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Urban spatial location advantage: The dual of the transportation problem and its implications for land-use and transport planning

Enda Murphy *

School of Geography, Planning and Environmental Policy, Planning Building, Richview, Clonskeagh, Dublin 14, Ireland

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ABSTRACT

Numerous recent studies have investigated the relationship between the location of jobs and housing in urban areas and how this relates to urban commuting patterns. Few have utilised the dual of the transportation problem of linear programming (TPLP) to provide insights into these relationships Accordingly, this analysis utilises the TPLP to determine dual variable values (shadow prices) for a study area in Dublin, Ireland. The approach determines the pattern of relative location advantage for the peak and off-peak travel periods and for public and private transport for 1991 and 2001. The results are set against the expected results for hypothetical urban structures. The results show that the pattern of relative location advantage has altered sharply over the study period for off-peak trip-making but has remained more or less the same for trip-making in the peak period. For the off-peak period, the pattern of relative location advantage has shifted from the central area to the periphery specifically for private transport trips; for public transport, the pattern has remained focused on the city centre. This indicates that private transport users can react more quickly to changes in the distribution of land-use activities than their public transport counterparts due to the relatively fixed nature of the latter mode. This implies that the public transport network needs to be reorganized to better reflect the revised pattern of trip-making specifically for the off-peak period. The results demonstrate the value of using the approach for providing information about the spatial organisation of land uses within cities and where future development may be targeted.

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1. Introduction

Recent debates in the academic literature relating to transport and land-use have (among other things) been heavily concerned with issues surrounding spatial interaction, land-use arrangements and the efficiency of the transport network. In particular, research has tended to concentrate on major issues such as jobs-housing balance, excess commuting and accessibility issues (see Horner, 2004). Even though journey-to-work trips generally account for a minority of overall daily trip making (Horner, 2004), much of the focus of the research has been on commuting and particularly on the location of jobs and housing and the increased efficiency and sustainability of travel patterns which may result from a greater juxtaposition of jobs and housing. This issue, which ties in directly with the concept of excess commuting, are the most relevant for the current study.

The evidence demonstrating the nexus between jobs-housing balance and more efficient commuting is variable. Some scholars (Giuliano and Small, 1993; Cervero, 1989; Horner, 2002; Zhao et al., 2009) have found that a better jobs-housing balance does in fact produce more efficient commuting patterns but others (Wachs et al., 1993; Peng, 1997) have found little

* Tel.: +353 1 7162810; fax: +353 1 7162716.
E-mail address: enda.murphy@ucd.ie

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evidence to support the assertion. In particular, Cervero (1989) argues that if urban areas are designed with a high jobs-housing imbalance then commuting will be greater than it could be under alternative (more efficient) jobs-housing arrangements. Nevertheless, the effectiveness of policies aimed at promoting a greater jobs-housing balance in urban areas continues to be unclear despite the fact that they are high on the policy agenda in many European and US cities.

Central to the jobs-housing debate has been the concept of excess commuting where a linear programming method is used to optimise spatial interaction between home and work locations within the context of a cost-minimising objective. These cost minimising solutions have been used as a proxy for the level of jobs-housing balance across metropolitan areas. They have been compared with observed commuting patterns to determine the 'efficiency' of trip making whereby any deviation from the cost-minimising solution is considered to be excessive (Murphy, 2009). Excess commuting is a term which refers to the empirical difference between the average minimum commute necessitated by the existing distribution of jobs and housing in urban areas and the observed commute (White, 1988; Frost et al., 1998; Horner, 2002; Loo and Chow, 2010; Murphy and Killen, 2011). The greater the deviation between observed commuting patterns and the minimum required by the morphology of jobs-housing arrangements, the more 'excessive' the observed commuting patterns are in urban areas. In excess commuting studies, the average minimum commuting cost is usually calculated using the transportation problem of linear programming (TPLP) which is a specific case of the linear programming problem (see Killen, 1983).

While the TPLP has been used extensively in the literature for transportation planning issues, little attention has been paid to the companion dual solution. This is unfortunate because as will be shown here, the dual has a specifically spatial interpretation. In particular, from a spatial planning perspective, dual solutions provide an indicator of the relative spatial advantage of individual zonal units which can be mapped. Moreover, the dual can provide additional information about where additions to the transport network would be most or least efficient; it is possible also to determine where new trips entering the system should originate and terminate in order to maintain optimum efficiency for spatial interaction purposes. The current paper demonstrates the use for planning purposes of dual solutions of the TPLP within the context of Dublin, Ireland.

2. The dual of the transportation problem of linear programming (TPLP)

2.1. Description

Linear programming problems have two companion solutions: the *primal* solution and the *dual* solution. The TPLP allocates resources from an area of supply to an area of demand in order to minimise costs. This is known as the primal solution to the TPLP. The companion dual solution is formulated in terms of an objective of opposite direction i.e. in this case – cost maximisation (see Hay, 1977; Killen, 1979, 1983). In the case of the TPLP, this objective can be interpreted as maximising the return to be realised from allocating resources from supply to demand areas. Specifically, the objective function of the dual is to maximise the difference between the cost of a unit of resource at a supply area and the cost of receiving a unit of that resource at a demand area. The relative differences in these costs on a zone by zone basis are referred to as *shadow prices*. Under conditions of optimal flow, a destination shadow price differs from an origin shadow price by the difference in the transport cost associated with the two routes (see Killen, 1983). Thus, in terms of transport costs, the dual values for a set of supply or demand areas may be interpreted as the relative advantage of one location over another within the context of the optimal solution. In the case of origins (home in the case of home to work trips), a higher shadow price implies locational advantage; in the case of destinations (work in the case of a home to work trip), a higher shadow price implies locational disadvantage.

2.2. Formulation and interpretation

Assume Vj is the associated shadow price for a unit of resource at a destination j (dj) and Ui is the shadow price for a unit of resource at an origin i (oi). Then, the dual problem maximises S, the value added to the unit of resource by the transfer between origin and destination (i.e. the transport cost). Using the same notation as for the primal of the TPLP, the dual transportation problem is to find Ui and Vj such as to:

$$\text{Max. } S = \sum_{j}^{n} djVj - \sum_{i}^{m} oiUi \tag{1}$$

$$\text{s.t. } Vj - Ui \leqslant cij \quad \text{for all} \quad i,j \tag{2}$$

where Ui = the marginal cost of increasing oi; Vj = the marginal cost of increasing dj; and both Ui and Vj are unrestricted in sign. Constraint (2) ensures that the shadow price difference between each origin and destination must be less than or equal to the transportation costs. To elaborate, if we assume that ($Vi - Ui$) and cij are the shadow price differential and the per unit transport costs respectively, it is only profitable to bring a route into use if the shadow price differential exceeds the per unit cost of transport. Mathematically, therefore, it is only profitable to bring a route into use if:

$$(Vj - Ui) - cij \geq 0 \tag{3}$$

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