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Examining the efficiency of peak and off-peak travel patterns using excess travel and travel economy measures

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Abstract

In recent years there has been an increase in the level of attention being paid to the empirical difference between observed travel patterns and those necessitated by the distribution of jobs and housing in urban areas. In the academic literature, this issue has been investigated fairly extensively within the context of the excess commuting and commuting economy frameworks in various city-regions. Within these frameworks, one area that has received considerably less attention is the case of off-peak travel which is used as a proxy for non-work travel. Accordingly, the current research specifically addresses this period using the city-region of Dublin, Ireland as a case study. The approach uses data from an urban traffic simulation model to determine the minimum, maximum and random travel costs for the study area which are compared with observed costs. The results show that non-work travel is associated with more efficient travel behaviour driven by the intermixing of land use arrangements associated with these trip types and the transport network. They also show that there are only slight improvements in the efficiency of off-peak travel over the time horizon but considerable improvement during the peak period as a result of the extent of jobs decentralisation.

Keywords: Excess commuting; commuting economy; jobs-housing balance; non-work travel

Résumé

Au cours des dernières années il ya eu une augmentation du niveau d'attention est accordée à la différence empirique entre les modes de déplacement observés et ceux rendus nécessaires par la répartition des emplois et de logements dans les zones urbaines. Dans la littérature académique, cette question a été étudiée assez largement dans le contexte de l'excès de déplacements et les déplacements des cadres de l'économie dans diverses villes-régions. Dans ces cadres, un domaine qui a reçu beaucoup moins d'attention est le cas de Voyage hors pointe qui est utilisé comme un proxy pour voyage non-travail. En conséquence, la recherche actuelle porte spécifiquement sur cette période en utilisant la ville - région de Dublin, en Irlande comme une étude de cas. L'approche utilise les données à partir d'un modèle urbain de simulation de trafic pour déterminer le minimum, les coûts au maximum et aléatoires voyage pour la zone d'étude qui sont comparés avec les coûts observés. Les résultats montrent que Voyage non - travail est associé à un comportement de Voyage plus efficace entraînée par le mélange des arrangements d'utilisation des terres associés à ces types de déclenchement et le réseau de transport. Ils montrent aussi qu'il n'y a que de légères améliorations dans l'efficacité de Voyage hors pointe sur l'horizon de temps, mais une amélioration considérable au cours de la période de pointe en raison de l'ampleur de la décentralisation des emplois.

Mots-clé: excès de navettage; équilibre emplois-logements; déplacement hors travail

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1. Introduction

In recent years, the excess commuting framework, which is characterised by the deviation of observed commuting cost from a theoretical minimum commuting cost (Horner, 2002; Ma and Bannister 2006), has been utilised extensively to measure the efficiency of urban commuting patterns and the morphology of jobs-housing characteristics (Murphy, 2012). Numerous scholars from a range of academic disciplines have used the excess commuting concept to aid understanding of commuting efficiency in various cities (Frost et al., 1998; Horner, 2002; Niedzielski, 2006; Murphy, 2009). In particular, the framework has been used repeatedly as a useful proxy for either regional job-housing balance or imbalance (Horner, 2002; Horner and Murray, 2003) but also as a means for assessing the efficiency of regional commuting patterns more generally (Murphy, 2012).

The current paper applies the excess commuting and recently developed commuting economy framework to off-peak travel in Dublin, Ireland. It uses data from a Dublin traffic simulation model to assess the relative efficiency of trip making in the peak and off-peak periods. Given the scepticism surrounding the application of the excess commuting framework to all but specific types of trips, the paper provides a rationale for application of the framework to trips in the off-peak period. In this regard, the paper argues that analysis of aggregate off-peak trip making provides useful indicators of the differing nature of peak and off-peak trips. Applied within the context of the excess commuting and commuting economy frameworks, it is possible to identify differences in the nature of trip-making for the two periods which is useful for understanding the nature of travel change for the two periods especially when a temporal analysis is undertaken and the data is disaggregated by mode of transport (as is the case for this study).

