Regional Science and Urban Economics 52 (2015) 83–92

Contents lists available at ScienceDirect

Regional Science and Urban Economics

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

Correlated environmental impacts of wastewater management in a spatial context

Sophie Legras *

INRA, UMR 1041 CESAER, F-21000 Dijon, France
AgroSup Dijon, UMR 1041 CESAER, F-21000 Dijon, France

ARTICLE INFO

Article history:
Received 27 February 2014
Received in revised form 5 March 2015
Accepted 10 March 2015
Available online 18 March 2015

Keywords:
Wastewater management
Residential water pollution
Land use
Commuting
Polycentricity

ABSTRACT

In this paper we analyze how wastewater management affects water quality and urban spread, through agents' residential location choice between sewer-serviced suburbia, and septic dependent exurbia. We adopt an urban economics model of monocentric city, then a polycentric city, with two different residential areas: suburbia, where there is access to a sewer system and the residential lot size is small, and exurbia, where there is no access to sewerage and the residential lot size is larger to accommodate the sanitary arrangements to meet the regulation on individual septic systems. According to the abatement efficiency gap between wastewater treatment technologies, improving water quality may be achieved at the expense of higher or lower urban spread. We also conduct an analysis of a polycentric city to highlight how asymmetric decision making between primary and secondary cities may have beneficial consequences at the local level, but be detrimental to aggregate environmental performance of the polycentric city. Our conclusions illustrate the unexpected impacts, positive and negative, that managing an environmental issue can have on another issue on the same scale or the same issue on a larger scale.

1. Introduction

Since an increasing share of the population lives in cities and their close hinterlands it is crucial to understand how urban development, and the form it takes, impacts on the environment. Urban growth is associated with numerous types of environmental damage: the transport of people and goods contributes to local air pollution and greenhouse gas emissions (Kahn, 2006; Glaeser and Kahn, 2010; Hensher, 2002); the increase in impervious surfaces alters the functioning of water ecosystems (Lohse et al., 2008); and land fragmentation affects biodiversity (Merenlender et al., 2009; Tannier et al., 2012); etc.

Urban development can take different forms that do not exhibit the same environmental performance. Studies stress the importance of the urban/rural gradient for understanding the environmental impact of urban development: urban, suburban, exurban areas and their residential patterns do not necessarily have an effect on the same environmental issues, and do not necessarily affect them in the same manner (see for the case of biodiversity, Hansen et al. (2005)). Additionally, the organization of productive activities matters. Polycentric urban structures are becoming a prominent feature of the landscape worldwide, and the impacts of the decentralization of jobs and people within metropolises on sprawl and greenhouse gas emissions are not straightforward (Gaigné et al., 2012; Legras and Cavailhès, 2012). Consequently, the form of urban development can have different impacts on various environmental issues, and the nature of the correlation between these affected environmental issues is crucial in the design of efficient public policies. However, the environmental impacts of urban development are often considered in isolation. The purpose of this paper is to clarify the nexus between two environmental issues attributable to urban development by analyzing how wastewater management policies affect the urban form, including both water quality, its primary purpose, and urban spread.

Why focus on wastewater management to investigate the link between two components of the environmental performance of urban development? In a recent paper, Newburn and Berck (2011a) point to the crucial role played by the choice of wastewater technology on the type of development occurring at the urban fringe: additional costs entailed by the extension of municipal sewers can significantly reduce the reservation price of agricultural land in suburban use, while exurban development can occur immediately, and entails only onsite conversion costs. Then the bid rent of households with a preference for large lots can exceed the agricultural landowner's reservation price for future suburban use in what has been described as an exurban “feasible zone” where development leapfrogs. This theoretical work establishes a strong link between the choice of wastewater technology and the type of residential development chosen by households. This link was

* UMR CESAER, 26 bd Docteur Petitjean, BP 87999, 21079 Dijon Cedex, France. Tel.: +33 3 80 77 25 36; fax: +33 3 80 77 25 71.

http://dx.doi.org/10.1016/j.regsciurbeco.2015.03.002

invoked by Maryland Governor O'Malley in recommending a "septic bill", adopted in 2012[1]. This piece of legislation is aimed at limiting the development of new residential lots based on septic systems, especially in rural areas. Its justification is twofold: to reduce wastewater-related polluting inputs to Chesapeake Bay, and to curb urban sprawl. Other states or countries are experiencing evolutions in their wastewater management rules. For instance, in France, areas not serviced by collective sewer systems have to be registered, and all individual septic-based installations inspected; this is supervised by local council mayors and landlords are liable for all costs (of inspection, necessary upgrading, and inspection upon sale of the property). The objective to improve the efficiency of individual wastewater treatment options imposes a cost which may affect future residential developments.

Relying on wastewater management as an indirect solution to limiting urban spread seems appealing given the apparent lack of efficiency of direct instruments (Newburn and Berck, 2011b; Harrison et al., 2012). An empirical examination by Newburn and Berck (2011b) shows that policies aimed at limiting urban growth are more efficient at managing suburban rather than exurban development, and have the potential adverse effect of encouraging development in exurbia, and hence higher reliance on septic systems and a stronger hold on land resources. Similarly, Harrison et al. (2012) show that septic-based development has increased significantly in the Baltimore region since the passage of Maryland's Priority Funding Area legislation aimed at new developments where there is an existing collective wastewater infrastructure.

