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Environmental performance of the urban form

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ABSTRACT

Urban polycentricity and periurban areas are increasingly common features of regions worldwide. This paper presents a spatially explicit model to explore the environmental performance of the urban form with respect to two variables, natural or agricultural land consumption, and greenhouse gas emissions from commuting. It introduces different lot sizes based on residential location, which provide a stylized representation of the decrease in lot size with distance, observed in the real world. In doing so, this model emphasizes the role of residential lot size in the environmental consequences of urban development. It points out to the possibility of conflicting environmental objectives in the management of urban development.

1. Introduction

The share of population worldwide has increased from 30% in 1950 to 54% in 2014, and it is expected to reach 66% by 2050 (United Nations, 2014). Urban growth is associated with a number of environmental issues, particularly those related to the conversion of land to urban uses with several environmental concerns (alteration of the water cycle, damage to biodiversity, etc.), and those related to the commuting behavior of households, that contribute to the emissions of greenhouse gases (GHG) and air pollutants. Therefore it is important to understand how urban development, and the form it takes, affect the various components of the environmental performance of a city. This question is now largely studied. For instance, Kahn and Walsh (2015) provide a survey of works on the link between cities and the environment. Besides exogenous attributes such as climate, they identify local air pollution and green space as endogenous attributes of urban growth. In this respect, the link between cities and the environment is grasped through the role of environmental amenities, the carbon footprint of cities, how urban environmental amenity dynamics affects the system of cities, and the private costs and benefits of investing in green buildings. We propose in this paper a model in which the urban system (more or less polycentric and more or less spread), GHG emissions and land consumption are endogenous.[1]

Modern urban development increasingly takes the form of polycentric urban structures and sprawling cities into large periurban belts, in contrast with the standard urban economics model of the monocentric and dense city. We analyze two aspects of the environmental performance of a polycentric region with three urban areas, each of which is made of a city with a business district (either a primary or a secondary business district) where jobs are concentrated, surrounded by dense residential zones on both sides and further by two periurban belts where density is lower. The environmental performance is assessed with respect to two variables: the emissions of GHG resulting from commuting to work and the consumption of agricultural/natural land for urban uses. The degree to which urban development affects both issues depends on how activities, and households, organize around primary and secondary cities, and in cities or periurban belts.

The first environmental issue we address is transport-related GHG emissions. Transportation is responsible for 24% of GHG emissions in EU-28 (29% in the US), making it the second highest emitting sector after energy, and on-road vehicles contribute to 71,9% of these emissions (79% in the US). Furthermore, GHG emissions from the transport sector increased by 36% in EU-28 between 1990 and 2007 (and by 27% in the US between 1990 and 2006) (European Environment Agency, 2012; Environmental Protection Agency, 2015). Although substantial pollution reduction can be achieved by implementing technological innovation (Glaeser and Kahn, 2010), this is unlikely to be sufficient to stabilize the contribution made by the transport sector (European Environment Agency, 2012), and in particular by commuting, the transportation of people to and from their workplace. There is a large empirical literature that analyzes the impact of city size and structure on GHG emissions, via commuting (Brownstone and Golob, 2009; Glaeser and Kahn, 2010). Among the theoretical contributions, Gaigné et al. (2012) stress the importance of between and within cities' relocation of

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[1] However, we do not analyze the environmental externalities provided by neighboring residences since this usually implies a two-dimensional space (see for instance Caruso et al. (2015)).

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activities and households on commuting behavior. In contrast to the large consensus in favor of compact cities to reduce their ecological footprint, Gaigné et al. (2012) show that when activities can relocate within and between cities, a density-increasing policy may reshape the city in a way that generates more GHG emissions, through a more monocentric configuration. They argue that a density-increasing policy should be supplemented by a policy favoring the emergence of secondary centers to ensure a reduction in GHG emissions. In this paper, we show that the type of residential development (urban vs periurban) also matters through the density difference it introduces.

