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Land use dynamics and the environment

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ABSTRACT

This paper builds a benchmark framework to study optimal land use, encompassing land use activities and environmental degradation. We focus on the spatial externalities of land use as drivers of spatial patterns: land is immobile by nature, but local actions affect the whole space since pollution flows across locations resulting in both local and global damages. We prove that the decision maker problem has a solution, and characterize the corresponding social optimum trajectories by means of the Pontryagin conditions. We also show that the existence and uniqueness of time-invariant solutions are not in general guaranteed. Finally, a global dynamic algorithm is proposed in order to illustrate the spatial-dynamic richness of the model. We find that our simple set-up already reproduces a great variety of spatial patterns related to the interaction between land use activities and the environment. In particular, abatement technology turns out to play a central role as pollution stabilizer, allowing the economy to reach a time-invariant equilibrium that can be spatially heterogeneous.

1. Introduction

Land use activities are usually defined as the transformation of natural landscapes for human use or the change of management practices on human-dominated lands (Foley et al., 2005). It is widely accepted that these activities have greatly transformed the planet's surface, encompassing the existence and evolution of spatial patterns (for instance, Plantinga, 1996; Kalnay and Cai, 2003; Chakir and Le Gallo, 2013). In this regard, spatial economics analyses the allocation of resources over space as well as the location of economic activity and, thus, the formation of spatial patterns. In particular, great effort has been devoted to understanding firms' location, transport costs, trade, and regional and urban development (Duranton, 2007). However, the mechanisms behind the interaction between land use and the environment that can induce spatial patterns, designated in our paper as spatial drivers, are still far for being understood. In this paper we contribute to the theoretical foundations of land use change and the environment by considering the interaction between land use activities and pollution. To this end we will develop a theoretical model that focuses on the spatial externalities of land use as drivers of spatial patterns.

There is an abundant literature on the interaction between land use and pollution. Agricultural research in particular has devoted great attention to the effects of pollution on agricultural land use (for instance, Adams et al., 1986; Deschênes and Greenstone, 2007). About the environmental influence of land use, many papers have identified significant environmental

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impacts of land use (among others, Matson et al., 1997; Kalnay and Cai, 2003). Moreover, Foley et al. (2005) point out that the effects of environmental degradation due to land use are global but also regional/local. Although this literature has been very fruitful, the dominant approach has been empirical. There is indeed a general agreement about the lack of explicit modeling of the spatial drivers behind the interaction between land use and pollution. Closely related to the integrated assessment approach, bottom-up models of agricultural economics (for instance, de Cara et al., 2005) have contributed to the understanding of the spatial drivers of land use. However, these models focus on partial equilibrium (mainly the supply side) and do not completely consider the intertemporal dimension of the problem. In this paper we use an alternative approach based on the dynamic spatial theory (see Desmet and Rossi-Hansberg, 2010, for a survey).

Within this theory, considering the forward-looking dimension of agents' decisions, the natural spatial generalization of the Ramsey model is presented in Brito (2004) and Boucekkine et al. (2009, 2013a). Both include a policy maker who decides the trajectory for consumption at each location. The main feature of these models is the spatial dynamics of capital, which flows in space to meet optimal decisions according to a partial differential equation (PDE). Although these sophisticated models are very promising, several technical problems have been identified (Boucekkine et al., 2013b). In particular, the application of parabolic PDEs in this new field has opened a set of questions still not solved by the mathematical literature. To date, there have been few pragmatic approaches that provide alternative set-ups. For instance, Costello and Polasky (2008) provide a dynamic framework to study the optimal harvesting of renewable resources in a stochastic spatial (partial equilibrium) model. Taking advantage of the special structure of the problem, they are able to analytically characterize the equilibrium. Desmet and Rossi-Hansberg (2009, 2010, 2013), more in line with the spatial Ramsey model, follow the idea of imposing enough structure to the spatial problem (through factors' mobility, diffusion of technology, and land and firm ownership) as well. Agents are assumed to be myopic. While each location solves a static problem, their model is dynamic in time. Indeed, each location decides the optimal amount to consume, how much to invest in R&D, and how much to save, taking land revenues, prices and salaries as given. Finally, all savings are coordinated by a cooperative that invests along the space. Even if this approach allows us to understand some important geographic features, the structure of their framework makes the planner's problem intractable (see also Desmet and Rossi-Hansberg, 2012). Another interesting alternative is the one followed by Brock and Xepapadeas (2008, 2010). Considering Derzko et al. (1984), they approximate (linear quadratic) the original nonlinear optimal control problem, around a time-invariant equilibrium. However, as we will show later, neither existence nor uniqueness of time-invariant solutions are ensured in an environmental spatial Ramsey framework.

We use in this paper the spatial generalization of the Ramsey model in order to understand the spatial drivers behind land use and the environment. To the best of our knowledge, our paper provides a first analytically tractable general equilibrium framework of land use that, without approximating the original optimal control problem, encompasses (i) spatial and time dimensions which are presented in a continuous manner, (ii) spatial externalities due to pollution and abatement activities, and (iii) the social optimum. Our starting point is the spatial Ramsey model in Boucekkine et al. (2009, 2013a). We propose a benchmark framework in continuous time and space to study optimal land use. Each location is endowed with a fixed amount of land, which is allocated among production, pollution abatement, and housing. Although the unique production input (land) is spatially immobile by nature, this is a model of spatial growth where local actions affect the entire space through pollution. Indeed, we assume that the production generates local pollution, which flows across locations. In this regard, we illustrate the diffusion mechanism by means of the well-known Gaussian Plume equation (see Sutton, 1947a,b). Finally, we consider that local pollution damages production due to its negative effect on land productivity. Moreover, we assume that pollution as a whole (global pollution) may also reduce production. This indirect consequence of pollution can be linked, for instance, to the negative effect of anthropogenic GHGs on climate change.[1]

We prove the existence of a social optimum when the planning horizon is finite. The policy maker decisions are characterized by the Pontryagin conditions. We additionally extend our analytical results to the time-invariant equilibrium. As observed above, this particular equilibrium is crucial to apply solution methods based on approximations of the original problem around a time-invariant equilibrium. We show in this respect that the existence and uniqueness of time-invariant solution are not guaranteed in general. Finally, to illustrate the richness of our model, we undertake numerical simulations. To this end we adapt the methodology first developed in Camacho et al. (2008) to the current problem. Our algorithm is an alternative framework to other numerical tools that focus on the local dynamics around a time-invariant solution. This numerical analysis is actually global, where we simulate the entire trajectory of the states, controls, and co-states from their initial distributions until they eventually reach, or not, a time-invariant equilibrium. With the numerical tool in hand, we study the different drivers of spatial heterogeneity. We find, among other things, that the abatement technology stands out as a fundamental element to achieve time-invariant solutions, which are compatible with the emergence of long-run spatial patterns. Moreover, even if our paper focuses on land use dynamics, many simulated scenarios are consistent with the predictions of spatial models of natural resources such as the harvesting stochastic spatial approach of Costello and Polasky (2008).

The paper is organized as follows. Section 2 describes the economic model. Section 3 is devoted to the analytical results of our paper. In Section 4 we introduce the algorithm that is applied in the numerical exercises of Section 5. Finally, Section 6 concludes.

[1] According to Akimoto (2003), tropospheric ozone, methane and CO are well-known examples of pollutants that flow across locations. Methane and CO have both local and global effects. Moreover, CO affects the oxidizing capacity of the atmosphere, raising the lifetime of GHGs.