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Employment sub-centres and the choice of mode of travel to work in the Dublin region

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Abstract

In this paper, travel-to-work patterns are analysed for a number of key employment sub-centres in the Dublin region. Geographical Information System (GIS) visualisations and regression analysis are used to identify a small number of employment sub-centres using a large sample of travel to work data from the 2002 Census of Population modified with travel-specific data by the Dublin Transportation Office. The journey to work is then analysed across these employment sub-centres in the context of a travel mode choice model. The estimation results illustrate the varying effects that travel attributes such as travel time and travel cost have on the choice of mode of travel across employment destinations highlighting the role of trip destination as a main driver of travel behaviour in the Dublin region.

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1. Introduction

Issues related to the spatial distribution of homes and workplaces in the Dublin region and the travel patterns that they generate, have raised interest and debate about the desirability of integrating land use policies to promote higher urban densities and transport policies aimed at reducing car-based trips and traffic congestion.

The analysis presented in this paper aims to contribute to the understanding of current travel-to-work patterns in Dublin and to the development of appropriate modelling frameworks for analysing travel mode choice in the region. It has two main objectives: first, to identify key employment sub-centres in the Dublin region and to characterise them in terms of their composition by industrial and socio-economic group. Second, to illustrate the differences and similarities in travel behaviour in the context of the choice of travel-to-work mode across employment destinations. Results from the analysis carried out confirm the existence of strong car dependencies in commuting trips to suburban employment sub-centres.

The well-documented economic growth experienced in Ireland during the 1990s directly contributed to a significant rise in living standards placing Ireland among the top positions on this ranking at international level (Walsh, 2004). The Dublin and Mid-East region in particular has experienced unprecedented levels of growth and change in the last decade. Regional Gross Value Added (GVA) increased by 8.3% per annum in the period between 1993 and 1999, the highest increase recorded for any Irish region (O'Leary, 2003).

Very rapid and sustained increases in employment accompanied and facilitated the high growth rates experienced in Ireland in the last decade. A key feature of this employment growth was the significant increase in employment rates among women aged 25-44, with the resulting growth in the proportion of households with two or more employed members (Walsh, 2004). The increase in female participation rates in the labour market in Ireland and in the Dublin region have had major implications for female commuting patterns. Nationally, the percentage of females commuting longer distances has increased notably since 1991. The literature on gender commuting differences has suggested that female commuters are more sensitive to travel time than male commuters, particularly when there are children in households (see recent examples in MacDonald, 1999; Sermons and Koppelman, 2001).

Work practices have also changed significantly in this period, with greater flexibility for many in the start time and duration of the working day. In many sectors shift work has extended the duration of the weekly production cycle of firms and this has had impacts on the time and length of the commute periods of the typical workday.

House prices in the Mid-East region have risen at high rates on a sustained basis also. Concern has grown among urban planners and the public at the increasing financial difficulties of first-time buyers of homes in the region to afford homes at relatively close distances to their workplaces. This has contributed to the rapid development of new housing estates far from the main regional employment centres, with many of the smaller towns between 50 and 80km from central Dublin

becoming local focal points for new housing developments and extending further the commuter belt.

Car ownership rates in Ireland have increased rapidly along with rising incomes and employment rates. In 1990, Ireland had 226 cars per 1,000 inhabitants. By 2004, this had risen to 385 cars per 1,000 population (Eurostat, 2006). Although the increase was one of the highest recorded for the EU15 member states, the car ownership rate remains significantly below the European average[2].

On the supply side, there has been little increase in the total length of key arterial roads nationally (namely motorway, National Primary and National Secondary roads) in the past decade, despite the growth and regeneration particularly in inner city districts. The combination of all of these factors has had major implications for commuting and travel patterns in the Dublin region. The numbers travelling to work by all modes of transport has increased by over 16% in the most recent census period 1996-2002, further accentuating trends documented by Horner (1999) for the period 1981-1996. These related to the increasing proportions of long distance commuters, focused around the major urban centres and the increased use of the car for shorter journeys. These effects may be seen nationally in the comprehensive set of maps presented by Walsh, Foley, Kavanagh and McElwain (2005). This study used small area data from the 2002 Census of Population.

