Commuting Economy: An alternative Approach for Assessing Regional Commuting Efficiency

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Abstract

This paper revisits the notion of random commuting within the excess commuting framework. In doing so, it argues that the average random commute, is a more appropriate basis for measuring the efficiency of urban commuting patterns. Using this as a base, the paper introduces two new measures of commuting efficiency based on measuring the collective commuting economy of individuals for the journey to work: commuting economy and normalised commuting economy. It is argued that because the average random commute has an intrinsically behavioural interpretation, the measures introduced yield more explicit explanations of the overall nature of travel behaviour within the constraints set by land use geography and the spatial distribution of the transport network. The framework is applied for two different years, 1991 and 2001, and for different modes of transport. The results show that the average actual commute has moved further away from the average random commute, implying that greater intermixing of residential and employment functions has led to more efficient commuting behaviour.

1. Introduction

In his original paper 'Wasteful Commuting', Hamilton (1982) introduced the concept of random commuting within the excess commuting framework in order to highlight the inability of the monocentric urban model to predict regional observed commuting patterns accurately. Hamilton’s work concluded that the monocentric model was a poor predictor of regional commuting costs due to the fact that its predictions were somewhat close to those found under random commuting conditions. Since then, successive excess commuting studies have focused almost exclusively on comparing the average...
minimum and maximum commuting costs with average actual commuting costs in an attempt to determine the regional ‘efficiency’ of journey-to-work patterns (see Ma and Banister, 2006a). One notable exception is the recent work of Charron (2007) who compared actual commuting patterns with random commuting patterns in a selection of US cities. Charron’s work argued that real spatial behaviour is poorly represented by the optimising assumptions of commute minimisation or maximisation and should be viewed within the context of a broader range of behavioural commuting possibilities associated with urban form.

This paper revisits the random commuting concept within the excess commuting framework. Our work differs from that of Hamilton (1982) and Charron (2007) in that we develop a specific conceptual framework for measuring the ‘efficiency’ of regional commuting patterns using random commuting ($T_{\text{rand}}$) as the base. In doing so, we introduce two new measures which we argue provide a more appropriate means of benchmarking the behavioural efficiency of commuting patterns. It is worth pointing out at the outset that we define ‘efficiency’ as the extent to which actual commuting costs deviate from those assumed under random commuting conditions. The second way in which our research differs from previous work concerns our application of the framework developed to trips disaggregated by mode of transport. While the excess commuting framework has been applied to disaggregate data in the past including different occupational groups (Horner, 2002; Rodriguez, 2004; O’Kelly and Lee, 2005) and different household structures (Kim, 1995), rather surprisingly, there has been a paucity of mode-specific analysis undertaken. An exception in this regard is the work of Horner and Mefford (2007) who developed a conceptual approach synthesising research on spatial mismatch and jobs–housing balance within the broader applications environment of the excess commuting framework; Murphy (2009) also undertook mode-specific analysis within the traditional excess commuting framework and used sensitivity analysis to explore the impact of changes in the density of the transport network for users of public and private transport. Undoubtedly, the lack of focus on this area of research is due to the unavailability of adequate data in many cities. Nevertheless, it is unfortunate that more mode-based analysis has not been undertaken precisely because such an analysis provides additional insights into the manner in which changes in urban spatial organisation and developments in the transport network are influencing commuting behaviour.

The first part of the paper provides a brief outline of the current excess commuting framework focusing, in particular, on its methodological and conceptual development. Then, the random commuting framework is discussed and two new measures of commuting efficiency are proposed. The framework is then applied to Dublin, Ireland. Finally, the implications of the framework for understanding commuting behaviour within the context of urban spatial reorganisation and transport network developments are outlined.

2. The Excess Commuting Framework

Excess commuting is a measure of the extent to which the actual average commuting cost ($T_{\text{act}}$) in an urban area exceeds a theoretical minimum average commuting cost ($T_{\text{min}}$), assuming that the spatial distribution of residences and workplaces is fixed. Put another way, it is the surplus commuting 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, 2002). Essentially, the excess commuting measure separates the morphological and behavioural components of urban commuting. As a result,
the amount of commuting that is forced by the distribution of residences and workplaces and the amount that is due, for whatever reason, to individuals not behaving optimally can be identified (Ma and Banister, 2006a; Charron, 2007).

2.1 Methodological and Conceptual Development

The original excess commuting framework was pioneered by Hamilton (1982) who criticised the commute-minimising assumptions of the general monocentric urban model. The monocentric model assumes that, because individuals value accessibility, they tend to minimise commuting costs when choosing a residential location. Thus, the spatial distribution of residences is assumed to follow a density gradient which declines exponentially from the city centre outwards because individuals are assumed to be prepared to pay more for better access to employment opportunities at the centre (Alonso, 1964). Workplaces are also assumed to follow a density gradient which declines outwards from the city centre, but this gradient is steeper due to agglomeration effects and the greater tendency of employment to cluster at the centre. The difference between the employment and residential density gradients is indicative of the physical separation of residences and workplaces and gives rise to a minimum commute that can be calculated. Applying this approach to a selection of US and Japanese cities, Hamilton compared the minimum commute with the actual commute in order to determine the extent to which individuals were commuting above the minimum required under the assumptions of the standard monocentric urban model. He referred to the difference as wasteful (excess) commuting, this being the portion of commuting not imposed on individuals by urban form. Hamilton found that wasteful commuting ranged from 70 to 87 per cent and concluded that the standard monocentric model did a poor job of predicting actual commuting costs. Hamilton’s work established the basic theoretical foundations of a framework that identifies the amount of commuting necessitated by urban form and the amount due to the fact that individuals do not behave according to optimal commute-minimising criteria.

