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Pollution and land use: Optimum and decentralization

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Abstract

Space matters not only by inducing transport costs but also by mitigating pollution damages. Previous models of pollution either disregard space altogether or presume a predetermined separation between polluters and pollutees. In our model, workers commute to factories and all possible location combinations of housing and industry around a circle are considered. We investigate optimal allocations and their decentralization. The tradeoff between pollution costs and transport costs, along with the non-convexity inherent in spatial models, results in multiple local optima. With negligible commuting costs, the optimal allocation has one industrial and one residential zone. As commuting costs increase, the number of zones of each type increases until an allocation is reached in which housing and industry are completely intermixed. The global optimal allocation is decentralized by imposing a tax per unit area of industrial land at a particular location equal to the total damage caused by the pollution from that unit area, evaluated at the global optimum. Location-specific Pigouvian taxes by themselves are inefficient.

JEL classification: R13; H23

Keywords: Pollution; Space; Zoning; Pigouvian taxes; Land use; Non-convexities; Regulation; Agglomeration

1. Introduction

For many decades and throughout much of the world, the tension between industrial pollution and households has been crucial in urban areas. Some cities mainly in developed countries (e.g., Washington DC, Stockholm, San Francisco, etc.) have introduced green buffer zones between densely populated areas and stationary pollution sources, while others have intermixed polluting industry and households (e.g., Lima, Shanghai, Bangkok, Moscow, etc.). What cities have come to recognize is that space can and should be used as a means of controlling pollution. Separating polluter and pollutee typically reduces pollution damages but leads to increased commuting costs. When pollution damages are low relative to transport costs, separation into industrial and residential areas is uneconomic and uniform distribution of industry and housing over space is economic. However, above a certain threshold, the agglomeration of housing and industry in separate residential and industrial areas becomes desirable. As pollution damages relative to transport costs rise, separation into larger areas becomes efficient.

This paper focuses on the role of space in the control of pollution externalities. Accordingly, we concentrate on pollution from stationary sources and avoid dealing with congestion and vehicles emissions in residential areas for which separation by space does not reduce damages.[1]

The existing papers on spatial pollution from stationary sources (Tietenberg, 1974a, 1974b, 1978; Henderson, 1977, 1985, 1996; Hochman and Ofek, 1979; and Baumol and Oates, 1988) have the common weakness that they all take the pattern of land use between housing and industry as fixed, assuming that housing is in one zone and industry is in another. This pa-

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[1] Note that this applies only to commuting inside the residential and industrial zones. Travel on interstates and freeways near residential areas can be considered a stationary source of pollution and our results apply. Indeed, the increasingly common bypasses around highly populated areas separate expressways and dwellings, with green buffer zones in between.

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per relaxes this assumption, treating as endogenous the pattern of land use. More specifically, this paper characterizes the optimal resource allocation and joint location of polluting firms and their workers' housing around a circle, as well as policies that decentralize the optimum. To eliminate those factors which are not essential for isolating the role of land use in pollution control we: (i) specify a city without a predetermined center; (ii) assume a constant returns to scale production function so that production processes are not the source of any endogenous separation and agglomeration of housing and industry; (iii) assume a ring-shaped city to avoid dealing with edge-of-city effects; and (iv) assume all workers to be identical and all firms to be identical to avoid the complications introduced by heterogeneity. Accordingly, if pollution does not exist, a uniform layout of the city emerges with factories and houses intermixed.

In studies where agglomeration is due to positive production externalities like external scale economies, (e.g. see Lucas, 2001; Lucas and Rossi-Hansberg, 2002; and Rossi-Hansberg, 2004), an industrial zone is located in the midst of a residential zone and intensities of land use increase with proximity to the joint center of the two zones. Such a layout is the result of a balance between two forces of attraction operating on two land uses: the primary attraction between firms due to scale economies and the attraction between households and industry caused by commuting costs.

