Journal of Urban Economics 94 (2016) 13–31

Contents lists available at ScienceDirect

Journal of Urban Economics

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

Congestion, agglomeration, and the structure of cities[☆]

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ARTICLE INFO

Article history:
Received 1 October 2014
Revised 10 May 2016
Available online 14 May 2016

JEL Classification:
R13
C51
D62
R40

Keywords:
Congestion
Agglomeration
Externalities
Spatial equilibrium
Urban structure
Estimation

ABSTRACT

Congestion costs in urban areas are significant and clearly represent a negative externality. Nonetheless, economists also recognize the production advantages of urban density in the form of positive agglomeration externalities. The long-run equilibrium outcomes in economies with multiple correlated but offsetting externalities have yet to be fully explored in the literature. Therefore, I develop a spatial equilibrium model of urban structure that includes both congestion costs and agglomeration externalities. I then estimate the structural parameters of the model using a computational algorithm to match the spatial distribution of employment, population, land use, land rents, and commute times in the data. Policy simulations based on the estimates suggest that congestion pricing may have ambiguous consequences for economic welfare.

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1. Introduction

For much of the latter half of the 20th century, the focus of transportation planning centered around increasing road capacity in urban areas. While this policy undoubtedly had positive effects by reducing transportation costs and increasing access to land that was previously underutilized, it ultimately led to ever-increasing traffic congestion and the realization at the turn of the 21st century that increased capacity was no longer useful in reducing congestion or improving urban mobility. The ineffectiveness of new capacity stems in part from the fact that people and businesses are mobile and can choose where to locate and where to travel within urban areas. In other words, increased capacity can lead to higher travel demand instead of lowering congestion appreciably, which is referred to as induced demand. Researchers have studied the effects of various transportation policies on mobility, congestion, and urban structure.[1]

Policymakers and planners have become increasingly interested in innovative ways to deal with traffic congestion. These policies range from adding carpool lanes, which is common in the United States, to rationing driving by allowing only certain license plate numbers to enter heavily congested areas on certain days or at certain times, which is common in Latin America. Even transit investment and ridership have shown signs of reversing long declining trends.

Nonetheless, for economists, congestion pricing or congestion tolls are often seen as the panacea for mitigating problems associated with traffic congestion.[2] Congestion in urban areas clearly represents a negative externality in the sense that one person's commuting decision places costs on other commuters. Therefore, an efficient policy could be to internalize those costs by taxing commuters at a level equal to the marginal social cost of their commuting decisions. For policymakers, this has the added benefit of being an additional revenue source. Even though congestion

☆ For their comments and suggestions, I thank Nathaniel Baum-Snow, Jan Brueckner, Gerald Carlino, Satyajit Chatterjee, Daniele Coen-Pirani, Dennis Epple, Burcu Eyigungor, Maria Marta Ferreyra, Jeffrey Lin, Antoine Loeper, Tomoya Mori, Ronni Pavan, Jordan Rappaport, Stephen Redding, Esteban Rossi-Hansberg, Holger Sieg, William Strange, and Matthew Turner and participants at numerous conferences and seminars. In addition, I thank Jennifer Knudson for valuable research assistance. The views expressed here are those of the author and do not necessarily represent the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

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[1] Baum-Snow (2007) estimates the effect of highway construction on suburbanization in the 20th century. Duranton and Turner (2011) look at the role of transportation infrastructure and service provision on congestion. A summary of the economics of urban transportation is provided by Small and Verhoef (2007)

[2] See Arnott et al. (1993) for a detailed treatment of congestion and congestion pricing.

http://dx.doi.org/10.1016/j.jue.2016.05.002
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pricing has been slow to gain public acceptance, recently there have been examples of its implementation in different forms.

While congestion pricing has clear benefits, it may lead to reduced employment density, which could affect productivity through a reduction in positive agglomeration externalities.[3] Furthermore, empirical evidence by Rosenthal and Strange (2003), Arzaghi and Henderson (2008) and Ahlfeldt et al. (2015) shows that the production advantages of proximity can attenuate very rapidly across distances of a few miles or even a few city blocks. Thus, there are two offsetting externalities at work in urban areas, a negative congestion externality and a positive agglomeration externality, and both are related to the clustering of employment. This paper shows that these two offsetting externalities are of similar magnitude. The important implication is that congestion pricing may reduce welfare.

