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Zoning in cities with traffic congestion and agglomeration economies

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ABSTRACT

We analyze land use regulations in cities with traffic congestion and production spillovers. Land is allocated between residential and industrial uses inside the city boundary or between urban and rural uses at the city boundary. The production is dispersed over the city, and people and firms freely choose locations of residence and production. We derive conditions for optimally adjusting land uses expressed in terms of observable data, and modify and extend the findings of the literature. According to numerical simulations, the land use control combined with production subsidy is almost as efficient as the first-best policy mix.

1. Introduction

Because of the far-reaching and binding nature of zoning, an abundance of empirical and theoretical studies have examined it. Focusing on the theoretical studies, there are two different strands. The first line of study originates from Tiebout. In Tiebout's world, zoning is viewed as a collective property right that protects the value of properties and enhances the efficiency of resource allocation in metropolitan areas (Oates, 1969; Hamilton, 1975; Fischel, 2004).

The second line of studies is grounded on urban models of Alono (1964), Mills (1967), Muth (1969) and Brueckner (1987) and focuses on the spatial structure of cities (Rubinfeld, 1978; White, 1978; Pines and Sadka, 1985; Joshi and Kono, 2009). However, most of these spatial models deal with zoning in cities with residential land use only. Of course, mixed land use is a typical urban landscape, even for American cities (Wheaton, 2004), and more so for old cities around the world (Mumford, 1961). Because production is restricted to the city center in most of these models, they consider the land allocation between (1) residential use and agriculture (Brueckner, 2007; Anas and Pines, 2008), (2) residences and roads (Kanemoto, 1977; Arnott, 1979; Pines and Sadka, 1981), and (3) nonresidential use and residences around the city center (Stull, 1974; Helpman and Pines, 1977; Sullivan, 1983a,b,c).

In contrast, we analyze land use control in cities with traffic congestion and agglomeration economies where land use is mixed for residence and production. Some authors do analyze the two types of externalities with or without mixed land uses, but the analysis is either limited or largely numerical. Rossi-Hansberg (2004) analyzes optimal land use in cities with mixed land use and agglomeration economies, while abstracting from congestion externalities. Arnott (2007) examines both types of externalities in cities where land use is not mixed, and deals with congestion tolls only. Anas and Rhee (2006, 2007) analyze the urban growth boundary (UGB), but their analysis is largely numerical in cities with no agglomeration economies.

However, incorporating scale economies into the model introduces analytical difficulties, leading to generic nonexistence of price-taking equilibrium. For example, one big firm may dominate the whole market, and the First Welfare Theorem could trivially hold. We avoid this degenerate case by treating the scale economies as production spillovers external to individual firms in the fashion of Chipman (1970). Since a firm's production technology is assumed constant returns to scale in its own inputs, the number of firms is immaterial; firms are treated as if they are atomistic, behaving competitively. In this way, perfect divisibility in production and the associated competitive behavior at the microlevel are compatible with scale economies at the macrolevel, and the analysis

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proceeds as usual in the perfectly competitive market with atomistic agents.

By the presence of the externalities our model has, the laissez-faire market equilibrium is not efficient, and the government may have a reason to step in. Then, the question is how. By the nature of externalities we analyze, we are naturally inclined to consider a policy mix: congestion tolls and production subsidies. However, suppose that for some political and administrative reasons, the city government cannot adopt the first-best policy mix and has to resort to some other policies. Arguably, it is all about planning, and city planners are presumably dominating the scene. For this reason, we take the land use control as a policy to be analyzed together with the economist's favorites. Another reason for choosing to analyze zoning in this paper is the connection between land use, transportation, and urban economy. This topic is undoubtedly one of the age-old themes because of its practical significance in both transportation and regional planning around the world (Handy, 2002; Knaap and Song, 2004).

Although we study a collection of cities, they are all member cities, located side by side, belonging to a single metropolitan area with an exogenous population. The study is separate from (albeit related to) the literature on how the optimal system of cities differs from the equilibrium system. We do not look at intra-metropolitan zoning from the city system's perspective. At the same time, because there is a large literature dealing with the interplay between agglomeration and congestion, we sidestep from this literature and instead focus on land allocation problems and the efficiency of zoning relative to other second-best Pigouvian policy instruments. In specific, we analyze the land allocation problem between residential and industrial uses (called "zoning" in our paper) and between urban and rural uses at the city boundary [greenbelts and urban growth boundaries (UGB)].

