Cities 70 (2017) 135–152

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Effects of urban land-use regulations on greenhouse gas emissions

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A R T I C L E I N F O

Keywords:
Urban form
Greenhouse gas emissions
Land use
Climate change
Smart growth
Zoning

A B S T R A C T

This article describes a model-based exploration of the greenhouse gas (GHG) emissions impacts of urban land-use regulations. Two forms of regulation are considered: floor area ratio (FAR) restrictions and urban growth boundaries (UGBs). The model is designed so that regulation causes an endogenous adjustment of urban spatial structure, which in turn leads to changes in residential and transportation emissions. A novel aspect of the framework is that it captures regulation-induced inter-city migration. Results indicate that cities with low emission intensities should be cautious about adopting smart growth controls for climate change mitigation purposes. Even if such a regulation reduces per capita emissions everywhere, it can have the unintended consequence of increasing total emissions by pushing households to cities with higher emission intensities. Model variations reveal that this outcome is less likely if migration is costly or all urban areas are subject to some degree of regulation. Reducing emissions through land-use regulation generally carries a high abatement cost because consumers suffer from higher housing prices. Nevertheless, it could be an attractive mitigation option if policies are deployed in the right places, coordinated across cities, or generate substantial co-benefits (e.g., improved air quality, agglomeration economies, avoided infrastructure expansion).

1. Introduction

This article describes a model-based exploration of the greenhouse gas (GHG) emissions impacts of urban land-use regulations. Such policies are ubiquitous, and through their effects on urban form, they could strongly influence GHG emissions in an increasingly urbanized world. In addition, given the difficulties of formulating consistent climate policies on national and global levels, environmentally conscious cities could turn to land-use regulations as mitigation instruments governed and operating at the urban scale. The findings of this study shed light on several key research questions with clear policy relevance. Under what circumstances will urban land-use regulations reduce emissions? When they do reduce emissions, what will be the abatement cost borne by consumers due to higher housing prices? What factors do these outcomes most critically depend on? In short, this study advances the literature by developing a modeling framework for analyzing urban land-use regulations, and using it to enhance our understanding of their emissions and welfare impacts.

The remainder of this article is organized as follows. Section 2 contains a literature review. The model developed for this study is presented in Section 3. Section 4 describes the numerical simulations and the parameter values used as inputs. Results of the simulations are reported and discussed in Section 5. In Section 6, model variations are constructed to examine whether results are sensitive to different assumptions or additional model features. Section 7 concludes with a summary of the most salient findings of this study.

2. Literature review

2.1. Urban form and greenhouse gas emissions

It is well established that more compact urban forms are associated with lower GHG emissions (Grubler et al., 2012, chap. 18), an important consideration at a time of growing anxiety about climate change (IPCC, 2014). This relationship is based on several pathways related to emissions from the transportation and residential sectors. In transportation, higher population densities tend to shorten commutes as well as encourage investment in, and use of, public transit (Kennedy et al., 2011; Lohrey & Creutzig, 2016; Marshall, 2008). In the residential sector, homes in denser cities are typically smaller and more likely to be part of multi-family buildings, which use energy more efficiently than single-family detached houses (Ewing & Rong, 2008; Kennedy et al., 2011).

Myriad empirical studies have analyzed the linkages between urban form and GHG emissions. Glaeser and Kahn (2010) present data that reveal striking heterogeneity in per capita emissions across U.S. cities. Taking as examples the two cities at opposite ends of the range, an average household in Memphis produces 75% more residential and transportation emissions than an average household in San Diego. The

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http://dx.doi.org/10.1016/j.cities.2017.07.016
Received 7 February 2017; Received in revised form 29 June 2017; Accepted 15 July 2017
0264-2751/

observed heterogeneity has a number of explanations, but the authors find that urban form is a major factor.[1] In particular, more compact cities produce less emissions from automobile use and residential electricity consumption. Gasoline consumption decreases with census tract density and increases with distance to downtown. Electricity use and emissions from electricity are lower in denser cities. Marshall (2008) uncovers an inverse relationship between population density and vehicle travel across U.S. cities, with an elasticity of −30%. Ewing and Rong (2008) determine that residents of more sprawling U.S. counties typically live in larger homes and are more likely to reside in single-family detached houses, both of which lead to higher residential energy use. Andrews (2008) shows that residential and transportation emissions decrease with population density across municipalities in New Jersey.

Kennedy et al. (2011) study data from ten global cities that exhibit even more dispersion in per capita GHG emissions than the U.S. cities analyzed by Glaeser and Kahn (2010). For example, Denver produces over five times as much emissions as Barcelona does on a per capita basis. The analysis identifies a significant, inverse relationship between urban density and transportation emissions. Three sprawling North American cities – Denver, Los Angeles, and Toronto – feature the highest per capita transportation emissions by a substantial margin. Notably, New York, which is denser than these other cities, has much lower transportation emissions similar to those of the European cities in the sample. All four North American cities consume more fuel for heating and industrial uses than their climates would imply, likely due to larger home sizes. Lohrey and Creutzig (2016) find that transportation emissions decrease with density across a sample of global cities. They show that a threshold density for high public transit use exists around 50 persons per hectare, and that a large public transit mode share reduces emissions significantly.