In subsequent analysis, White (1988) was critical of the inability of Hamilton’s monocentric model to account for the actual distribution of residences and workplaces and developed a different approach for calculating the minimum commute for the same US cities examined by Hamilton. She used the transport problem of linear programming to calculate the average minimum commute for her study areas. The transport problem assumes that the study area is divided into a system of zonal units. The origin—destination—i.e. residence and workplace—totals are known for each zone as well as the complete journey-to-work cost matrix (normally expressed in terms of distance or time). The algorithm determines the assignment of trips from origins to destinations that minimises average travel cost (see Killen, 1983). The transport problem can be expressed as

\[
\text{Min } Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} X_{ij}
\]

s.t. \(\sum_{i=1}^{m} X_{ij} = D_j \forall j = 1, \ldots, m\) \hspace{1cm} (2)

\(\sum_{j=1}^{n} X_{ij} = O_i \forall i = 1, \ldots, n\) \hspace{1cm} (3)

\(X_{ij} \geq 0 \forall i, j\) \hspace{1cm} (4)

where, \(m = \text{number of origins}; n = \text{number of destinations}; O_i = \text{trips beginning at zone } i; D_j = \text{trips destined for zone } j; c_{ij} = \text{travel cost from zone } i \text{ to zone } j; X_{ij} = \text{number of trips from zone } i \text{ to zone } j; \text{ and } N = \text{total number of trips.}\) The objective function (1) minimises average
transport costs. Constraint (2) ensures that trip demand at each destination zone is satisfied, while constraint (3) limits the number of trips leaving each origin zone to the number of trips originating there. Constraint (4) restricts the decision variables, $X_{ij}$, to non-negative values. The amount of excess commuting ($EC$) is then given by

$$EC = \left(1 - \frac{T_{\text{min}}}{T_{\text{act}}} \right) \times 100$$

where, $T_{\text{act}}$ is the average actual commute which is assumed to be known from empirical data; and $T_{\text{min}}$ is the average minimum commute as computed by the transport problem ((1)–(4)).

In behavioural terms, $T_{\text{min}}$ can be interpreted as the limit towards which $T_{\text{act}}$ will tend as the cost to individuals of consuming zonal separation—i.e. distance or time—becomes more punitive. White’s analysis found much less excess commuting than Hamilton (only 11 per cent) and suggested that the predictive power of the monocentric model is robust when the actual distribution of employment and housing is considered.

A number of scholars have used $T_{\text{min}}$ to measure the jobs–housing balance within cities (Giuliano and Small, 1993; Merriman et al., 1995; Horner, 2002) and have sought to inform transport policy on the basis that a lower jobs–housing balance contributes to more efficient and more sustainable commuting patterns (Cervero, 1989).

White’s method has become the most widely used method for calculating the minimum commute in excess commuting studies and is considered to be methodologically more robust, mainly due to the fact that it takes account of the actual distribution of residences and workplaces in urban areas. Despite this, the approach is not without its weaknesses, most notably in its assumption that the minimum solution of the transport problem implies that individuals must have a perfect understanding of the decisions of other workers as well as a common objective (Ma and Banister, 2006a). In reality, this is not often the case and research by Cropper and Gordon (1991) has demonstrated that excess commuting results vary when other determinants of location choice are considered. Other weaknesses include the assumption of job homogeneity; the fact that the zonal configuration used in the transport problem influences the solutions that emerge, particularly for aggregated zonal systems (Horner and Murray, 2002); the difficulty of using the transport problem to deal with two-worker households because of the nature of the data required (Kim, 1995; Buliung and Kanaroglou, 2002); the sensitivity of the solutions to different commuting costs—for example, distance versus time (Small and Song, 1992); as well as the impact of where the urban boundary of the study area is placed (Frost et al., 1998).