The objectives of the paper are twofold. First, a comparison of the ‘efficiency’ of peak and off-peak trip making is offered within the excess commuting and commuting economy frameworks. ‘Efficiency’ is defined narrowly here specifically within the context of the excess commuting and commuting economy framework. Moreover, it is also accepted that differences emerging in the results for the two traffic periods may not, in reality, be inefficient (e.g. trips that are chained in the off-peak, or trips for comparison goods etc.). Second, the paper applies the analysis to data for two time periods and for different modes of transport to investigate the changes in travel behaviour within the context of dynamic changes in the urban structure of Dublin. Neither of these core objectives have been addressed in the related literature and, as such, the current exploration provides additional understanding about the hanging dynamics of peak and off-peak peak commuting over time and within the context of the efficiency indicators used in the excess commuting and commuting economy framework.

2. Excess commuting, commuting economy and off-peak travel

Attempts to measure the efficiency of travel and land use arrangements have taken different approaches over the last few decades. However, there has been a relatively fruitful and consistent literature utilising the excess commuting and commuting economy frameworks (see Hamilton, 1982; White, 1988; Horner, 2002; Murphy and Killen, 2011). The concept of excess commuting (EC) emerged from the economics literature in the early 1980’s when Hamilton (1982) sought to test the robustness of the monocentric urban model for estimating urban commuting. Since then, the concept has evolved quite a bit. Subsequent work by White (1988) utilised a more appropriate linear programming approach for calculating the average minimum commute while Horner (2002) introduced additional concepts such as capacity utilisation. Ma and Bannister (2006) provide a comprehensive review of the evolution of the framework as well as the range of methodological and contextual extensions to it from the early 1980s until 2006. The reader is referred to that paper for further details. However, since that review, there have been some further developments including the development of the commuting economy concept (Murphy and Killen, 2012) as well as the utilisation of the framework to investigate attainable reductions in metropolitan average trip length (O’Kelly and Niedzielski, 2008). All of these initiatives have brought new dimensions to what is now a fairly strong conceptual framework for understanding travel behaviour within the context of land use change.

Excess Commuting is a measure of the deviation of an urban area’s observed average travel cost from a theoretical minimum average travel cost. It has been described as the surplus travel cost resulting from the fact that the actual geography of travel deviates from the pattern that minimises total journey cost (Hamilton, 1982; White, 1988; Frost et al., 1998; Horner and Murray, 2002; Murphy, 2009). The minimum commute is taken to be the optimal allocation of individuals from origin to destination in a manner that minimises overall travel cost (e.g. travel distance or time). Effectively, it allocates individuals to job locations assuming that they travel to the
closest possible workplace destination on average. It has been applied extensively to commuting where the difference between the actual commute and the minimum commute can be thought of as excessive in the sense that it is not required by the fixed physical separation of origins and destinations. It is expressed as a percentage of the actual commute as follows:

\[
EC = \left( \frac{T_{\text{act}} - T_{\min}}{T_{\text{act}}} \right) \times 100
\]  

(1)

where EC is the excess commute, \( T_{\text{act}} \) is the observed commute, and \( T_{\min} \) is the theoretical minimum commute. In an extension to the excess commuting concept, Horner (2002) used the transportation problem of linear programming (TPLP) to maximise the cost of allocating workers from residences to workplaces i.e. the inverse of the minimisation objective. He interpreted the maximum commute as a worst case scenario where every worker in the study area travels to the furthest possible workplace. Essentially, given a fixed distribution of origins (residences) and destinations (workplaces) in a city region, the maximum commute \( T_{\max} \) places a cap on overall travel possible by trip makers. Horner used the addition of \( T_{\max} \) to develop a measure for what he refers to as capacity utilisation \( (C_u) \) - the percentage of travel cost capacity of a city-region being consumed by daily trip making:

\[
C_u = \left( \frac{T_{\text{act}} - T_{\min}}{T_{\max} - T_{\min}} \right) \times 100
\]