One of the most relevant trends in urban development across the world is employment decentralisation and the emergence of employment sub-centres (Ingram 1998). There has been extensive agreement in the literature about the

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[2] The car ownership rate for the EU25 in 2004 was estimated to be 472 cars per 1,000 inhabitants (Eurostat, 2006).

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monocentric nature of the spatial distribution of employment in the GDA (see Convery et al. (2006) for details). However, the analysis carried out in this paper from the 2002 Irish Census of Population illustrates some degree of employment suburbanisation in Dublin. The differences in commuting behaviour that arise when jobs move away from the CBD have been well acknowledged in the literature (Crane and Chatman 2003; Nechyba and Walsh 2004). This paper attempts to understand these differences in the Dublin context.

It is not the intention to argue in favour of or against the existence of a polycentric structure in the GDA. The objective is to provide an analysis of travel behaviour across employment destinations. However, the results from the identification of employment sub-centres illustrate a certain degree of employment concentration at suburban areas.

A number of methodologies are applied that range from the use of regression analysis for the identification of employment sub-centres and the use of GIS tools in assessing and characterising each sub-centre, to the specification and estimation of discrete choice models for the analysis of travel-to-work mode choice.

The next section presents an overview of the literature on the identification of employment sub-centres. In Section 3, the data sources are briefly introduced and Section 4 presents the methodology used for the identification of employment sub-centres where a number of key employment sub-centres are identified. Specification and estimation results from a binary travel mode logit model follow this analysis, and a comparative study of aggregate direct and cross elasticities

across employment sub-centres is presented. The paper concludes with a summary of key findings and policy implications.

2. Literature

A number of methodologies on the identification of employment sub-centres have been introduced over the last decades. These vary from the visual identification of employment clusters to more sophisticated approaches using regression analysis and non-parametric procedures. Guiliano and Small (1991) introduce a new branch of analysis based on the computation of measurements of employment density values and the visual identification of clusters of employment zones on maps. The procedure consists of the definition of a sub-centre as a set of continuous zones, each of which has an employment density above a minimum cut-off value (10 employees per acre) together with a minimum total employment above 10,000 employees. Previous knowledge on the area is necessary in order to identify the various sub-centres and set the cut-off points.

The definition of employment sub-centre has evolved over the years since Giuliano and Small's (1991) study. From the notion of a sub-centre as a cluster of contiguous zones with larger absolute value of employment density and total number of jobs, researchers are now closer to McMillen's (2001) definition of a sub-centre as '*a site with significantly larger employment density than nearby locations and a significant effect on the overall employment density function'*.

More sophisticated approaches have used regression analysis to identify sub-centres of employment (McDonald, 1987; McDonald and McMillen, 1998; McDonald and Prather, 1994). One of the main advantages of the regression

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analysis approach is that it offers a sound statistical procedure where employment density is a function of distance to the CBD rather than an absolute value. The main idea is based on the identification of sub-centres that significantly differ from the monocentric employment density pattern (McDonald and Prather, 1994). These procedures work best for centralised cities where assumptions about symmetric employment density function with respect to the CBD can be made (McMillen, 2001). These procedures need to be complemented with visual inspections of identified clusters and some previous knowledge of the area of study. McDonald and Prather's (1994) methodology is used in this dissertation for the identification of employment sub-centres in the GDA.

Recent studies offer non-parametric procedures to identify employment sub-centres. Craig and Ng (2001) use the employment density function quantile smoothing splines to produce a series of concentric circles of employment density. A two-stage non-parametric procedure is introduced by McMillen (2001). In a first step, a locally weighted regression (LWR) procedure is used to identify employment sub-centre candidates followed by a semi-parametric regression procedure used to test whether the previously identified candidates have an effect on the overall employment density. One of the latest procedures for the identification of employment sub-centres introduces a methodology based on the use of contiguity matrices (McMillen and Smith 2003).

Disaggregate data from the San Francisco Bay Area are used in Cervero and Wu (1998) to study the effect of the process of employment suburbanisation on mode choice and vehicle occupancy. In contrast to previous research, results suggest that job decentralisation has contributed to a substantial increase in the average vehicle

miles travelled, with the largest mode shifts from public transport to private car happening when central employment locations move to suburban employment locations.