Just as a given distribution of origins (residences) and destinations (workplaces) has an associated minimum travel cost ($T_{\text{min}}$), there exists also an associated maximum travel cost ($T_{\text{max}}$) where, subject to the constraints (2)—(4), the objective of the TPLP is to determine the values of $X_{ij}$ that

$$\text{Max } Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} X_{ij}$$

In a behavioural sense, $T_{\text{max}}$ can be interpreted as the limit towards which $T_{\text{act}}$ will tend as the reward to individuals of consuming zonal separation, however, it is measured, becomes greater. Horner (2002) first introduced the concept of the average maximum commute ($T_{\text{max}}$) arguing that commuting efficiency needed to be analysed within the context of the range of available commuting of a city (Figure 1). He argued convincingly that cities which appear ‘efficient’ when judged by excess commuting values alone may, in fact, be ‘inefficient’ when their level of capacity utilisation ($C_o$) is considered, where $C_o$ is given by
In more recent studies, Niedzielski (2006) and Ma and Banister (2006b) have utilised the maximum commute concept in excess commuting studies in Poland and South Korea. Together, $T_{\text{min}}$ and $T_{\text{max}}$ 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. $(T_{\text{max}} - T_{\text{min}})$ is a function of the land use geography of the city region concerned. Consider a city region where all of the trip origin zones (residences) are located in one area and all of the trip destinations (workplaces) are located in another (Figure 2(a)). In this case, $T_{\text{max}}$ and $T_{\text{min}}$ 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 intermixed (Figure 2(b)). In this situation, considerable scope exists for $T_{\text{min}}$ to be low and for $T_{\text{max}}$ to be high. If in a city region, the value of $(T_{\text{max}} - T_{\text{min}})$ increases through time, this suggests that land uses in that city are becoming increasingly intermixed (see Ma and Bannister, 2007).

Perhaps the most important implication of excess commuting research to date is that the framework offers a means of benchmarking urban commuting patterns. This implies that excess commuting studies may provide a useful indicator for changing land use and transport patterns over time. Yet few temporal studies have been undertaken indicating perhaps the difficulties involved in acquiring large datasets for urban areas. Exceptions to this trend are Frost et al. (1998), Ma and Banister (2006b) and Yang (2008) who undertook temporal excess commuting analysis.

$$C_u = \left( \frac{T_{\text{act}} - T_{\text{min}}}{T_{\text{max}} - T_{\text{min}}} \right) \times 100 \quad (7)$$

Figure 1. Schematic of the existing excess commuting framework.

Figure 2. Hypothetical city regions.
One of the most notable policy implications of excess commuting research is that it demonstrates the potential savings (of whatever size) that could be made if individuals behaved more efficiently. Indeed, recent work by O’Kelly and Niedzielski (2008, 2009) demonstrates possible savings that could be achieved by more efficient spatial interaction. Any potential savings are tied to jobs–housing balance policies (although not exclusively) where the underlying idea is that a more harmonised balance of jobs and housing within urban zonal units will create a reduction in urban commuting costs with obvious associated benefits for urban sustainability.

3. Random Travel Patterns: Developing the Conceptual Approach

Given that $T_{min}$ represents the lower limit towards which $T_{act}$ will tend as the cost to individuals of consuming zonal separation becomes more punitive and $T_{max}$ the limit towards which $T_{act}$ will tend as the reward to individuals of consuming separation increases, there is obviously a third value of interest—namely, that which represents a situation where individuals are behaving in such a way as to be insensitive to zonal separation. Where individuals are insensitive to separation, the resultant travel pattern will in effect be random—that is, similar to the situation emerging when trip origins are assigned to destinations at random. We refer to the average trip cost associated with this solution as $T_{rand}$.

The values $T_{min}$, $T_{max}$ and $T_{rand}$ each with its behavioural interpretation, represent what we refer to as the urban travel scale (Figure 3 (a)). The value of this scale is that it offers a more complete framework against which values of $T_{act}$ can be measured and interpreted. Intuitively, we expect that for any given city region, $T_{act}$ will lie between $T_{rand}$ and $T_{min}$ (as is shown in Figure 3), but it is possible for $T_{act}$ to exceed $T_{rand}$ (see Hamilton, 1982).

Previous scholars have sought to explain the characteristics of city and regional travel patterns in terms of the value of $T_{act}$ relative to $T_{max}$ and/or $T_{min}$—i.e in terms of where $T_{act}$ falls relative to one or both ends of the urban travel scale. As stated already, $T_{min}$ and $T_{max}$ are a function of the geography of trip origins and destinations, that is of land use geography. On the other hand, $T_{rand}$ relates solely to a particular type of behaviour—namely, one where separation is of no importance. The further $T_{act}$ departs from $T_{rand}$, the greater the

![Figure 3. Schematic of the commuting economy approach.](image-url)
role that separation is playing in determining travel behaviour, either as a disincentive (where $T_\text{act} < T_\text{rand}$) or as an incentive (where $T_\text{act} > T_\text{rand}$) (Figure 3(b)). Bearing in mind that we are seeking to describe and understand travel behaviour, it seems most logical to use measures where $T_\text{rand}$ (rather than $T_{\text{max}}$ and/or $T_{\text{min}}$) is the base. We argue that it is more logical to compare actual commuting with a pattern of random commuting where cost is considered unimportant in determining the behaviour of individuals for the journey to work than with a pattern of commute minimisation where it is considered extremely punitive or commute maximisation where it is considered extremely rewarding. Thus, while we consider $T_{\text{max}}$ to be a useful indicator of jobs–housing imbalance, we argue that $T_{\text{rand}}$ is the more appropriate upper limit on urban commuting cost. Using the same logic as that underlying $EC$ in (5)

$$C_e = \left(1 - \frac{T_{\text{act}}}{T_{\text{rand}}}\right) \times 100$$  

(8)

gives the extent to which $T_{\text{act}}$ is falling below (positive) or above (negative) $T_{\text{rand}}$—i.e. the extent to which collective behaviour as expressed by the actual trip pattern is departing from random behaviour and reacting to the consumption of zonal separation. This represents the extent to which individuals are economising on commuting costs and can be thought of as the collective commuting economy ($C_e$) of workers (Figure 3(b)). Because the $C_e$ measure is independent of $T_{\text{min}}$ and $T_{\text{act}}$, it demonstrates the extent to which actual behaviour is reacting to the cost of consuming the separation that exists between residences and workplaces in the urban region.