If we consider \( T_{\max} - T_{\min} \) as a finite scale determined by the distribution of origins and destinations, then the relative location of the actual average travel cost, \( T_{\text{act}} \), on the scale indicates the amount of available travel resources being used by urban trip making. As \( T_{\text{act}} - T_{\min} \) increases relative to the total range of travel available, \( T_{\max} - T_{\min} \), trip making becomes less efficient because more of the available distance or time resources in the study area are being consumed. Together, \( T_{\min} \) and \( T_{\max} \) represent the range of commuting possibilities that a given distribution of trip origins (residences) and destinations (workplaces) permits i.e. the ‘commuting capacity’. The magnitude of this range i.e. \( (T_{\min}-T_{\max}) \) is a function of the land-use geography of a city region. Consider a city region where all of the trip origin zones (residences) are located in one area and destinations (workplaces) in another (Figure 1(a)). In this case, \( T_{\min} \) and \( T_{\max} \) will be quite similar and hence the urban commuting range will be relatively small; the opposite will be true of a city region where the distribution of trip origins and destinations is inter-mixed (Figure 2(b)). In this situation, considerable scope exists for \( T_{\min} \) to be low and for \( T_{\max} \) to be high. If in a city region, the value of \( (T_{\min}-T_{\max}) \) increases through time, this suggests that land-uses in that city are becoming increasingly inter-mixed (see Ma and Bannister, 2007).

A further extension has been provided recently by Charron (2007) and Murphy and Killen (2011) who introduce the notion of random commuting \( (T_{\text{rand}}) \). \( T_{\text{rand}} \) is assumed to be the average commuting cost that is achieved in a city region if individuals are assumed to travel randomly between their place of origin and destination. To be more specific, \( T_{\text{rand}} \) relates solely to a particular type of travel behaviour – that is one where no disutility is associated with the separation between origin and destination. Put another way, travel cost is considered irrelevant under such behaviour. The further \( T_{\text{act}} \) departs from \( T_{\text{rand}} \), the greater the role that separation is playing in determining travel behaviour whether it is as a disincentive (where \( T_{\text{act}} < T_{\text{rand}} \)) or indeed as an incentive (where \( T_{\text{act}} > T_{\text{rand}} \)). Murphy and Killen (2011) argue that \( T_{\text{rand}} \) is the more appropriate upper limit on commuting cost and suggest that this should be utilised as the de facto benchmark for understanding and evaluating the efficiency of travel behaviour. They suggest two alternative indicators which measure the extent to which behaviour is moving from or towards random behaviour and thus becoming more or less efficient – commuting economy and normalised commuting economy. Using the same logic as that underlying EC in (1), commuting economy is given by:
During and in particular, a move towards more service chaining for non-act has also relocated to the there. This has led to include the discretionary nature of non-act which this could happen as rand to which this could happen as

\[
T_{act} = \begin{cases} 
1 & \text{if } T_{act} \text{ is falling below (positive) or above (negative) } T_{rand} \text{ i.e. degree to which behaviour as expressed by } T_{act} \text{ is becoming either more or less random. This represents the extent to which individuals are economising on commuting costs. To go further, } T_{min} \text{ and } T_{max} \text{ represent the greatest extent to which } T_{act} \text{ can depart from } T_{rand} \text{ in either direction. Where } T_{act} \text{ is less than } T_{rand}, \text{ as we would expect, the statistic:} \\
NC_e = \frac{T_{rand} - T_{act}}{T_{rand} - T_{min}} \times 100 
\]

represents the extent to which } T_{act} \text{ is below } T_{rand} \text{ relative to the theoretical extent to which this could happen as determined by land-use geography i.e. } T_{min}. \text{ Thus, this is considered to be a normalised commuting economy (NC_e) indicator. Together the values, } T_{min}, T_{max} \text{ and } T_{rand} \text{ represent what Murphy and Killen (2011) refer to as the urban travel scale. It values lies in its ability to offer a more complete framework against which values of } T_{act} \text{ can be measured and interpreted.}

Within the context of this paper, all of the following measures are calculation for the study area of Dublin, Ireland. The contribution of this paper is to calculate these measures for the peak and off-peak period. Research in this area to date has applied these concepts and produced indicators exclusively to assess the morning and evening commute. Of course, this is largely because of difficulties associated with acquiring suitable data for the off-peak but is also due to a range of potential difficulties with applying such a framework to non-work trips. Horner and O’Kelly (2007) have pointed some of these which include the discretionary nature of non-work travel in that it cannot be modelled as a relatively fixed distribution of origins and destinations to the same extent as the commute, its diversity in terms of the trip being undertaken, and the problem of trip chaining for non-work travel