The relationships between employment suburbanisation and public transport use is further explored in Modarres (2003) using Census data from Los Angeles County. Main employment sub-centres are identified using Nearest Neighbour Hierarchical Cluster Analysis and a Kriging function with public transport accessibility assessed for each of these employment sub-centres. Results illustrate inadequacies in connecting employees to their workplaces and suggestions are made to formally adopt a '*hierarchical public transport system*' where the regular identification of employment sub-centres serves to reduce the spatial mismatch between residences and job destinations by public transport.

The process of employment suburbanisation has been studied in areas other than the US (see examples for Jerusalem in Alperovich and Deutsch (1996) and for Canada in Shearmur and Coffey (2002)). European studies of employment suburbanisation are found in a number of recent research papers for a cities in France and in Spain (Muñiz, Galindo et al. 2003; Aguilera 2005; Guillain, Le Gallo et al. 2006). Guillain et al. (2006) explore the spatial distribution of employment in the Ile-de-France region. The study combines exploratory data analysis for the identification of employment sub-centre with sectoral analysis. The relationship between commuting patterns and urban shape is studied by Aguilèra (2005) for three main French cities (Paris, Lyon and Marseille). Results from the analysis show that most residents at employment sub-centres work outside their employment sub-centre of residence and that most people working at employment

sub-centres live far away from their workplace thus, increasing the commuting distance.

3. Data sources

The area selected for the analysis is the Greater Dublin Area (GDA) and it includes the four inner counties of Dublin: Dublin City, South Dublin, Dun-Laoghaire-Rathdown and Fingal, and the four adjacent counties to Dublin: Kildare, Meath, Wicklow and Louth. Figure 1 shows a map of the GDA and the location areas.

Aggregate and disaggregate level data from the 2002 Irish Census of Population are used in this paper. Disaggregate census data are provided at the individual level and are used in the identification of employment sub-centres and the estimation of the travel mode choice model. This data set is a 30% sample from the 2002 Irish Census of Population and it provides socio-economic information on individuals and the characteristics of their households, means of travel, distance and journey times to work as well as place of residence and place of work[3]. The sample has been adjusted by the DTO to limit records to trips within the Dublin region, resulting in a set of 187,684 valid journey-to-work records. The travel data were further revised by the DTO to deal with records returning blank or invalid entries in fields such as travel distance to work, travel time and speed.

Origin-destination travel time and travel cost matrices are provided by the DTO at the electoral district level for all possible origin-destination trips by both, car and public transport. Car travel costs are computed as the

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[3] Census of Population 2002 Place of Work Sample of Anonymised Records (POWSAR) User Guide. (www.cso.ie/census/documents/ PlaceofWork-SARUserGuide2002.pdf

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monetary costs associated with fuel consumption and they are directly proportional to travel distance. Car travel costs take into account parking charges at the destination and parking restrictions. Public transport costs consist of a system of varying fares with distance and a boarding penalty measure, which accounts for the fact that the bus is an inferior mode in relation to rail. Car and public transport travel times are computed for the morning peak period and they include walking time to stop/station and waiting time at the stop/station for public transport and in-vehicle time in minutes for public transport and private car travel.

Aggregate data are provided at the electoral district level for the Greater Dublin Area and used to produce a series of maps that illustrate the composition of each employment sub-centre by industrial and socio-economic group. The aggregate data set is the 2002 Small Area Population Statistics (SAPS) and it contains 1,161 variables for 4,334 electoral divisions or electoral districts along with all towns with a population of 1,000 or more and many other administrative areas[4].

[Figure 1 here]

3. Identification of employment sub-centres in the Dublin region

Assessing travel behaviour requires an understanding of the linkages between the transportation network, the spatial structure of the city and the processes of policymaking that generated them. Cities in Europe and in the US have gradually abandoned their historic spatial structure around a single central employment

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[4] http://www.cso.ie/census/SAPs.htm

centre or central business district (CBD) to adopt more decentralised spatial patterns of population and employment. The Dublin region is not an exception to this worldwide trend. Research has shown that over the last decade, the spatial distribution of service-based industry has gradually moved away from its traditional location in the city centre and has located in the suburbs, contributing to the consolidation of a polycentric urban structure (Murphy, 2004). Traditional urban public transport networks with a radial structure may not be sufficient to cover the transportation needs of more suburbanised cities[5] (Modarres, 2003). This may have enormous consequences in terms of commuting and travel behaviour.