$T_{\text{min}}$ and $T_{\text{max}}$ represent the greatest extent to which $T_{\text{act}}$ can depart from $T_{\text{rand}}$ in a downward and upward direction respectively. In particular, where $T_{\text{act}}$ is less than $T_{\text{rand}}$, as is generally expected to be the case, the statistic

$$NC_e = \left(\frac{T_{\text{rand}} - T_{\text{act}}}{T_{\text{rand}} - T_{\text{min}}}\right) \times 100$$  

(9)

represents the extent to which $T_{\text{act}}$ is below $T_{\text{rand}}$ relative to the theoretical extent to which this could happen as determined by land use geography—i.e. $T_{\text{min}}$. In other words, we propose a revised commuting range from that suggested by Horner (2002) using $T_{\text{rand}}$ as the upper limit on commuting cost. We refer to this measure as normalised commuting economy. Thus, the measure allows us to determine the extent to which collective behaviour is tending towards commuting economy while taking account of the theoretical extent to which it is possible within the constraints set by land use geography.

In summary, because our statistics use $T_{\text{rand}}$ as the baseline against which $T_{\text{act}}$ is being measured and because $T_{\text{rand}}$ has an intrinsically behavioural interpretation, we argue that $C_e$ and $NC_e$ yield more explicit explanations of the overall nature of travel behaviour within the constraints set by land use geography.

### 3.1 Determination of $T_{\text{rand}}$

In any urban area, and in the absence of any travel cost constraints, the range of possible commuting configurations is incredibly large and is constrained by the fixed distribution of origins (residences) and destinations (workplaces) in the urban system—i.e. by urban form. The minimum and maximum commutes ($T_{\text{min}}$ and $T_{\text{max}}$) represent the endpoints of the range within which many possible random commuting outcomes exist. The number of possible commuting configurations ($N_f$) in a city that has been sub-divided into origin (residential) and destination (workplace) zones is given by

$$N_f = N!$$  

(10)

s.t. $\sum_{i=1}^{n} X_{ij} = D_j$ $\forall i=1,...,n$  

(11)
\[
\sum_{j=1}^{m} X_{ij} = O_i \quad \forall \ j = 1, \ldots, m \tag{12}
\]

\[ X_{ij} \geq 0 \quad \forall \ i, j \tag{13} \]

where, \( N! \) is the factorial of the total number of trips in the urban area. Constraints (11)–(13) are identical to those of the transport problem and they limit commuting possibilities to those supported by the fixed distribution of jobs and residences. Charron (2007) has identified two methods for calculating \( T_{\text{rand}} \). First, he has suggested using the following equation

\[
\frac{1}{N^2} \sum_{i=1}^{m} \sum_{j=1}^{n} O_i D_j c_{ij} \tag{14}
\]

This is in fact the most likely commuting configuration associated with a given distribution of origins and destinations (the entropy-maximising solution) in the absence of commuting cost constraints. As Charron (2007) acknowledges, the average cost associated with this single solution will not necessarily be that generated by finding the average cost associated with a large number of solutions each of which has been generated at random. Specifically, if the distribution of commuting costs of many solutions, each generated randomly, turns out not to be symmetrical, then the solution derived from (14) will be biased.

The second method identifies the Monte Carlo simulation approach for randomly generating a large number of random commuting configurations. Given the range of potential random commuting configurations within a given urban region, this would seem to be a more appropriate method of generating \( T_{\text{rand}} \). Unfortunately, Charron provides little explanation of the type of Monte Carlo approach used, its application or the number of simulated configurations used for generating \( T_{\text{rand}} \).

In our analysis, we use a random simulation algorithm known as the hit-and-run algorithm to simulate many random assignments from which \( T_{\text{rand}} \) is computed. The hit-and-run algorithm is a specific type of Markov chain Monte Carlo (MCMC) sampling method for generating points from general continuous distributions over bounded open regions (Smith, 1984; Kiatsupaibul et al., 2002). The method proceeds iteratively by taking steps of random length in randomly chosen directions and, in effect, randomly generates a large number of trip matrices from a specified solution space. In our approach, the solution space is specified by the fixed distribution of origins (residences) and destinations (workplaces) in the study area.

Methodologically, it is essential that a large number of random simulations be generated so that the range of potential solutions is explored satisfactorily. This becomes more important as the size of the zonal system and hence the number of possible commuting configurations increases. For this study, in excess of 400 million random simulations were undertaken for each computation of \( T_{\text{rand}} \). Every 1000th simulation was stored and the average of the values associated with these solutions was taken to be \( T_{\text{rand}} \).