3. Data and methods

3.1 Dublin

Prior to the late 1990s, Dublin was best characterised as having an essentially monocentric urban structure where the majority of employment was located in the city centre with scattered employment at the periphery (Murphy, 2004; MacLaran et al, 2010). After the Celtic Tiger economic boom beginning in the 1990s, the morphology of Dublin’s built environment witnessed dramatic changes. This period of prosperity was characterised by industrial restructuring and in particular, a move towards more service-based industry away from heavy manufacturing (Williams and Shiels, 2002). A substantial proportion of this new service-based employment has located in the suburbs while many older manufacturing industries have also relocated to the there. This has led to a major restructuring in the development of office and industrial space away from the central towards ‘edge city’ locations at the periphery (see MacLaran et al, 2010). Simultaneously, rapid population increases fed a rapid acceleration in housing development and much of that development has occurred in a highly dispersed manner at the periphery of the region and beyond (Williams and Shiels, 2002; MacLaran, 2010). The failure to provide adequate public transport infrastructure to facilitate emerging employment centres at the periphery has led to increased demand for car-based commuting with its associated negative environmental consequences for the region. A monocentric city, with the majority of employment and service functions located in the core and with the majority of residences located in outlying areas, generates a primarily radial pattern of trip making with significant flows along a limited number of major radial routes. By way of contrast, a city where residential and non-residential functions are more interspersed (i.e. polycentric cities), as is now the case in Dublin, generates a more diffuse pattern of trip making. Specifically, these land use changes have created geographies of travel that have become increasingly complex and dispersed characterised by greater numbers of inter-suburban, cross-city and reverse commutes with a greater reliance on the private car to serve those trips. Between 1991 and 2002, the proportion of individuals driving to work increased in all counties of the Greater Dublin Area (GDA) with the greatest increases, in relative terms, occurring in the outlying counties (Murphy, 2009). Over the same period, the proportion of public transport trips decreased despite significant public transport investment.

3.2 Data

The study area for the current analysis comprises the Greater Dublin Area (GDA) which consists of seven local authority administrative districts. The data for the study was derived from a Dublin Transportation Office (DTO)
traffic simulation model for the 2001 peak (8-9AM) and off-peak periods (2-3PM) and a comparable DTO model for the same periods in 1991. The total number of trips recorded for 2001 was 327 001 while the corresponding figure for 1991 was 234 834. The model has two main components: the Highway Model (primarily car based) and the PT Model (public transport based). In the PT model both bus and rail trips are modelled and interchanges between PT modes is permitted. The model is based upon a 463 zonal sub-division of the Dublin Region and is derived primarily from the Irish District Electoral Division (DED) system. The model components have been independently validated to within five percent of actual travel patterns using goodness-of-fit statistics (WSP, 2003, 88). The off-peak data relates solely to the entire suite of non-work travel which includes retail, recreation, leisure and entertainment trips, among others. However, it does not provide an individual breakdown of non-work trips by purpose which, quite obviously, is a limitation of the analysis.

Two types of journey-to-work flow matrices were available for the peak and off-peak period: private transport trips and public transport trips. Thus, the data was such that, unusually for such studies, comparisons could be made by time of day as well as between 1991 and 2001. The key limitation of the 1991 data relates to the off-peak period data where only data for bus trips are available. Thus, we use these in this study as a proxy for public transport trips overall although the dataset is not completely comparable with the 2001 off-peak data. However, given that bus trips amounted for 83% of all off-peak public transport trips in the Dublin region in 1991 we feel that using the bus data as a proxy for public transport overall, while not ideal, can be justified.

Euclidean (ED) and road network (ND) distances were available for each mode of transport and they were taken as a proxy for the cost of physical separation between zonal units. Intra-zonal travel distances were estimated by assuming that each zonal unit is approximately circular in shape (see Frost et al, 1998). In a similar manner to other studies, this study excluded those trips originating and destined for locations outside the study boundary (see Frost et al, 1998; Horner, 2002; Murphy, 2009).

