (2014) report that newer vintages of commercial real estate consume more electricity than older vintages and class "A" higher-quality real estate consumes more electricity than lower-quality real estate. They interpret these results to mean that a building's quality to its users and electricity inputs are complements. Given that building quality is likely to be a normal good, this suggests that rising incomes in cities around the world will lead to increased commercial building electricity consumption. They also find that tenant contract terms matter. When tenants pay their own electricity bills through triple net leases, they consume less electricity. Government tenants, who presumably face soft budget constraints, consume more electricity.

7.5.4.1 Commercial real estate energy efficiency and human capital

A key difference between residential single-family homes and commercial entities is that the former are small utility maximizers, while the latter are large profit maximizers. In contrast to the large number of residential households, each of whom spends relatively little on electricity bills, commercial electricity consumers are fewer in number and have much larger electricity bills. Kahn and Kok (2014) study Walmart's electricity consumption across its 220 California stores using monthly data provided by the company covering the years 2006–2012. The company provided additional data on each Walmart's store's climate conditions, year built, and the size and purpose of the store. Kahn and Kok use as a control group a set of other major retail stores that are independently managed but of the same size and age as these Walmart stores. In comparing the electricity consumption across these two sets, an interesting pattern emerges. The Walmart stores feature almost no cross store variation in their electricity consumption per square foot. Using their management systems, Walmart has standardized efficiency gains in electricity consumption. A human capital explanation for this is that Walmart's size is such that it is cost-effective for it to invest in high-quality managers who focus on energy efficiency and then apply the cost-saving innovations that they identify to each of its stores. This claim mirrors an argument explored by Bloom et al. (2010) who found that higher-quality managers of UK manufacturing plants use less electricity in producing output. This research agenda suggests that there is an inverse relationship between corporate management quality and *X*-inefficiency. Given that electricity consumption contributes to the global climate change externality, this hypothesis and the potential for economies of scale in achieving energy efficiency merit future research.

7.5.4.2 The market for green buildings

Urban residential and commercial structures are differentiated products. One attribute of such products is their energy efficiency. Standard economic logic suggests that when the price of electricity is high or is expected to rise (perhaps because a carbon tax is expected in the future), there will be greater demand for "green buildings." An emerging vehicle demand literature has documented that rising gasoline prices are associated with rising demand for fuel-efficient hybrid vehicles (Li et al., 2009; Klier and Linn, 2010; Beresteanu and Li, 2011). There are other factors such as personal ideology that also correlate with demand for distinctive green cars such as the Toyota Prius (Kahn, 2007). Gas prices are highly salient in that car drivers refuel on a weekly basis. In contrast, many households never see their monthly electricity bill because they pay with automatic billing. Sexton (2014) uses data from South Carolina and documents that when households sign up for automatic billing payments, their electricity consumption increases by 4% and commercial consumers increase their consumption by 8%. He attributes these effects to the absence of salient bills as these consumers no longer are confronted with what they are actually paying for electricity.

While fuel economy is the defining attribute of a "green car," in the case of "green buildings," there continues to be an open debate about what objective attributes signal a building's "greenness." The presence of solar panels is one possible definition. In the United States, the government has played an active role in being a market maker. The ENERGY STAR program, jointly sponsored by the US Environmental Protection Agency and the US Department of Energy, is intended to identify and promote energy-efficient products, appliances, and buildings. In a parallel effort, the US Green Building Council, a private nonprofit organization, has developed the LEED green building rating system to encourage the "adoption of sustainable green building and development practices."[33] The inventory of certified green commercial space in the United States has increased dramatically since the introduction of rating schemes (Kok et al., 2011).

[33] The LEED label requires sustainability performance in areas beyond energy use, and the requirements for certification of LEED buildings are substantially more complex than those for the award of an ENERGY STAR rating. The certification process for homes measures six distinct components of sustainability: sustainable sites, water efficiency, materials and resources, indoor environmental quality, innovation, and energy performance. Additional points can be obtained for proximity to public transport and for awareness and education.