4. Study Area, Data and Assumptions

Since 1991, the population of the Greater Dublin Area (GDA) has increased by 23 per cent and currently lies at 1.66 million (Central Statistics Office, 2006). Much of this new population has been accommodated at the periphery where annual housing completions have increased rapidly since 1991 (Murphy, 2004). Over the same period, the GDA has witnessed a rapid decentralisation of major employment functions (Parker, 1999; MacLaran and Killen, 2002).

The evolving spatial structure of Dublin has impacted upon travel patterns. Between 1991
and 2002, the proportion of individuals driving to work increased in all parts of the GDA with the greatest increases, in relative terms, occurring in the outlying counties (Table 1). Over the same period, the proportion of public transport trips decreased despite significant public transport investment (Murphy, 2006). Land use dispersion, and particularly the increasing juxtaposition of residential and employment functions, has been accompanied by an increased dependency on the private car in the outer areas of the urban region and an increase in the complexity of travel patterns which have become more difficult to serve adequately by public transport. Because of the foregoing changes and the rapidity with which spatial reorganisation has occurred, Dublin is an excellent location for studying the extent of urban commuting economy.

The study area comprises a large portion of the Greater Dublin Area (GDA) (Figure 4). The data used in this study were derived from a Dublin Transportation Office (DTO) traffic simulation model for the 2001 peak period (8–9 a.m.) and a comparable DTO model for the same period in 1991. Thus, any differences in the statistics that we calculate for the two years reflect solely the changes that have taken place in the intervening time. The DTO model provides an accurate representation of the geography of trip patterns in the study area for both years and has been independently validated (WSP, 2003, p. 93). The model is based upon a 463 zonal sub-division of the Dublin Region which is derived from the Irish District Electoral Division (DED) system.

In our analysis, we use trip data broken down by private and public transport in order to draw explicit conclusions concerning the evolving roles of both modes and highlight the land use and transport network planning implications of the emerging trends. For this reason and bearing in mind that our results use random commuting behaviour as the base, we are able to draw more explicit conclusions concerning the changing nature of trip-making and its implications for land use planning.

Table 1. Mode of transport to work for persons > 15 years in the GDA (percentages)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Passenger</th>
<th>Bus</th>
<th>Train</th>
<th>Public transport</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>Dublin</td>
<td>40.2</td>
<td>5.8</td>
<td>17.4</td>
<td>4.2</td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td>Kildare</td>
<td>45.7</td>
<td>9.2</td>
<td>6.2</td>
<td>1.5</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>Meath</td>
<td>44.4</td>
<td>9.5</td>
<td>3.8</td>
<td>0.5</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Wicklow</td>
<td>40.1</td>
<td>6.9</td>
<td>4.7</td>
<td>7.6</td>
<td>12.3</td>
</tr>
<tr>
<td>1996</td>
<td>Dublin</td>
<td>45.1</td>
<td>6.1</td>
<td>17</td>
<td>4.2</td>
<td>21.2</td>
</tr>
<tr>
<td></td>
<td>Kildare</td>
<td>52.9</td>
<td>9.6</td>
<td>5.9</td>
<td>2.3</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Meath</td>
<td>53.7</td>
<td>10</td>
<td>4.2</td>
<td>0.6</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Wicklow</td>
<td>48.2</td>
<td>7.6</td>
<td>4.1</td>
<td>6.1</td>
<td>10.2</td>
</tr>
<tr>
<td>2002</td>
<td>Dublin</td>
<td>48.3</td>
<td>4.5</td>
<td>15.2</td>
<td>4.6</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Kildare</td>
<td>60.8</td>
<td>6.9</td>
<td>5.4</td>
<td>4</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Meath</td>
<td>62.1</td>
<td>7.2</td>
<td>4.9</td>
<td>1.3</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Wicklow</td>
<td>56.6</td>
<td>6.2</td>
<td>3.8</td>
<td>6.2</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: www.cso.ie.
The total number of trips recorded for 2001 was 393,659 while the corresponding figure for 1991 was 133,341. The 1991 and 2001 datasets are based on the same zonal units. Three types of journey-to-work flow matrices were available: total trips, car trips and public transport trips. Public transport trips comprise both bus and rail journeys. Similarly, network distance commuting cost matrices were available for each mode of

Figure 4. Dublin study area and system of zonal configuration.
transport. The network cost matrices for public and private transport reflect the differences in the density of both networks. In addition, the public transport cost matrices incorporate interchanges between bus and rail services and reflect the relative use of those modes. Commuting costs were measured in two ways: the Euclidean distance (ED) between zone centroids and the route network distance (RND).

Similar to the approach of other studies (for example, Frost et al., 1998; Horner, 2002), trips originating from and destined for locations outside the study boundary were excluded. In the case of Dublin, the vast majority of trips occur within the urban boundary used in this study. In addition, intrazonal trip lengths were estimated using the value associated with the radius of a circle circumscribing each zone (see Frost et al., 1998).