3.3 Formulations

From the preceding discussion, it should be clear that a necessary prerequisite for attaining values associated with the efficiency indicators described in 1-4, is the calculation of $T_{\text{min}}$, $T_{\text{max}}$, and $T_{\text{rand}}$ and $T_{\text{act}}$ – the values on the urban travel scale (see Murphy and Killen, 2011). For $T_{\text{max}}$, the TPLP was used to determine the assignment of trips from origin to destination that minimised mean commuting cost. The objective function and constraints of the TPLP are given by:

Min: $Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}X_{ij}$ (5)

s.t. $\sum_{i=1}^{n} X_{ij} = D_{j}$ $\forall j = 1,\ldots,m$ (6)

$\sum_{j=1}^{m} X_{ij} = O_{i}$ $\forall i = 1,\ldots,n$ (7)

$X_{ij} \geq 0$ $\forall i, j$ (8)

where, $m =$ number of origins; $n =$ number of destinations; $O_{i} =$ trips beginning at zone $i$; $D_{j} =$ trips destined for zone $j$; $c_{ij} =$ travel cost from zone $i$ to zone $j$; $X_{ij} =$ number of trips from zone $i$ to zone $j$, and $N =$ total number of trips. The objective function (2) minimises average transport costs. Constraint (3) ensures that trip demand at each destination zone is satisfied while constraint (4) limits the number of trips leaving each origin zone to the number of trips originating there. Constraint (5) restricts the decision variables, $X_{ij}$, to non-negative values. It should be noted that travel costs, $c_{ij}$, may be expressed in terms of any measure of zonal separation, for example travel distance, travel time or indeed a generalised cost measure.

$T_{\text{max}}$ was also determined using the TPLP where the objective function is the inverse of the minimisation problem discussed previously (5) and is given by:

Max $Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}X_{ij}$ (9)
The approach for calculating $T_{\text{and}}$ utilised the Markov Chain Monte Carlo (MCMC) hit-and-run algorithm desired by Murphy and Killen (2011, 1261-62). It is given by the following:

$$N_T = N!$$  \hspace{1cm} (10)

s.t.  

$$\sum_{i=1}^{n} x_{ij} = D_j \hspace{1cm} \forall i = 1, ..., n$$  \hspace{1cm} (11)

$$\sum_{j=1}^{m} x_{ij} = O_i \hspace{1cm} \forall j = 1, ..., m$$  \hspace{1cm} (12)

$$X_{ij} \geq 0 \hspace{1cm} \forall i, j$$  \hspace{1cm} (13)

where $N_T$ is the number of possible commuting configurations in a city; $N!$ is the factorial of the total number of trips in the urban area. Constraints (11-13) are identical to those of the transportation problem and they limit commuting possibilities to those supported by the fixed distribution of jobs and residences. Finally, $T_{\text{act}}$ was calculated from observed trip data and associated travel costs.

4. Results

4.1 Peak and off-peak travel scales

From the results in Table 1, it can be seen that, on average, there has generally been an increase in the travel ranges ($T_{\text{min}}$-$T_{\text{max}}$) during the peak and off-peak period between 1991 and 2001. The one exception to this trend is the decline in the travel range for private transport (ED). To be more concrete, a general widening of the travel range suggests a greater intermixing of land use arrangements along the lines of that suggested in Figure 1 (a). The general decline in the values of $T_{\text{min}}$ (for private transport) and increase in the values of $T_{\text{max}}$ support this assertion. The decline in the values of $T_{\text{min}}$ are worth noting because they suggest that origin and destination opportunities have moved closer together. However, the results show a significant dichotomy between peak and off-peak changes over the time horizon. Over the ten year period, the average range increased by 4.2 kms for the peak but only by 0.95 kms for the off-peak period. This is an interesting result because it suggests quite different land use changes for travel activity associated with the peak and off-peak periods. It implies that there has been much greater inter-mixing of home-work (peak) land uses over the period which has been aided by significant decentralisation of employment in the study area (Murphy, 2012). On the other hand, there has only been a slight increase in the range for the off-peak period implying less intermixing of land uses associated with off-peak (non-work) travel activity (i.e. retail, leisure, recreation etc.). This may be related to the fact that land uses associated with off-peak travel activity (i.e. non-work) are generally more dispersed throughout a city-region in the first instance so the possibilities for further inter-mixing are more limited than for those associated with the peak period (i.e. jobs-housing). Thus, in 1991 Dublin exhibited urban spatial structure characteristics that were largely monocentric in nature with relatively centralised employment and strong radial flows from the centre outwards (see Murphy, 2004). On the other hand, retail (convenience shopping), recreation, leisure and entertainment among others were much more dispersed and decentralised (see Parker, 1999). By virtue of this arrangement, there was considerably less scope for a decline in $T_{\text{min}}$ for off-peak land uses when compared with the peak period.

