Economics of Transportation 2 (2013) 18–37

Contents lists available at SciVerse ScienceDirect

Economics of Transportation

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

The economics of cordon tolling: General equilibrium and welfare analysis ☆

Alex Anas [a,*], Tomoru Hiramatsu [b]

[a] Department of Economics, State University of New York at Buffalo, Amherst, NY 14260, USA
[b] Department of Economics, Kumamoto Gakuen University, 2-5-1 Oe Kumamoto 862-8680, Japan

ARTICLE INFO

Article history:
Received 15 December 2011
Received in revised form
3 August 2012
Accepted 5 August 2012

Keywords:
Road pricing
Computable general equilibrium
Welfare analysis

ABSTRACT

We study optimal cordon tolling in a general equilibrium model of the Chicago MSA. Adjustments in travel, housing and labor markets blunt the toll's impact. Residence relocations drive job relocations and vice versa. The outflow of jobs and residences out of the cordoned area is checked by switches to public transit. Higher output outside the cordon exceeds output losses within the cordon and total real and nominal gross MSA product rises. Optimal downtown and City cordons achieve up to 65% of the gains from Pigouvian pricing on all major roads, but 50% of these gains can be from annualized real estate value increases. In the case of an outer cordon encircling the inner suburbs, toll-avoidance causes jobs, residences and real output to increase within the cordon. Such outer cordons though less efficient in pricing congestion can concentrate activity toward the centers an issue that was inconclusively debated 20 years ago.

1. Introduction

As the urbanization of the world's population continues, the negative externality of traffic congestion grows. Pricing a negative externality at its marginal social cost is the well known first-best remedy originally proposed by Pigou (1932). This has been advocated for traffic by Walters (1961) and by Vickrey (1963). But first-best road pricing on every congested road is difficult to implement. In practice, road pricing has focused either on the tolling of congestion on selected major roads only, or on charges within certain areas only, or on cordon tolling in which motorized vehicles crossing inward the perimeter of a targeted area roughly between, say, 7:00 am and 6:00 pm are tolled. Singapore has had a complex program of road pricing installed in 1975 and modified in 1998 which includes cordon tolling.[1] In Norway, the cities of Bergen, Oslo and Trondheim have had cordon tolling since the 1980s and Stavanger since 2001. More recently, cordon tolling has been used in the central areas of London, Stockholm and Milan since 2003, 2006 and 2008 respectively.[2] Cordon tolling is considered successful in having reduced congestion and emissions, although the environmental benefits are secondary in magnitude compared to the time savings. Welfare gains are believed to exceed the costs of implementation, but there is some debate on whether the policy is regressive or progressive. Eliasson and Mattsson (2006) studied travel adjustments in the case of the Stockholm cordon and concluded that progressivity can be achieved in part by committing the toll revenues to public transit improvements.

This paper is an empirical analysis of the potential effects of cordon tolling policies using a spatial computable general equilibrium (CGE) model of the urban economy, calibrated for the Chicago MSA. The model, RELU-TRAN2,[3] consists of 14 city and suburban subareas plus a peripheral zone interconnected by the labor, housing and travel markets. The model synthesizes two strands from modern urban economics. The first strand is based on the fact that the location of firms and consumers evolve simultaneously and ought to be modeled in a way that properly accounts for the linkages and feedbacks between them (Anas and Xu, 1999). The second strand is that real estate development and building durability are central in urban economies and that urban areas evolve by a cycle of demolition and construction of durable buildings in response to changes in the demands for space (Anas and Arnott, 1993). The original RELU-TRAN model's detailed structure, equation system and solution algorithm are described

☆ The paper was presented at "Urbanics II, the 2nd workshop on urban dynamics" held in Termas de Chillan, Chile, sponsored by the University of Chile at Santiago and the Millennium Institute for Complex Systems, March 26–29, 2012; at a conference of the Japanese Association for Applied Economics held in Fukuoka, Japan, June 9-10,2012; and at the workshop on "New perspectives on transportation infrastructure pricing" held in Chicago and co-sponsored by the Royal Institute of Technology, Stockholm and The University of Illinois at Urbana-Champaign, August 20–21, 2012. An earlier version was presented at the North American Meetings of the Regional Science Association International, Miami, November 9–12, 2011.

* Corresponding author. Tel.: +1 716 645 8663; fax: +1 801 749 7805.
E-mail addresses: alex.anas@verizon.net, alexanas@buffalo.edu (A. Anas).

[1] For discussions of the effects of the Singapore scheme see Santos et al. (2004) and Olszewski and Xie (2005).

[2] For London see Santos (2008); for Stockholm, Eliasson et al. (2009) and for Milan, Rotaris et al. (2010).

[3] RELU-TRAN: Regional Economy, Land Use and Transportation.

2212-0122/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecotra.2012.08.002

in Anas and Liu (2007). In RELU-TRAN2, the travel behavior of the consumer has been extended to include the choice of automobile by technological fuel intensity (TFI) and equations that calculate the effect of congestion on gasoline use. Appendix A provides a technical summary description of RELU-TRAN2 including these new features. Appendix B explains how the model was calibrated, how its fit to the data was evaluated and how the various elasticity measures of the calibrated model agree or disagree with estimates from the relevant literatures.