5. Results

5.1 All Trips

Figure 5 shows the urban travel scale results for 1991 and 2001, while Table 2 shows the results for the newly developed ‘efficiency’ indicators $C_e$ and $NC_e$ using Euclidean distance as a measure of zonal separation. The travel scales for the two periods show that $T_{max} - T_{min}$ has increased since 1991. Thus, as expected, the impact of land use developments in Dublin has been to increase the ‘intermixing’ of residential and employment functions. In effect, the land use geography of the city region has moved more towards Figure 2(b). One might have expected that the spread of the city region outwards would have led automatically to longer morning commutes, but this outward spread has been more than counteracted by the increased intermixing: $T_{act}$ has actually decreased.

Whether measured by $C_e$ or $NC_e$, there has been a significant increase in the ‘efficiency’ of commuting patterns (Table 2). The $C_e$
measure shows that actual commuting was 15.4 per cent further away from random commuting in 2001 than in 1991 which suggests that the cost of separation between residences and workplaces was playing an increasing role in determining more efficient commuting behaviour over the period. The $NC_e$ values support this assertion: they show that normalised commuting economy was 15.6 per cent greater in 2001 than in 1991. Undoubtedly, this was facilitated by the decentralisation of employment functions over the period as evidenced by the reduction of $T_{min}$. Regardless of which measure is utilised, the results demonstrate clearly that commuting behaviour has moved towards achieving greater commuting economies over the period. This is a highly significant result when viewed against a background of increasing traffic congestion (DTO, 2005) and the decentralisation of major land use functions in the Dublin region. It suggests that congestion is being caused by the sheer growth in trip numbers. At the regional level, however, behaviour is actually becoming more efficient.

5.2 Mode of Transport

In considering the results by mode of transport, it is important to differentiate at the outset between the results emerging for the different measures of zonal separation—namely, Euclidean distance (ED) and route network distance (RND). The difference between ED and RND values reflects the extent to which the route network may or may not facilitate greater commuting economies. This will be discussed in greater detail in the next sub-section.

On a more general level, the results that emerge will also reflect the differing nature of public and private transport networks relative to the evolving land use geography of the Dublin region. Regarding the former, the private transport network is, in effect, ubiquitous. Users of this network may choose their route and time of departure. By way of contrast, users of the public transport network are constrained by the fact that the network is less dense, by the routes that are operated and by the service frequencies offered. Bearing this in mind, one would expect public transport users to be achieving fewer economies. The results (Table 3; Figure 6) support this: the $NC_e$ values show that private transport users economised more than their public transport counterparts in 1991 and in 2001, regardless of which commuting cost measure is used. The values for $Ce$ reveal a similar result: the commuting patterns of private transport users are further removed from random than their public transport counterparts. This suggests that movements associated with public transport are considerably less efficient than those associated with private transport.

The results in Table 3 reveal a further trend. Looking specifically at the results for ED reveals that, whether measured by $Ce$ or $NC_e$, the increase in efficiency of network use between 1991 and 2001 for private transport users (21.0 per cent for $Ce$; 23.7 per cent for $NC_e$) exceeds that of public transport users (19.7 per cent for $Ce$; 23.6 per cent for $NC_e$). This suggests that the impact of recent land use developments (i.e. the move towards Figure 2(b)) has been to place public transport users at an increased disadvantage, albeit only slightly when the $NC_e$ measures are considered. However, the corresponding results for RND suggest that, between 1991 and 2001, the increase in efficiency of public transport network use (24.4 per cent for $Ce$; 31.4 per cent for $NC_e$) exceeded that of public transport users (19.7 per cent for $Ce$; 23.6 per cent for $NC_e$). In relative terms, this suggests that the public transport network has improved more than the private transport network since 1991. Thus, while land use developments have been more favourable to private transport users, the combined impact of changes in urban land uses and the transport network has been to the advantage of public transport users. However, this improvement may be related to the fact that public transport users who were using
the network most inefficiently in 1991 have transferred to the private transport network, thereby improving overall user efficiency.

Within the context of an increasing advantage for public transport, the \((T_{\text{max}} - T_{\text{min}})\) values for that mode for 1991 and 2001 deserve scrutiny. Recall (Figure 2) that an increasing value of \((T_{\text{max}} - T_{\text{min}})\) suggests an increasing intermixing of residences and workplaces. As can be seen, and as would be expected given recent land use developments in the study area, the \((T_{\text{max}} - T_{\text{min}})\) values for both public and private transport increased between 1991 and 2001. Of particular interest within this context is the fact that, in relative terms, the increase for public transport Euclidean distance (ED) (37.6 per cent) is greater than for private transport (23.7 per cent). However, when the respective transport networks (RND) are considered, the increase for private transport (45.4 per cent) is marginally greater than the corresponding increase for public transport (42.2 per cent). This suggests that, in relative terms, the greater intermixing of residential and employment functions since 1991 has facilitated greater increases in the range of trip possibilities available for public transport users than has been the case for private transport users. Over the same period, the greater ubiquity of the private transport

Figure 6. Urban travel scales, by mode of transport and commuting cost measure.