The evidence indicates that more compact urban forms are associated with lower GHG emissions, but many cities around the world are spreading out. This phenomenon, known as urban sprawl, is most evident and acute in the U.S. (Mieszkowski & Mills, 1993). In 1950, 65% of the American urban population lived in central cities and the remaining 35% lived in suburbs. By 1990, these percentages had flipped (Nechyba & Walsh, 2004). Population densities in both central city and suburban areas fell over this period. According to Marshall (2008), the average urban population density in the U.S. fell by 13% per decade from 1960–1990 and 34% from 1990–2000. Data from the two most recent U.S. censuses reveal a further 12% decline from 2000–2010 (U.S. Census Bureau, 2000, 2012). Urban sprawl is a dominant tendency in many other countries. Cities throughout the formerly socialist states of Central and Eastern Europe are undergoing low-density suburban sprawl, often around deteriorating urban cores (Schmidt, Fina, & Siedentop, 2015). Bart (2010) and Siedentop and Fina (2012) document substantial sprawl in Ireland, Portugal, and Spain, where increases in road transport carbon dioxide (CO_2) emissions and artificial land cover are outpacing population and economic growth. Chinese cities like Guangzhou and Dongguan are adding urban land at historically unprecedented rates and quickly approaching the expansive forms of U.S. urban areas (Schneider & Woodcock, 2008). On the other hand, there are notable counterexamples to urban sprawl. Supported by consistent policy priorities and investment in public transit, Oslo has become denser while experiencing significant population growth. Urban population densities have increased throughout Norway and Sweden (Næss, Næss, & Strand, 2011).

The dominant cause of urban sprawl has been lower transportation costs enabled by the widespread diffusion of cars and trucks. In this sense, sprawl could be viewed as a beneficial process through which consumers are maximizing their well-being (Glaeser & Kahn, 2004, chap. 56). However, other drivers of urban sprawl are related to negative externalities and policy failures. Sprawling development requires greater public infrastructure expenditures to extend power lines, roads, and sewage systems (Brown & Southworth, 2008; Nechyba & Walsh, 2004). Massive federal spending on highways (in contrast to low investment in public transit) distorts transportation mode decisions in favor of automobiles (Glaeser & Kahn, 2004, chap. 56; Hart & Spivak, 1993). The failures of many central cities to control crime and maintain adequate public schools have driven former central city residents to the suburbs (Berry-Cullen & Levitt, 1999). Land-use regulations which restrict housing supply and raise prices push residents to communities on the urban periphery in search of affordable housing (Bertaud & Brueckner, 2005; Glaeser, Gyourko, & Saks, 2005). Externalities such as climate change are largely unpriced, so the private costs of emitting activities like driving are lower than their social costs.

Analysts have increasingly emphasized the potentially significant contributions that efforts to limit urban sprawl could make toward reducing GHG emissions and mitigating climate change. Marshall (2008) suggests that better urban design is an undervalued mitigation strategy that could have long-term impacts similar in magnitude to those of technological innovation. Stone, Mednick, Holloway, and Spak (2009) project that strong urban densification in the Midwestern U.S. would reduce year 2050 transportation emissions by the same amount as full adoption of hybrid-electric vehicles. Hankey and Marshall (2010) estimate that year 2020 U.S. passenger vehicle emissions would be 18% lower than year 2000 emissions under a high densification scenario but 17% higher under a high suburbanization scenario. If urban design is neglected, the increase in vehicle travel could offset improvements in vehicle efficiency and carbon intensity of fuels. Clearly, policies that counteract urban sprawl and lead to more compact urban forms have the potential to significantly reduce GHG emissions. Since urban land-use regulations are implemented by individual cities or urban areas, they can be effective tools for reducing emissions in the absence of political will to address climate change at higher levels of government.

2.2. Urban land-use regulations

Urban land-use regulations have a fascinating history, particularly as they proliferated and evolved over the twentieth century. Rather than provide a lengthy survey of the vast suite of land-use regulations in effect in cities around the world, this subsection focuses on the two forms of regulation analyzed in this study. For a broad overview of urban land-use regulations, see Downs (1994) and Fischel (2004, 2015).

2.2.1. Floor area ratio restriction

A floor area ratio (FAR) restriction imposes an upper limit on the ratio of building floor space to lot area. For example, a 60% FAR restriction applied to a lot of 10,000 square feet (ft^2) limits the building floor space constructed on it to 6,000 ft^2. FAR restrictions less than 100% are in place in many suburbs, as they mandate that a portion of each lot be dedicated to lawns, trees, and other uses apart from physical housing. Dense city centers may be subject to FAR restrictions many times greater than 100%, which effectively limit the number of stories in a building. For example, a 500% FAR restriction limits building height to five stories if the whole lot is covered, or ten stories if half the lot is covered. Therefore, maximum building heights, which are another popular form of urban land-use regulation, function in largely the same manner as these FAR restrictions.

FAR restrictions are typically adopted for reasons other than concerns about sprawl or climate change. Proponents of these regulations argue that they prevent excessive densities that would lead to undesirable levels of traffic congestion, noise, and air pollution. They also preserve natural light and aesthetic value (Ewing & Rong, 2008). Austin, Texas uses FAR restrictions extensively for these purposes. Its zoning code specifies permitted uses for each lot, and many uses are subject to FAR restrictions. For example, Austin imposes maximum

[1] Other explanations include the climate, as it affects heating and cooling degree days, and the fuel mixes used for electricity generation and home heating.