To date, there has been little research studying the full equilibrium outcomes in the presence of these two offsetting externalities and the consequences for policy, although several theoretical papers have approached the subject.[4] Research by Anas and Kim (1996) perhaps represents the first equilibrium model to include different types of externalities with mobile agents and complete land markets. Later, Arnott (2007), using a simple theoretical setup, more explicitly makes the point that congestion and agglomeration represent offsetting externalities and therefore lead to ambiguous policy prescriptions in urban areas.[5] Finally, perhaps the most similar work is by Ahlfeldt et al. (2015), who estimate an equilibrium model that includes transportation costs but not an endogenous congestion externality explicitly.[6]

This paper, however, is the perhaps the first to bring data to a spatial equilibrium model of city structure to estimate the magnitude of congestion and agglomeration externalities simultaneously and do so in a way that lends itself to practical policy analysis. To accomplish this, a model is developed that can realistically capture the observed centralization of employment and residential population. I start with the theory introduced by Lucas and Rossi-Hansberg (2002), who develop a circular city framework with transportation costs and agglomeration economies, where firms and workers are free to locate anywhere in the city. I then extend the theory by adding an endogenous congestion externality to the model. Finally, I enhance the land use specification by allowing variation on the extensive margin, in addition to the intensive margin, to better capture the observed transitions between commercial, residential, and agricultural land use across space.

The structural model is estimated using a computational method of moments estimator to match detailed land use and price data, along with employment, population and commuting data from the census. Overall, the model produces a good fit of the underlying characteristics of urban areas. Most notably, the model is able to capture complex land use patterns characterized by the relative extent of commercial, residential, and agricultural use across space. Mixing of different land uses occurs at varying levels in different locations in cities, meaning that the extent of land use is as much an important aspect of urban spatial structure as the intensity of land use. This is a feature of the data that is not captured by most existing models.

Comparative statics based on the estimates both confirm previous findings about urban spatial structure and provide new insights. The estimated model is particularly well suited to study policies designed to mitigate the negative effects of congestion. Therefore, I simulate a congestion pricing policy in which a congestion tax is implemented equal to the marginal social cost of congestion. Revenues are then returned to workers in a nondistorting lump-sum tax. The results show that congestion pricing has ambiguous effects on important economic measures — the insight being that congestion pricing leads to more dispersion of employment and, in turn, lost productivity, which completely offsets the positive effects from lower congestion costs. This result has very important ramifications for urban policy.

The rest of the paper is organized as follows. Section 2 establishes some empirical regularities of urban structure using data from select cities. Section 3 develops the model, defines equilibrium conditions, and discusses the characteristics of equilibrium. Section 4 outlines the estimation procedure and discusses in detail the variation in the data that identifies structural parameters in the model. Section 5 presents the estimation results and discusses the fit of the model. Sections 6 and 7 present comparative statics and policy simulations based on the estimated parameters. Finally, Section 8 concludes.

2. Evidence on the structure of cities

Before introducing the theoretical model, it is important to establish some basic empirical regularities about the structure of cities. The characteristics of interest for this research lie in the spatial distribution of residential density, commercial density, land use, wages, and commute times. In particular, we are interested in how these quantities change in relation to the distance from dense business districts. For illustrative purposes, data are presented for three cities: Columbus, Ohio; Philadelphia; and Houston. These cities differ in both size and transportation networks. Houston (2,100,380 employees) and Philadelphia (2,559,383 employees) are considerably larger than Columbus (845,815 employees), while Philadelphia is the only city of the three with significant transit use, at 9.2% versus 3.3% and 1.0% for Houston and Columbus respectively. Underlying data come from the 2000 Census Transportation Planning Package and the U.S. Geological Survey. Details of the data are included in Appendix A.

Fig. 1 shows residential and employment densities for all three cities as a function of distance from the city center. In all three cities, residential densities decline substantially from the center of the city outward. However, Philadelphia is unique in that it maintains a much higher residential density near the city center. Houston and Columbus follow similar patterns (adjusting for population), with little residential density in the central business district followed by higher density and then gradually declining density.

Employment densities for all three cities are similar to residential densities in that they all decline moving away from the city center. However, employment is much more clustered relative to residential population. In all three cities, there is extremely high employment density at the center, followed by sharp declines, and the gradients are much steeper than residential density gradients. This is true even in Philadelphia, which displays significant residential density. For example, the maximum employment density for a census tract in Philadelphia is more than 220,000 employees per square mile, while the maximum residential density is only 35,000 workers per square mile. The discrepancies in Houston and Columbus are even greater.

[3] Agglomeration economies were perhaps first proposed by Marshall (1890) and then further dissected by Jacobs (1969). Important work on the scale, structure, and determinants of agglomeration externalities includes, among others, (Duranton and Puga, 2001; Rosenthal and Strange, 2001), and (Henderson et al., 1995). For a review of the empirical literature see Rosenthal and Strange (2004). For theoretical foundations, see Fujita and Thisse (2002) and Duranton and Puga (2004).

[4] Important work on urban spatial structure starts with classic circular city models by Von Thünen (1826), Mills (1967), and others. Work by Fujita and Ogawa (1983) presents an urban spatial model in which both firms and workers are mobile. See Anas et al. (1998) for a review of research on urban spatial structure.

[5] This research is also related to work by Mayer and Sinai (2003), Brueckner (2002), and Ng (2012).

[6] Other examples of structural estimation of equilibrium location models with externalities include Brinkman et al. (2015); Holmes (2005), and Davis et al. (2014).

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