Table 3. \(C_e\) and \(NC_e\) efficiency measures, by mode of transport and commuting cost measure (percentages)

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<tbody>
<tr>
<td>Private transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991 ED</td>
<td>15.1</td>
<td>+21.0</td>
<td>20.2</td>
<td>+23.7</td>
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<td>2001 ED</td>
<td>36.1</td>
<td></td>
<td>43.9</td>
<td></td>
</tr>
<tr>
<td>1991 RND</td>
<td>19.2</td>
<td>+20.5</td>
<td>27.4</td>
<td>+18.2</td>
</tr>
<tr>
<td>2001 RND</td>
<td>39.7</td>
<td></td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>Public transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991 ED</td>
<td>8.1</td>
<td>+19.7</td>
<td>16.7</td>
<td>+23.6</td>
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<tr>
<td>2001 ED</td>
<td>27.8</td>
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<td>40.3</td>
<td></td>
</tr>
<tr>
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<td>+24.4</td>
<td>9.3</td>
<td>+31.4</td>
</tr>
<tr>
<td>2001 RND</td>
<td>29.2</td>
<td></td>
<td>40.9</td>
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network has facilitated a greater increase in the range of trip possibilities by private transport over the period. Nevertheless, the increase in the \((T_{\text{max}} - T_{\text{min}})\) value for public transport suggests that the public transport network has evolved in such a way as to serve a considerably greater range of trip possibilities than in the past.

As mentioned already, the private transport network is, in effect, ubiquitous whereas that for public transport is constrained by the service that is on offer. In the case of the Dublin region, the public transport network underwent significant changes between 1991 and 2001. In the outer areas of the region, additional routes have been added and service frequencies have increased. While the routes concerned in most cases operate to and from the city centre, the aforementioned improvements have also facilitated those commuting to significant nodes along those routes. Significant developments have also occurred in the public transport network closer to the central area. New routes have been introduced, thereby increasing the density of the network, while priority bus lanes have increased public transport efficiency relative to private transport.

**The role of the transport network on commuting economy.** The differences that emerge in the \(C_e\) and \(NC_e\) Euclidean distance (ED) results for public and private transport reflect solely the differences in the distribution of origins (residences) and destinations (workplaces) in the study area—i.e. the land use geography. This is because using Euclidean distance as a measure of zonal separation ensures in effect that both modes operate along an identical network. By comparing the results for ED and RND broken down by mode of transport, the impact of the transport network, as reflected by the \(c_i\) values of the commuting cost matrix, can be identified. Specifically, subtracting the ED results from the RND results isolates the role that the transport network plays in the solutions for each mode (Table 4). In Table 4, a positive value for the results indicates the extent to which the transport network is contributing to greater commuting economies; on the other hand, a negative value suggests that the impact of the network is to contribute to commuting diseconomy for that particular mode.

The results emerging from Table 4 suggest two trends. First, they highlight the extent to which improvements in the public transport network alluded to already, and particularly increases in the density of the network, have transformed the public transport network from one which conferred significant diseconomy on its users in 1991 to one which now confers commuting economy. Undoubtedly, improvements in the transport network have also been facilitated by the increased intermixing of residential and employment functions alluded to earlier which has allowed users of the public transport network to access more employment opportunities along public transport routes. Secondly, the results show that, whether measured by \(C_e\) or \(NC_e\), the private transport network is conferring fewer economies on its users than in 1991. This reduction in the ability of the private transport network to confer similar levels of commuting economy upon its users, as in 1991, is related largely to the increasing value of \(T_{\text{rand}}\) over the period making it more difficult for car users to economise on

<table>
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<tr>
<th>mode of transport</th>
<th>(C_e) (RND - ED) network impact</th>
<th>(NC_e) (RND - ED) network impact</th>
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</thead>
<tbody>
<tr>
<td>Private transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>+4.1</td>
<td>+7.2</td>
</tr>
<tr>
<td>2001</td>
<td>+3.6</td>
<td>+1.7</td>
</tr>
<tr>
<td>Public transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>-3.3</td>
<td>-7.4</td>
</tr>
<tr>
<td>2001</td>
<td>+1.4</td>
<td>+0.6</td>
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commuting costs. The foregoing results reinforce the earlier suggestion that land use developments and network improvements over the period have been to the advantage of public transport users. Yet, despite the improvements, public transport continues to lose market share to private transport (Table 1) suggesting that spatial reorganisation has primarily facilitated increased patronage levels for private transport.

6. Discussion and Conclusions

There has been considerable debate in the academic literature about the merit or otherwise of excess commuting research for informing urban policy-making. Much of the debate has centred on the use of $T_{min}$ as an indicator of jobs–housing balance in urban areas. It has been argued that urban policies aimed at encouraging a greater jobs–housing balance tend to increase commuting efficiency despite the evidence for this phenomenon being mixed (Peng, 1997; Horner, 2002). While jobs–housing balance indicators are of course important, we feel that the real value of the commuting economy approach lies in its usefulness as a mechanism for monitoring the reaction of commuting behaviour to changes in urban spatial organisation and the transport network over time.