A growing empirical hedonic real estate pricing literature has sought to estimate the market capitalization of such green attributes using hedonic regressions of the form

$$\log\left(\text{price}_{ijt}\right) = B_1 * X_{jt} + \delta_t + \pi_j + B_2 * \text{Green}_{it} + \varepsilon_{ijt} \tag{7.16}$$

In this regression, the researcher controls for housing structure observables and includes interactions of time- and geographic-fixed effects (e.g., zip code by year fixed effects). Controlling for these variables, the researcher tests whether B_2 is positive. One recent study investigated the capitalization of solar panels into the price of homes in San Diego County and Sacramento County in California. Solar panels are a source of pride for environmentalist households and lower the operating costs of owning a home. Dastrup et al. (2012) found that all else equal that solar homes sell for a 3% price premium. A plausible concern is that the presence of solar panels is correlated with other unobserved measures of a structure's quality. Using their panel data on home sales, they observed some solar homes that sold before the solar system was installed. They exploited this within home variation to establish that homes that in the future will install solar panels do not sell for a price premium before such an installation.

In another California hedonic real estate study, Kahn and Kok (2014) study the capitalization of energy star and LEED homes in California. The control groups are homes in the same zip code and on the same street as the energy-efficient homes sold at the same point in time. Kahn and Kok report that ENERGY STAR homes sell for a 3% price premium, but LEED homes do not sell for a price premium. The open question here pertains to what this label premium represents in terms of the present value of saved operating expenses and in terms of better indoor air quality and home performance.

A homeowner who wants solar panels faces a make-versus-buy decision. She can either buy a home that already has them or purchase a home and have the system installed. This option places restrictions on how high the solar price premium for resold homes can be. Over time due to international competition, the price of solar panels is declining. An emerging literature is studying this adoption decision. State and national subsidies have certainly played a role in encouraging the adoption of solar panels (Bollinger and Gillingham, 2012). Kahn and Vaughn (2009) documented the clustering of LEED buildings in liberal/environmentalist states such as California. An open topic concerns the diffusion of solar technology to cities in the developing world. Such cities often suffer from grid reliability challenges and solar would allow households to be independent.

For the commercial real estate market, a series of papers that study investor and tenant demand for "green" office space in the United States show that buildings with an ENERGY STAR label—indicating that a building belongs to the top 25% of the most energy-efficient buildings—or an LEED label have rents that are 2–3% higher as compared to regular office buildings. Transaction prices for energy-efficient office buildings are higher by 13–16%. Further analyses show that the cross-sectional variation in these premiums has a strong relation to real energy consumption, indicating that tenants and investors in the commercial property sector capitalize energy savings in their investment decisions (Eichholtz et al., 2010, 2013).

There has also been recent research on the supply side of the green commercial buildings market focused on the motivations of real estate owners and developers to compete on who "is the most green." The LEED certification has different levels of building greenness such as silver, gold, and platinum, and the threshold of points needed to cross to a higher level of greenness can be achieved through relatively minor investments (Noonan et al., 2013; Matisoff et al., 2014). An open question is whether such a "green" arms race actually contributes to overall sustainability goals such as reducing greenhouse gas emissions. The LEED criteria include many indicators of sustainability (such as using recycled materials), while the ENERGY STAR criteria are more narrowly focused on energy consumption.[34]

There are several possible next steps for this "value of green buildings" literature. Note that hedonic regressions such as Equation (7.16) do not control for the actual energy and water consumption of the building. Suppose that in estimating Equation (7.16), the key explanatory variable is a dummy that equals one if the building is LEED-certified. If continuous indicators of operating expenses could be observed, would the discrete certification dummy still be capitalized? Given asymmetrical information about a building's actual operating costs, does the green building dummy act as a coarse partition. Or do green buildings perform better on other criteria such as offering higher indoor air quality and hence raising worker productivity and quality of life? This literature could also explore whether green certification is more valuable in areas with higher average electricity prices. By including such an interaction term, scholars could study whether the demand for green buildings is mostly tied to minimizing operating costs. Such research could mimic Ito's (2014) spatial regression discontinuity design to observe the pricing of nearby buildings located in different electric utility zones.