Contrary to the above studies, in our model of pollution externalities the spatial layout results from a balance between two opposing forces: one is the repulsion of households from industry that is the source of the pollution and the other is the attraction between households and industry caused by increasing-with-distance commuting costs. The balance between the attraction and repulsion forces leads to the agglomeration of the two land uses into a set of alternating industrial and residential zones. The intensity of land use in each zone increases with proximity to the center of the zone where the density peaks. Furthermore, depending on the specific parameters, empty buffer zones may exist between the industrial and the residential zones.

Additionally, in our model for every specified level of commuting costs, there can be an infinite number of local optima but only one global optimum. When commuting costs are very low, the global optimum entails a single industrial zone and a single residential zone. When commuting costs rise above a certain threshold, the global optimum changes to an allocation with two (or more) industrial zones in each of which industry agglomerates, and two (or more) residential zones in each of which households agglomerate. As commuting costs continue to rise, successive thresholds are reached, each with more industrial zones and an equal number of additional residential zones, until a final threshold is reached above which the global optimum is a uniform allocation of mixed residential and industrial land uses without commuting.

We also investigate decentralization of the global optimum. Spatially differentiated Pigouvian taxes per unit emission levied on industrial polluters will not generally support the optimum in either the short run (fixed household and firm locations) or the long run (endogenously determined locations). Whether or not the model's solution entails separating land uses, only if the dispersion function is linear in emissions or if locations are predetermined and fixed and the dispersion function is convex in emissions, will the typical Pigouvian taxes offered in the literature (Baumol and Oates, 1988; Rausser and Lapan, 1979; Spulber, 1985) be optimal. Henderson (1977) showed the insufficiency of Pigouvian taxes, proposing an additional lump-sum tax along with the Pigouvian tax. Hochman and Ofek (1979) proved that the optimum can be achieved by levying a tax on each unit of industrial land equal to the spatial aggregate of added damages contributed by that unit of land. In a non-spatial model, Polinsky (1980) demonstrated the failure of the Pigouvian tax and also derived a tax equal to the added damages caused by a firm. Our analysis shows, under more general conditions than considered in previous papers, that a spatially differentiated added-damages tax is sufficient to achieve the global optimum. We also argue that with our specifications a laissez faire solution will always yield an inefficient allocation without zoning and without commuting. We conclude our analysis by showing how our results can be linked to results of another model to obtain a broader scope of results.

The following section presents the model. Section 3 specifies the social optimum problem. Section 4 derives and investigates conditions for a local optimum, and the price system that supports it. To gain insight and intuitive understanding, Section 5 investigates a number of special cases using bid-rent analysis. Section 6 characterizes the local optima where the number of zones is predetermined, based on the interpretation of the special cases, and Section 7 describes the global optimum. Section 8 presents possibilities of extending our results and concluding remarks.

2. Model specification

Assume a ring-shaped featureless strip of land of unit width. Let L be the circumference of the circle equidistant from the two boundary circles of the ring (see Fig. 1); as a result, L is also the total area of the ring. This circle is the location axis in the ring. The point due west on this ring is arbitrarily chosen as the origin. The clockwise distance from the origin is designated by x; $x = 0$ and $x = L$ are the two coordinates of the origin and $0 \leqslant x \leqslant L$. Only circumferential travel is costly.

Firms produce a (numéraire) composite good, using a constant-returns-to-scale, neoclassical production technology, with land and labor inputs and pollution emissions as a by-product. In particular, output per unit distance at x is $F(a(x), a(x)n(x), a(x)e(x)) = a(x) f(n(x), e(x))$, where $a(x)$ is the proportion of land occupied by industry at x, $n(x)$ the number of workers per unit of industrial land at x, $e(x)$ the quantity of emissions per unit of industrial land at x, and $f(n(x), e(x))$ the output per unit of industrial land at x, where the intensive (per unit land) production function $f(n, e)$ fulfills $f(\lambda n, \lambda e) < \lambda f(n, e)$ for $\lambda > 1$.

Each household commutes with transport cost per unit distance of t units of composite good, to a firm to which it supplies one unit of labor. A household derives utility from land and the composite good, and disutility from the pollution concentration