The focus of this paper has been on providing an alternative method of benchmarking commuting 'efficiency' based on measuring the extent to which individuals are collectively economising on urban commuting costs. This benchmarking has been achieved by using $T_{rand}$ rather than $T_{min}$ and/or $T_{max}$ as the basis for our measures. We have demonstrated that $T_{rand}$ is a more appropriate base measure because it relates solely to a specific type of behaviour where cost is irrelevant in decision-making. If our framework was applied to more than one city, it would undoubtedly provide valuable information about the influence of different urban structures on collective commuting economy and more generally about the sensitivity of commuters to land use separation within different socio-spatial and network provision contexts. Given the current focus in policy-making circles on reducing energy consumption and environmental emissions, this would surely provide a useful means of analysing the efficiency of commuting patterns in various urban structures.

The development of new measures that are based on $T_{rand}$ also allows for explicit behavioural interpretations to be drawn from the results. They demonstrate the extent to which individuals are collectively reducing commuting costs from those associated with random commuting. The empirical analysis for Dublin has shown that individuals are approximately 35 per cent away from behaving as random commuters; in essence, their choice of locations is far from random. The temporal analysis has demonstrated that collective behaviour has evolved in such a way as to suggest that increased utility is being placed on land use separation. This is hardly an indictment of the fact that origins and destinations are becoming increasingly irrelevant as some have surmised.

Although a temporal analysis was undertaken previously by Frost et al. (1998) and more recently by Ma and Banister (2006b) and Yang (2008) within the excess commuting framework, the application of the revised framework to two different time-periods is a significant contribution to current research. Set against the specific behavioural assumptions of $T_{rand}$, our analysis offers important additional insights for furthering our understanding of urban commuting patterns within the context of urban spatial reorganisation and the changing configuration of the transport network. With regard to the former, the results for Dublin suggest that greater commuting economies can be achieved in urban structures with a higher degree of residential and employment intermixing than in cities that are more
monocentric in form. We would expect that cities with a greater intermixing of land uses would display more efficient spatial interaction, at least for the journey to work. With regard to the latter, our analysis has presented a means of isolating the impact of the transport network on the solutions. The results for Dublin have demonstrated that improvements to the public transport network are offering its users the opportunity to economise on commuting costs; the opposite was the case in the past.

Previous analysis of this kind has provided little insight into the differing nature and role of public and private transport in the measurement of commuting efficiency. This is unfortunate when it is considered that the relative roles being played by the various modes of transport in any city are generally different. In particular, there is ample evidence that the suburbanisation of functions that were traditionally located in city centres, most notably employment opportunities, have altered the role that public transport systems, which tend to have route networks that focus on the city centre, can play in serving travel demand, especially for the journey to work (Schwanen et al., 2001, 2004; Vega and Reynolds-Feighan, 2008). Our analysis of public and private transport separately has allowed the evolving roles of these modes to be compared and, in particular, for the impact of the various changes that have been made to the public transport network to be highlighted. The results for the period under consideration have shown that the commuting economy of public transport users has improved at greater rates than for private transport users. In policy terms, this implies that the movement towards greater intermixing of residential and employment functions has increased the role played by public transport in servicing a greater range of trip possibilities. Of course, the market share of public transport has declined over the study period, but there is every reason to believe that this relates to other issues—for example, socioeconomic trends—and not to the evolution of land use arrangements within the study area.

The method has some limitations. One drawback of the proposed measures lies in their failure to provide information about the extent to which greater commuting economy is enforced by changing urban structure and the evolving transport network, as against conscious decision-making on the part of the individual to economise to an increasing extent on commuting costs. This is a difficulty which is not easily overcome and would require data on individual location decision-making characteristics. Moreover, many of the methodological issues discussed previously in relation to the minimum and maximum commutes are also issues which pose difficulties for the calculation of the random commute.

There is a further caveat which relates to the extent of the study area for 1991 and 2001. Given that it is the same for both years, it does a good job of catching the decentralisation of employment over the study period. However, the extent of the study area has not caught the impact of the dispersal of residences beyond the study boundary. The impact that this may have on the results is unknown and requires further investigation. Intuitively, it would be likely to contribute to a reduction in commuting economy, given the tendency for outlying commuters to travel greater distances for the journey to work (Murphy, 2004).

Despite some shortcomings, the approach proposed here opens up opportunities for further research. One obvious extension is the application of the approach to cities with varying urban structures and socioeconomic characteristics. This would certainly provide useful insights about the extent of variation in commuting economy for cities with alternative spatial organisation arrangements and where alternative...
transport and land use policies have been adopted. It would also be interesting to see how the results might change if time rather than distance was used as commuting cost. Intuitively, one might expect that individuals economise to a greater extent on time rather than distance for the daily commute. If this were to be the case, then the results presented here may underestimate the collective commuting economy being exercised by workers. Moreover, application of the framework to different occupational categories would surely lead to a more sophisticated understanding of commuting patterns both within and between different cities.

Note

1. The Greater Dublin Area (GDA) is taken as comprising the administrative districts of Dublin City, Dun Laoghaire–Rathdown, Fingal and South Dublin, together with counties Kildare, Meath and Wicklow.

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