Overall, the result of these land use changes – where origins and destinations have increased in proximity - has been a decline in average journey distances over the study period. To illustrate, $T_{\text{act}}$ has declined on average by 1.5 kms across all indicators (ED and ND) for the peak and off-peak periods indicating that the greater intermixing of land use functions has broadly had an impact on reducing the average journey distance travelled. However, the greater inter-mixing of land uses associated with travel during the peak period (i.e. jobs-housing) has facilitated more reductions in average distance travelled over the time horizon when compared with the off-peak period. The results show that mean $T_{\text{act}}$ values (for ED and ND) for the period declined by 1.6 kms between 1991 and 2001 while the corresponding decrease for the off-peak period was 1.5 kms.

Turning attention to Table 2, it provides the results associated with the various travel efficiency indicators used in the literature. For the purposes of this analysis, we focus only on the commuting economy ($C_e$) and normalise commuting economy ($NC_e$) indicators; it has already been argued elsewhere (Murphy and Killen, 2011) that these are more appropriate indicators of travel efficiency because they more effectively capture how behaviour is
responding to land use change than indicators such as excess commuting (EC) or capacity utilisation (C\textsubscript{u}). Nevertheless, EC and C\textsubscript{u} are provided for reference purposes. Looking at the results (Table 2), it is evident that whether measured in terms of C\textsubscript{u} or NC\textsubscript{e}, the general trend is for an increase in the efficiency\textsuperscript{1} of travel patterns over the period - and the trend is consistent across the peak and off-peak periods. The NC\textsubscript{e} indicator shows that, in overall terms, actual travel was 15.4 per cent further away from random travel in 2001 compared with 1991. Indeed, this trend towards increasingly non-random behaviour is also supported by the C\textsubscript{u} indicator.

However, the interesting trend is between the peak and off-peak period. For the peak period, actual travel was 23.2 per cent further away from random travel in 2001 than in 1991 but for the off-peak the corresponding figure was 7.6\%. The obvious implication here is that peak travel behaviour has reacted to changes in the spatial structure of home-work land uses. In particular, the decentralisation of jobs has brought destinations closer to origins (as evidenced by T\textsubscript{min}) and this has allowed for more efficient home-work travel. On the other hand, land use changes associated with off-peak travel activity have clearly not been as dramatic. The results imply that while travel economies are being achieved during the off-peak period, compared with 1991 they are considerably less pronounced than for the peak period.

Table 1. Peak and off-peak travel scales

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<tbody>
<tr>
<td>T\textsubscript{max} P</td>
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<td>15.9</td>
<td>19.7</td>
<td>24.3</td>
<td>10.2</td>
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<td>15.3</td>
<td>14.4</td>
<td>22.0</td>
<td>20.6</td>
<td>10.9*</td>
<td>11.4*</td>
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<tr>
<td>T\textsubscript{rand} P</td>
<td>11.3</td>
<td>11.9</td>
<td>15.1</td>
<td>16.9</td>
<td>8.7</td>
<td>9.0</td>
<td>10.4</td>
</tr>
<tr>
<td>OP</td>
<td>11.9</td>
<td>10.5</td>
<td>16.0</td>
<td>13.4</td>
<td>8.5*</td>
<td>8.4</td>
<td>10.6*</td>
</tr>
<tr>
<td>T\textsubscript{act} P</td>
<td>9.6</td>
<td>7.6</td>
<td>12.2</td>
<td>10.2</td>
<td>8.0</td>
<td>6.5</td>
<td>9.9</td>
</tr>
<tr>
<td>OP</td>
<td>7.6</td>
<td>6.6</td>
<td>13.1</td>
<td>8.0</td>
<td>6.8*</td>
<td>6.0</td>
<td>7.8*</td>
</tr>
<tr>
<td>T\textsubscript{min} P</td>
<td>2.9</td>
<td>2.1</td>
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<td>3.9</td>
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<td>0.97*</td>
<td>1.1</td>
<td>1.0*</td>
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<tr>
<td>T\textsubscript{min}T\textsubscript{max} P</td>
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<td>5.7</td>
<td>8.8</td>
<td>9.0</td>
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<tr>
<td>OP</td>
<td>14.0</td>
<td>13.7</td>
<td>18.1</td>
<td>19.8</td>
<td>9.9</td>
<td>11.3</td>
<td>13.3</td>
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</table>