7.5.4.3 Challenges in increasing the urban real estate's energy efficiency

Given the durability of the urban real estate stock, the vast majority of buildings are not new. An ongoing effort seeks to increase the energy efficiency of this stock, and many have argued that the equilibrium is unlikely to be a pareto optimum because of information asymmetries.

Consider a car buyer. The Internet offers easy to access information on any make and model's miles per gallon. Marketing experts have argued that this should be expressed as gallons per mile to help buyers calculate their annual operating expenses (Allcott, 2011a,b). In the case of apartments, there is no analogous energy labeling. Potential renters are likely to be unaware of what their monthly electricity bills will be in a building that they have never lived in before. This information asymmetry poses a sustainability

[34] http://www.usgbc.org/Docs/Archive/General/Docs1095.pdf.

challenge because if potential renters had full information about each apartment's energy efficiency, then the inefficient apartments would rent for less (especially in areas featuring high electricity prices) and this would incentivize the owners of these apartments to invest in greater energy efficiency.

In recent years, California has passed new regulations (AB1103) requiring the owner or operator to disclose the benchmarking data and rating to a prospective buyer, lessee of the entire building, or lender that would finance the entire building based on a schedule of compliance established by the State Energy Resources Conservation and Development Commission.

Recent research has examined the role of energy labels using data from around the world. The EU energy label seems to be quite effective in resolving the information asymmetry in understanding the energy efficiency of dwellings: Brounen and Kok (2011) estimated hedonic pricing gradients for recently sold homes in the Netherlands and documented that homes receiving an "A" label in terms of energy efficiency sell for a 10% price premium. It is relevant to note that the Netherlands has chosen a color-coded easy to understand educational labeling system where homes are partitioned into those that receive an "A," "B," "C," etc. This report card system is similar to how North Carolina reports grades for local school district's school quality (Kane et al., 2006). In the case of ENERGY STAR labeling, Houde (2014) uses a structural model to document that consumers respond to labels in different ways such that some greatly value such labels while others do not. The causes of these different responses merit future research.

Conversely, dwellings that are labeled as inefficient transact for substantial discounts relative to otherwise comparable, standard homes. Similar evidence has been documented for Singapore: Deng et al. (2012) found that homes labeled under the government-designed Green Mark scheme sell for a 4–6% price premium. In China today, no one trusted set of standards for ranking buildings exists (Zheng et al., 2012). The emergence of trusted energy efficiency standards is an important example of the public goods that developing country governments can cheaply provide in furthering urban environmental sustainability.

Electric utilities are becoming increasingly aware of the "power of big data" and are actively working with academics to devise strategies for encouraging energy efficiency. In states such as California where utilities must comply with a renewable portfolio standard (defined as the ratio of green power purchased divided by total power generated), one cost-effective strategy is to invest in energy efficiency and hence shrink the denominator. This regulatory pressure has increased the willingness of utilities to introduce field experiments to learn about what strategies are effective.

7.5.4.4 The renter/owner split incentive problem in cities

As predicted by the monocentric model, center cities are more likely to feature multi-family apartment buildings and multitenant commercial buildings than will be found in the distant suburbs. Such tall buildings offer significant economies of scale with respect to land consumption, but they raise issues of how to design proper energy efficiency incentives to encourage efficient investment by both the owner of the building and his or her tenants (see Levinson and Niemann, 2004; Maruejols and Young, 2011).

Based on the year 2000 census, 65% of metropolitan area housing units with five or more units were located within 10 miles of the CBD, while 42% of the metropolitan area single-family housing stock was located within 10 miles of the CBD. A "split incentive" literature has documented the energy efficiency challenge in multifamily housing (Levinson and Niemann, 2004). If the owner of the apartment complex pays the energy bills, then the renter faces a zero marginal cost for energy consumption. Since renters anticipate that they will not live in the building for a long period, they are unlikely to update energy-intensive durables such as the refrigerator or other appliances that they cannot easily take with them to their next home. If the renter pays the energy bills, then the owner has little incentive to invest in energy-efficient investments such as energy-efficient windows or an energy-efficient air-conditioning system. For evidence from the commercial real estate sector, see Kahn et al. (2014).