The second environmental issue we look at is the consumption of agricultural, forested or natural land for urban use, particularly in the form of urban sprawl, which is a major concern around the world. For example, in a survey carried out by the Pew Center for Civic Journalism in 2000, cited by Burchfield et al. (2006), 18% of Americans identified urban sprawl and land development as the most important issue facing their local community — the top response, tied with crime and violence. "*Urban land use quadrupled in the US between 1945 and 1997* (*three times the rate of population growth*), [*and*] *it became more dispersed* (*urban sprawl*, *edge cities*, *string cities along interstate highways*, *housing for senior citizens*, etc.)" (Bell et al., 2006). Concern for sprawl is not limited to the US; the European Environmental Agency issued a reference report that analyzes the drawbacks of urban sprawl: "*The sprawling nature of Europe's cities is critically important because of the major impacts that are evident in increased energy*, *land and soil consumption. These impacts threaten both the natural and rural environments*, *raising greenhouse*" (European Environment Agency, 2006). Between 2000 and 2006, the land uptake by urban and other artificial development represented only 0.1% of the total territory of 38 European countries (approximately 636 900 ha in 6 years (European Environment Agency, 2015)[2]); nevertheless, it is a major concern because "*this affects biodiversity since it decreases habitats*, *the living space of a number of species*, *and fragments the landscapes that support and connect them*" (European Environment Agency, 2015). Research works develop the environmental aspects of land use change, on biodiversity, ecosystem services, climate change, floodings or forest fires.[3] The same applies to France, where the growth rate of land artificialization reached, between 2006 and 2012, 0.49% per year (Janvier et al., 2015), or, according to another source, 490,000 ha between 2006 and 2014, that is an increase of 55,000 ha per year since 2008 (Fontes-Rousseau and René, 2015). Ahearn and Alig (2006) note that in large part, this new use of previously undeveloped land is for rural residences, oftentimes on the fringe of urban areas, and oftentimes with large lot sizes. Duranton and Puga (2015) provide an integrated treatment of the theoretical literature on urban land use inspired by the monocentric model, including extensions that deal with multiple endogenous business centers. Based on the Alonso–Muth–Mills monocentric model, urban economists have provided important theoretical insights over the last decades that analyze the causes and consequences of urban sprawl (see, e.g., Mieszkowski and Mills, 1993; Brueckner, 2000; Nechyba and Walsh, 2004; Glaeser and Kahn, 2004). Wu (2006), Wu and Plantinga (2003) and Lichtenberg et al. (2007) analyze how natural amenities, in particular open spaces, and land use regulation influence urban growth and explain leapfrogging.

The levels of GHG emissions and land consumption within an urban structure depend on where the households and firms decide to reside within it. Indeed, these choices may give rise to both polycentricity and periurbanisation or suburbanization, which are not neutral with respect to commuting patterns and residential land consumption. The emergence of polycentric urban structures is due to the interplay between urban costs (residential land rent and commuting costs) and the communication costs borne by firms decentralized in secondary business districts (SBD), required to access services in the central business district (CBD). On the one hand, urban costs rise with increasing city size and workers have to be compensated by firms through payment of higher wages (Timothy and Wheaton, 2001). This creates an incentive for firms to locate outside the main center, in secondary centers where urban costs are lower. On the other hand, decentralized firms incur costs related to accessing specific services, such as finance, which are retained in the CBD. Schwartz (1993) for instance shows that about half of the business services consumed by US firms located in suburbia are supplied in city centers. However, decentralization is being facilitated more and more by falling communication costs. Cavailhès et al. (2007), using a two region model, analyze the interplay between urban costs, communication costs, and the trade costs of interregional shipment of commodities. They show that under certain conditions, polycentric agglomerations outperform monocentric cities on economic grounds: "*the emergence of sub-centers within cities is a powerful strategy for large cities to maintain their attractiveness*" (Cavailhès et al., 2007). However they do not take account of environmental concerns. Gaigné et al. (2012) extend this analysis to discuss the impact of increasing density policies on GHG emissions.

The major contribution of this paper is to contrast how the urban structure, and the economic parameters that shape it, affect two environmental issues which are highly dependent on the location choice of households and firms. Our model provides analytical solutions in which the presence and size of secondary business districts (SBD) and population location in dense cities or less dense periurban belts are endogenous. The labor market (wages in the CBD and the SBD) and communication costs determine the repartition of firms between the CBD and the SBD and the land market determine the residential equilibrium by way of the usual tradeoff between transport and housing costs. We introduce two types of residential areas, the city (i.e. dense housing) and the periurban belts (i.e. less dense housing[4]), around each business district, and we allow residential densities to differ between areas. With three different lot sizes (i.e. primary and secondary cities and periurban belts), we roughly account for the increase in lot size with distance from the business districts and the decrease in density observed in the real world, but we provide a richer depiction of the reality than under the more common assumption of a fixed lot size over the entire urban system. Moreover, this formalization allows us to derive analytical results in the study of environmental issues for which density differences are crucial.[5] We first assume that the housing lot sizes are exogenous (Sections 2–4) before introducing local public goods as determinants of these lot sizes (Section 5).

This paper sheds a new light on the debate relative to urban growth and its negative environmental impacts such as excessive land consumption and emissions of GHG. We point out that the usual policy instruments to limit these impacts (tax or toll on commuting, zoning and land regulation, etc.) can be complemented with non standard approaches targeted at the provision of local public goods (LPG) and at the level of communication costs between business districts. We also show that depending on the policy basis (transport costs, communication costs, housing lot size or local public goods), managing GHG emissions may either come at the expense of increased land consumption or induce a win–win solution in which both GHG emissions and land consumption are reduced.

We describe our modeling strategy in Section 2 and derive the decentralized equilibrium in Section 3. Section 4 analyzes the environmental outcomes of the equilibrium regional structure. Section 5

[2] A higher-resolution, new data source suggests that artificial surfaces are underestimated.

[3] See Duke and Wu (2013) and in this book, see particularly contributions by Lewis (2013); McCarl et al. (2013); Attavanich et al. (2013) and Montgomery (2013).

[4] We do not take into account the scattered pattern of housing in periurban belts.

[5] Our assumption of four different residential lot sizes can be relaxed progressively, by introducing an increasing number of lot sizes in a stepwise manner until reaching the standard urban economics framework of a monotonous increase of residential lot size with distance from the CBD.