*Bus data used as a proxy for all public transport trips

Table 2. Peak and off-peak travel efficiency measures

<table>
<thead>
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<td>EC P</td>
<td>69.8</td>
<td>72.4</td>
<td>63.2</td>
<td>79.2</td>
<td>43.6</td>
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<td>90.0</td>
<td>85.7*</td>
<td>81.7</td>
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</tr>
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<td>50.7</td>
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<td>58.9</td>
<td>42.0</td>
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<td>50.8</td>
<td>36.2</td>
<td>61.4*</td>
<td>47.6</td>
<td>54.0*</td>
</tr>
<tr>
<td>C\textsubscript{e} P</td>
<td>15.0</td>
<td>36.1</td>
<td>19.2</td>
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<td>8.1</td>
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</tr>
<tr>
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<td>37.1</td>
<td>18.1</td>
<td>40.3</td>
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<td>27.8</td>
<td>26.4*</td>
</tr>
<tr>
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<td>38.4</td>
<td>27.4</td>
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<td>42.9</td>
<td>25.3*</td>
<td>32.9</td>
<td>29.2*</td>
</tr>
</tbody>
</table>

*Bus data used as a proxy for all public transport trips

4.2 Peak and off-peak mode analysis

At the outset of the modal analysis, it is prudent to point to one limitation enforced by the data. That is, the 1991 off-peak data uses only bus trips as a proxy for overall public transport costs while all other costs are calculated from a combined origin-destination trip flow and cost matrix of bus and rail data. This means that off-peak costs are likely to be underestimates because they exclude rail trips which have higher average journey distances in the Dublin region than bus trips (see Murphy, 2012).

\textsuperscript{1} The term ‘efficiency’ is referred to specifically within the context of the commuting economy framework whereby a move away from random behaviour denotes greater ‘efficiency’ and vice versa.
network have been beneficial for users. Broadly speaking, these land use changes have effectively; the corresponding values for public transport were rather for public transport users generally have travel costs that are further away from random than public transport. Perhaps more interesting is the travel efficiency measure, the latter of which has a fixed and relatively inflexible network thereby ensuring that trip making is considerably further from origin to destination.

Table 3 shows changes in the mean travel ranges (which include both ED and ND measures) for the 1991 and 2001 peak and off-peak periods for public and private transport. The data shows that the travel ranges increased for both private and public transport between 1991 and 2001 suggesting greater intermixing of land uses over the period (see Figure 1(a)). On average, the overall travel range increased by 2.4 kilometres for private transport and by 2.2 for public transport indicating a slightly greater intermixing of functions for the users of land uses being accessed by private transport. Moreover, for private transport, the range has increased by 4.5 kms for the peak and off-peak periods respectively between 1991 and 2001. By way of comparison, the corresponding range increases for public transport for the peak and off-peak are 3.4 and 1.2 kms respectively over the time horizon.

Overall, this provides further evidence of a greater juxtaposition of jobs and housing during the peak period for private transport users reinforcing the implication that home-work land use arrangements have been to the advantage of private transport users. However, the same trend is not seen for the off-peak period. Here, the increase in travel range is considerably greater for users of public transport indicating that the intermixing of land use arrangements associated with off-peak travel activities as well as coverage improvements that have been made to the public transport network have been beneficial for users. Broadly speaking, these land use changes have facilitated reductions in the average actual travel (T_{act}) for both private and public transport trips between 1991 and 2001 but the greater reduction in T_{act} for private transport demonstrate that this mode has benefitted more from land use restructuring.