In this paper we analyze how wastewater management affects water quality and urban spread, through agents' residential location choice between sewer-serviced suburbia, and septic dependant exurbia. Our case considers a featureless landscape where proximity to water is not a determinant of residential location, in order to focus on analysis of the impact of a change to wastewater management costs on households' decisions. Indeed, recent hedonic analyzes point to the impact of distance to the water body on households' valuation of water quality (Walsh et al., 2011; Netusil et al., 2014). Consequently, the water pollution externality is considered implicitly and we treat the question of the ability of a policy targeted at wastewater treatment costs to help compliance with water quality requirements imposed externally — such as those coming out from the European Water Framework Directive[2]. We adopt an urban economics framework which allows us to assess aggregate water pollution and urban spread. We depart from Newburn and Berck (2011b)'s analysis by assuming a fixed lot size within each type of residential area in order to focus on the environmental impact of suburban and exurban developments. We depart also from previous studies that endogenize environmental externalities (see for instance Arnott et al. (2008) or Kyriakopoulou and Xepapadeas (2013)). We characterize wastewater treatment technologies according to their abatement efficiency. We show that in a monocentric setting, depending on the relative abatement efficiencies of septic and sewer systems, strategies that improve water quality by modifying wastewater management costs, may increase or decrease urban spread. We also conduct an analysis of a polycentric city to highlight how asymmetric decision making between primary and secondary cities may have beneficial consequences at the local level, but be detrimental to aggregate environmental performance of the polycentric city. Our conclusions illustrate the unexpected impacts, positive and negative, that managing an environmental issue can have on another issue on the same scale or the same issue on a larger scale.

Key to the proposition of joint management of water quality and urban spread is the assumption that septic- and sewer-based systems do not perform identically with respect to pollution abatement. Indeed, a number of papers raise awareness of the detrimental impacts of poorly designed, poorly sited or badly maintained septic systems on water quality, especially of groundwater (Arnade, 1999; Borchardt et al., 2003; Moore et al., 2003). Sewer systems contribute to water pollution, and there is a strand in the literature that assesses the environmental performance of different types of collective sewer systems (e.g. Lassaux et al. (2003)). However, few studies compare the impacts on water quality of sewer and septic systems which are not homogeneous: the former impacts mainly on surface water while the latter has a more direct effect on groundwater; the effluents they generate differ in type and quantity; and septic failure is diffuse and develops relatively unseen over time while sewer-related issues are more evident and are dealt with punctually and quickly. Consequently, no a priori assumptions are made in this paper regarding an efficiency gap. An empirical assessment of which system performs better under which conditions is beyond the scope of this study.

The paper is organized as follows. Section 2 presents a model of a monocentric city with a sewer serviced suburbia and a septic-dependant exurbia. In Section 3 we derive the spatial equilibrium, and analyze how wastewater management costs affect population distribution over suburbia and exurbia, and consequently urban spread and water quality. Section 4 extends the analysis to a polycentric context and introduces heterogeneous wastewater costs. Section 5 concludes.

2. The model

We initially set our analysis within the framework of a monocentric city. This is comprised of a central business district (CBD) encompassing all the firms which do not consume land, and two types of residential area — suburbia, where there is access to a sewer system and the residential lot size is h_s, and exurbia, where there is no access to sewerage and the residential lot size, h_e, is larger to accommodate the sanitary arrangements to meet the regulation on individual septic systems. This is in line with Heimlich and Anderson (2001) who state that recent land development in the US takes two major forms: continuous accretion of urban growth in suburbia at the fringe of an urban area, and multiplication of larger-lot housing beyond the urban fringe and in nonmetropolitan counties exurbia.

Suburban and exurban developments represent two fundamentally different types of growth: the former relies on access to sewers, and on small residential lots (<1 acre), the latter is not bound to a collective sewer and hence relies on septic systems and a larger lot size (540 acres per unit) (Heimlich and Anderson, 2001; Newburn and Berck, 2011a). We keep both lot sizes fixed but different in order to capture the gap observed between suburban and exurban areas. This assumption simplifies but is in line with the stylized fact that lot size increases stepwise with distance from the CBD. Furthermore, it allows us to derive analytical results on the city's environmental performance which we believe to some extent justifies recourse to this simplifying assumption. The assumption of fixed lot size in suburbia may be reinforced by the nature and mechanism of residential development in areas with access to collective infrastructure. The exurban lot size we consider can be regarded as a lower bound to actual exurban lot sizes, imposed for sanitary purposes when an individual wastewater system is used.

Space has one dimension, $x \in \mathbb{R}$ and is symmetric with $x = 0$: without loss of generality, we focus on the right-hand side of the city where $x \geq 0$. The borders of the various areas are determined endogenously. The city comprises a continuum of N individuals, exogenously determined. We seek to understand how the evolution of wastewater management costs may alter the residential choice of agents between suburbia and exurbia — hence our focus on a closed city framework.

Agents consume a level $q(x)$ of an aggregate consumption commodity, and an amount h_s or h_e of living space depending on whether they reside in suburbia or exurbia, with $h_s < h_e$. They commute from their place of residence to the CBD at a unitary cost $t > 0$ per distance traveled. They generate water pollution as a by-product of consumption with an emission factor assumed equal to 1. The wastewater infrastructure abates pollution to different extents according to the system in use,

[1] Senate Bill 236, Sustainable Growth and Agricultural Preservation Act of 2012.

[2] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.