Using a general equilibrium model is essential for understanding how cordon tolls would affect the urban economy and the sub-economies of the areas inside and outside the cordon. In particular, we will shed light on several aspects of cordon tolling policies. The first is the importance of public transit. Cordon tolling around the world is found in cities well-served by public transit. But in the United States less than 5% of person trips are by transit. The percentage is more than double the national average in the Chicago MSA but much lower there than in London, Stockholm or Singapore. The effects and benefits of cordon tolling can be quite different when public transit is not available or if it is available but its availability is limited by congestion at transit stations. In RELU-TRAN2, public transit is treated as an uncongested alternative to road transportation. Its availability, therefore, is determined by the accessibility of train and bus stops to particular residential areas and to trip destinations and by transit's uncongested travel time from each subarea of the model to each other subarea, which stays constant in the model.

The second aspect we emphasize is how the areas inside and outside the cordon change in gross product (real and nominal), the number of jobs and residences, and wages, rents and real estate development. A third aspect is how the cordon policy affects overall welfare and its components in aggregate but also how it affects the distribution of the welfare changes among different income groups.

Under our cordon tolling any car trip crossing the perimeter delineated by the cordon line in the inbound direction pays a flat cordon charge while trips entering by public transit or by non-motorized means (walking, bicycling) are exempt.[4] By repeated runs of the model we find the value of a cordon toll that maximizes welfare for any given location of a cordon, and we can optimize over three alternative locations of the cordon and the level of toll, while the model calculates the adjustments from the long run stationary equilibrium that prevailed before the cordon is installed to a new long run stationary equilibrium that comes about after the cordon policy goes into effect and the urban economy has adjusted fully. Transitory effects from the pre-cordon to the post-cordon equilibrium are not examined, but we will report simulations of the short run in which only route and mode choices adjust while other aspects remain fixed.

The three alternative cordoning arrangements are depicted in Fig. 1a. Fig. 1b depicts the model's network of major roads. Each zone also has a local road for access-egress to the major roads or for intra-zonal trips. The figure shows that the zones of the MSA make up five rings. The first is a downtown area to which we will refer as the Central Business District (CBD). The second ring consists of the rest of the City of Chicago, surrounding the CBD and includes the O'Hare airport area. The third ring consists of inner suburbs encircling the city and includes the Schaumburg suburban jobs sub-center, the fourth ring is composed of the outer suburban counties and the fifth is a peripheral exurban area. Table 1a lists the distribution among these rings, of residents, jobs, undeveloped land, floor space and trips by mode and origin/destination in the year 2000 Census which is the baseline of the CGE model. Table 1b provides more detail on the commuting pattern that is the distribution of the employed residents in 2000 by the home location (origin) and the job location (destination) of their commute. More than half of the commuters by car work in the inner suburbs, and nearly half of those riding public transit work in the CBD.

Our first cordon is one placed around the CBD (zone 3) as shown in Fig. 1a. It can be seen or inferred from Table 1b that in the year 2000 this area contained 14.4% of the jobs and 0.8% of the residents of the MSA. 44% of the MSA's trips to work by public transit and 9.5% of the work-trips by car terminated within the CBD. The second alternative cordon is around the entire City of Chicago (zones 1 through 5) that contained 35% of the jobs and 30% of the residents. 81% of all trips by public transit and 27% of car trips terminated within the City. These two cordons may be compared to those in London and Stockholm respectively. The London-type cordon is designed to encircle a relatively small central area (like our CBD) containing many jobs and well served by transit. The Stockholm-type cordon is designed to encircle an entire central city, one also served well by public transit. A difference is that the city of Chicago is much larger in population and land area than is the city of Stockholm and less well-served by transit than either London or Stockholm. The third alternative cordon also shown in Fig. 1a may be viewed as an extension of the Stockholm type but does not correspond to any of the actually implemented cordons in the world. It is located farther out and encircles both the City and its inner ring suburbs, an area containing 80% of the jobs and 65% of the residents in the year 2000 with 78% of all car trips and 95% of all trips by public transit terminating within this area.

An important but unanswered question about cordon tolling has been in what ways the economic profile of the area inside the cordon is altered. The question is an instance of the more general inquiry about the impact of road pricing on central city revitalization and whether road pricing centralizes or decentralizes land use, jobs, population and economic vitality. A special report of the National Research Council in 1994 concluded that:

> Neither theory nor research on the relationship between the cost of transportation and urban development provides compelling evidence to support whether congestion pricing would have a centralizing or decentralizing effect (Deakin, 1994).

We will show that the broad and counterfactual outer cordon that circumscribes the inner suburbs has the effect of centralizing jobs, residences and economic output, while the tighter CBD and City cordons decentralize the same activities out of the cordoned areas. But the outer cordon captures only about half of the welfare gains of the others because it does less to reduce congestion. Therefore, a meaningful trade-off exists between economic efficiency gains on the one hand and the concentration of economic activities towards the centers of metropolitan areas on the other hand.

The summary of the paper is as follows. In the next section we briefly review the existing literature on cordon tolling which contains idealized theoretical, numerical and a couple of limited empirical studies, but not a general equilibrium empirical analysis. In Section 3, we qualitatively discuss the processes of feedback between residential location, employment location and modal choice that drive the way housing markets, labor markets, production and real estate development are interconnected in the CGE model. Then, armed with this qualitative understanding, in Sections 4 and 5 we present the welfare analysis and the economic impacts of the cordon tolling policies in a series of tables and figures, providing detailed explanations of the results of the CGE analysis. Conclusions are in Section 6.

[4] All cordon schemes in practice have circumscribed compact areas in the urban centers. More generally, the number and shapes of the targeted areas would be dictated by the topology of the city and the network, and the loci of highly congested areas.