Table 4 provides a breakdown of changes between 1991 and 2001. It is notable that whether 1991 or 2001 is considered the indicators are higher for private transport than for public transport. Thus, a key result to highlight is that, private transport trip making is considerably further from random than public transport for all results irrespective of peak or off-peak or the measure of zonal separation being considered (see Table 2). For example, looking at the mean private and public transport C_e indicators (Table 4) for 2001 shows that private transport users were 37.9 and 38.7 per cent away from behaving as random travellers during the peak and off-peak periods respectively; the corresponding values for public transport were 29.7 and 28.3 per cent respectively. And the same trend holds for the NC_e indicator. Thus, it is possible to conclude that private transport users economise more on their travel costs than public transport users. Of course, there is little doubt that this is related to the relative density of the private and public transport networks, the latter of which has a fixed and relatively inflexible network thereby ensuring that trip making is considerably less direct on average from origin to destination.
shows that for the peak period the trend over the time horizon has been for public transport users to gain greater efficiency than its private transport counterparts. The results show that public transport users moved 2.4 per cent (23.2-20.8) further away from random travel than private transport users when the C_0 indicator is considered; when the normalise indicator is considered (NC_e) the extent of the shift is even more pronounced (11.2 per cent). By way of contrast, the opposite trend emerges when the off-peak results are consulted. Private transport users moved 6.5 per cent (11.6-2.5) further away from random travel behaviour than public transport users; one again, this trend also hold for the NC_e indicator (3.9 per cent) despite the magnitude of the shift being slightly less.

Some implications can be derived from these results. The decentralisation of jobs over the period has certainly assisted public transport to serve more destinations along its route network and thereby facilitate more direct and less random home to work travel. However, the same cannot be said for off-peak travel. It seems that land use changes over the period have indeed facilitated less random off-peak travel for public transport users but only marginally so when compared to private transport. This supports the assertion of Murphy (2012) that while the public transport network has reacted well to changes in the land use arrangements of home to work, it has not reacted very well to changes in the nature of off-peak travel through, for example, route and services changes to facilitate non-work trip making.

5. Conclusions and limitations

The first broad conclusion that can be drawn from the foregoing analysis is that the excess commuting and economy frameworks do provide valuable insights into the differences between peak and off-peak commuting. Table 4 demonstrate that in 1991 off-peak trips were significantly further away from random travel across both modes indicating considerably more efficient off-peak trips. However, there has been quite a dramatic change in this trend over the ten year period to 2000: both peak and off-peak trip making has moved further away from random behaviour but the gap between the peak and off-peak differential has narrowed considerably. In other words, peak hour trip making has gained considerably in its efficiency while off-peak trip making has gained only marginally to the point that travellers during both periods are economising on trips in a roughly similar manner. This is a very interesting result because it suggests that the general pattern of off-peak trip making has remained similar over the time horizon; on the other hand, travel behaviour has reacted to land use rearrangements associated with the journey to work (peak period) in such a manner as to become considerably more efficient over the period.

Ultimately what this suggests is that the decentralisation of jobs in the Dublin region has made trip making, on average, more distance efficient. However, it says nothing about the extent to which this decentralisation has improved or disimproved the role of public transport. In Dublin, these land use changes and the concomitant increase in efficiency of trip making has come hand in hand with a declining role of public transport in serving the journey to work over the time horizon. And of course this is the conundrum associated with such efficiency measures – on the one hand they point towards greater individual behavioural efficiencies being achieved as a result of land use change but say little, on the other, about the role of these changes (i.e. land use rearrangements) in undermining the possibility for collective travel (i.e. via public transport). In this regard, the results for Dublin show that despite the changes being associated with less random behaviour for public transport users, there has nevertheless been a decline in the proportional use of public transport and a corresponding increase in the use of the private car over the period under consideration (see Murphy 2009). In this sense, the use of the concept of efficiency is probably a little misleading and perhaps alternative terminology should be adopted to avoid misinterpretation.

Beyond these caveats, the excess commuting and commuting economy frameworks are highly useful in that they provide the possibility for scholars and policy makers to gain a deeper understanding of the nature of land use change during different periods of the day, across variable time horizons and across modes and, in particular, how behaviour is reacting to these changes through observed travel patterns. It is precisely because of analysing changes in behaviour through these frameworks that conclusions can be drawn about the nature of land use change over time, across modes and travel periods. In this regard, there is plenty of potential for further study. There has not yet been any serious analysis of off-peak travel using this framework and future research should focus on applying the framework to specific non-work trips (e.g. shopping, recreation, entertainment et.). This would allow for more concrete conclusion to be drawn about the nature of off-peak travel and how it is changing over time and in comparison to travel in the peak period.
References