This would appear to be a key example where a randomized field experiment research design would yield valuable new knowledge. Suppose that an REIT was willing to select at random which of its buildings in its portfolio that it would be willing to offer net leases versus triple net leases. This randomization of rental contract terms would allow the researcher to study how the building manager and the tenant change their behavior in the face of the new incentives. By studying the dynamics of such buildings' electricity consumption, the researcher could estimate whether incentives matter for overall electricity consumption. The nonexperimental evidence reported in Kahn et al. (2014) and Levinson and Niemann (2004) suggests that they do, but a field experiment design would be more definitive.

7.5.5 Carbon pricing and the building stock's energy efficiency

At this point in time, the global free-rider problem has precluded the adoption of the global carbon tax. Such a credible policy would raise local electricity prices and incentivize developers and owners of existing buildings to invest in energy efficiency. In many developing nations today, a huge wave of urbanization is taking place. The investments made now will last for decades. If the investors anticipate that carbon pricing will become a reality, then they are more likely to invest in energy efficiency now. Energy efficiency investments in new capital in the developing world's cities remain an important future research topic. Research on endogenous innovation (see Acemoglu and Linn, 2004) highlights an optimistic hypothesis. If there is a growing global demand for "green buildings," then this creates strong market incentives for engineers to focus their efforts in creating such new varieties. The empirical induced innovation literature has consistently reported evidence of improvements in energy efficiency of new products such as air conditioners shortly after energy prices rise (Newell et al., 1999).

7.6. CONCLUSION

In this chapter, we have explored the connection between cities and the environment, highlighting the bidirectional nature of this relationship. One set of the reviewed literature examines the role that environmental amenities play in determining the economic geography of where diverse households and firms locate both within cities and across cities. A second set of relevant literature explores how a city's economic geography and the composition of its durable capital impact the environment—focusing largely on energy consumption and carbon emissions.

We used the long-run history of Pittsburgh to illustrate our sweeping theme that the relationship between cities and their environment has changed over the last century in a systematic way. This change has had a profound impact on where and how individuals and firms choose to locate. These shifts in the geography of economic activity have in turn influenced how cities impact the environment.

In the past, as highlighted by the case of Pittsburgh, the comparative advantage of cities was largely determined by access to transportation and productive resource that arose out of the natural environment. As these cities grew into the economic engines that characterize the industrial age, unchecked externalities severely impeded quality of life for their residents. Over 40 years ago, Nordhaus and Tobin (1972) wrote

> *Many of the negative "externalities" of economic growth are connected with urbanization and congestion. The secular advances recorded in NNP figures have accompanied a vast migration from rural agriculture to urban industry. Without this occupational and residential revolution we could not have enjoyed the fruits of technological progress. But some portion of the higher earnings of urban residents may simply be compensation for the disamenities of urban life and work. If so we should not count as a gain of welfare the full increments of NNP that result from moving a man from farm or small town to city. The persistent association of higher wages with higher population densities offers one method of estimating the costs of urban life as they are valued by people making residential and occupational decisions.*

Due to a confluence of trends, many cities have enjoyed a sharp improvement in their nonmarket quality of life with many of these gains concentrated along environmental margins. As a result, the requirement for big cities to provide "combat pay" has attenuated as nonmarket quality of life has increased and is a complement of the modern consumer city.

Air quality, water quality, and energy efficiency have become an emergent property of the industry, buildings, regulations, voters, and households who locate within a city's borders. Progress along these dimensions has been seen in cities such as Chicago, London, and New York City. Researchers see the start of similar trends in China. As demonstrated in work surveyed by Zheng and Kahn (2013), China's emerging system of cities is wrestling with many of these same issues. Some of China's cities are choosing to specialize in heavy industry and this is raising pollution challenges. At the same time, rich eastern Chinese cities are deindustrializing and pollution is declining. As the urban middle class grows in cities around the world, more and more citizens will demand nonmarket quality of life and environmental progress.

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