We have four objectives. First, we do comparative statics that was not easily handled before (because of the very complexity of the model in the extended setting) and observe formal similarities between the zoning and the UGB aforementioned. As a byproduct, our treatment recasts the previous studies and extends their findings in that extended framework. Second, we measure the efficiency of zoning using the data in Seoul. In fact, we show that various second-best policies standing alone could be ineffective, whether it is congestion charges or production subsidies, and that zoning could be combined with other second-bests for a maximal welfare gain. Third, Anas and Rhee (2006) numerically show that the UGB reduces welfare no matter how small the UGB may be. Brueckner (2007) and Pines (2005) raised questions and attributed this "contradictory" result to some unknown, "atypical" features. We provide a theoretical clue and show that either expansionary or contractionary city could enhance efficiency in the real world. Fourth, although the land use-transportation model we use here has many good features, it is very complex to understand and handle for theoretical probe. We provide one methodology that greatly simplifies the welfare analysis using the model a la Anas and Kim (1996). Indeed, the theoretical statements made in this paper were possible because of this technical improvement.

We proceed as follows. Section 2 presents the model. Section 3 presents the theoretical analysis of the first-best and zoning policies, which is followed by the discussion of greenbelts at the end of the section. We proceed from the mono- to nonmonocentric cities and from the cities with transportation externalities only to the cities with both types of externalities. Section 4 measures the efficiency of the second-best policies using the data in Seoul. For a reference, we provide a glossary at the end of the paper.

2. The model

2.1. Overview

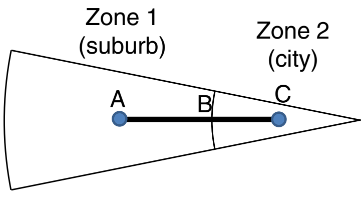
Without loss of generality, the city is assumed to have two zones indexed by $i = 1$ and 2. Fig. 1(a) shows the shape. The land inside a zone is homogeneous, so all lots belonging to the same zone are perfect substitutes for residence and production. Therefore, it does not matter where residences and production sites are located inside a zone. We can use this approach to model both monocentric and nonmonocentric cities. When the city is monocentric, we simply assume that zone 2 is the sole site for production. When it is nonmonocentric, the distribution of production over the zones is determined endogenously. When residences and production sites are accommodated in the same zone, the zone's land use is called mixed. The sum of residential and industrial lands equals the total area of a zone.

When both types of externalities are assumed to coexist, either mono- or nonmonocentric city could arise endogenously. When the city is nonmonocentric, the land use is called "completely mixed,""tricentric," or "pentacentric" in the literature, depending on the number of mixed use zones [e.g., Fujita and Ogawa (1982) and Anas and Kim (1996)]. In the two zone setup, nonmonocentricity means that production occurs in both zones, so the land use is mixed in both zones. Multiple spatial peaks (e.g., tricentric and pentacentric configurations) might arise in our discrete city setup, only when there are more than two zones.

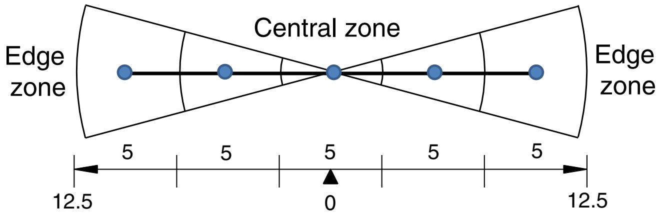
2.2. Firms and households

Competitive firms, modeled by a representative firm, use land, Q_i, and labor, M_i, according to the constant returns-to-scale production technology $X_i = E_i f(M_i,Q_i) \equiv E_i f_i$, where the subscript i is the zone index. The input and output markets are competitive. $E_i \equiv E_i(X_1,X_2)$ is a scalar increasing in both arguments, which is external to an individual firm and captures positive production externalities. We are not interested in specific sources and mechanisms of agglomeration economies. Though crude, this functional form is convenient for capturing various types of agglomeration economies. Residents supply labor to the firms, while generating commuting trips from a residence zone to a work zone.

We differentiate the workers by an ordered pair (i,j), where i, j are a worker's home and work zones, respectively. Each worker, or equivalently a household, derives utility from consuming the composite good, x_{ij}, and land, q_{ij}. The two zones in Fig. 1(a) are connected by the highway running from one zone's centroid to the other. It takes g_1 hours to get from A to B and g_2 hours to get from B to C. For simplicity, we assume that intrazonal travel also takes g_1 hours in zone 1 and g_2 hours in zone 2. $g_i \equiv g(F_i)$ is a function of zonal traffic volume, F_i, and $g'(F_i), g''(F_i) > 0$, in line with empirical studies (Small, 1992), where primes mean differentiation. Unless we note otherwise, we assume that the only travel is for commuting.



(a) Two zone city



(b) Seoul simulated (units: km)

Fig. 1. Physical shapes of the city.