Recent research in urban economics has focussed on the identification of spatial concentration patterns of employment at the local level. Most of the research carried out has concentrated on determining whether the emerging urban spatial structures respond to a polycentric pattern of clusters of activities (employment) or whether they are the results of a more dispersed urban structure (Anas et al, 1998).

To our knowledge, a detailed analysis of employment sub-centres in the Dublin region has not been published. This section presents a procedure for the identification and characterisation of employment sub-centres by socio-economic and industrial group. Following McMillen's (2001) definition, employment sub-centres are spatially contiguous districts with a significantly larger employment density than nearby locations. For the purpose of the analysis carried out in this

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[5] This is particularly evident in Dublin city where as mentioned earlier, the urban bus network predominantly focuses on the city centre with radial road routes extending along the main arterial routes to the suburbs and commuter areas.

study, these employment sub-centres are also the main destinations for the journey to work in the GDA.

3.1. Identification of employment sub-centres

Most of the procedures on the identification of employment sub-centres follow the systematic methodology of first, identifying candidate employment sub-centres, and then evaluating whether these candidate sub-centres have a significant effect on the overall employment density of the region. The extent to which some employment sub-centres attract less/more local residents than others - and therefore, generate more/less inter-zone trips - has generally not been considered relevant in the process of employment sub-centre identification. As it will become clear, this aspect is considered to be crucial for the analysis of the choice of travel-to-work mode presented in this paper.

The study of travel behaviour to employment sub-centres with the largest inter-zone trip volumes – understood as the number of commuting trips ending at each employment sub-centre with origin at areas other than the identified sub-centre – provides useful information for short-term action in producing adequate transport policies that help to reduce traffic congestion levels.

A two-phase approach is presented to identify employment sub-centre candidates in the Dublin region and to assess whether these sub-centre candidates are relevant for the analysis on the basis of their employment size and their employment self-containment ratio[6]. In general, relevant employment sub-centres are those that

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[6] The ratio of work trips to each employment sub-centre candidate originating within itself relative to work trips to the same employment sub-centre originating from other electoral districts

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attract the largest number of commuters and, in particular, those that attract the largest number of commuters from other districts.

The analysis concentrates on those residents in the Dublin region whose job destination is within the limits of the four Dublin inner counties. Dublin inner counties present the highest levels of congestion in the GDA and the purpose of this paper is to analyse travel mode choice across employment sub-centres where most traffic (and to some extent traffic congestion) is generated.

Table 1 gives several aggregate measures of spatial concentration of employment for the GDA using the sample distribution of employment shares by electoral district within the study area. It shows a relatively high concentration of employment with a computed Gini coefficient of 0.70 or 0.71 depending on the measure of employment used. The Theil entropy measure and Coefficient of Variation also confirm a highly concentrated employment distribution pattern.

[Table 1 Here]

A version of McDonald and Prather's (1994) procedure is followed to identify potential candidate employment sub-centres other than the CBD. The analysis is based on the assumption that the Dublin region is essentially monocentric. The monocentric city model assumes a city with a circular residential area around a CBD where all jobs are located.

The negative exponential function of employment density as a function of distance to the CBD is estimated

$$D(x) = D_o e^{-\beta x + \mu}$$

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where D is the employment density measured as the total number of workers per hectare, x represents the distance in kilometres to the CBD, D_o is a positive constant and β and μ are the density gradient and the random error term respectively.

Initially, the log version of the model is estimated using ordinary least squares (OLS), but since it fails the Breusch-Pagan test for heteroscedasticity, the same log version of the model is estimated using weighted least squares (WLS), which solves the problem. Given the uneven size of the urban zones used as geographical units (electoral districts), we estimate the following model using weighted least squares, where we weight each electoral district in proportion to its area in hectares (see Frankena (1978) and McDonald and Prather (1994) for a more detailed explanation):

$$\ln D(x) = \ln D_o - \beta x + \mu$$

As expected, a negative significant coefficient for distance to the CBD is obtained[7]. The idea behind McDonald and Prather's (1994) procedure is that by analysing the residuals from the estimated monocentric equation, we are able to identify spatially contiguous districts that show employment density values much higher than those predicted by the monocentric model.

This first phase produced a large number of electoral districts (126) that show employment density significantly above the upper 95% confidence limits for the

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[7] See the regression analysis of the employment density monocentric city model in Table A1 in the Appendix.

estimated values of the natural log of employment density[8], i.e. the employment density is greater than what would be expected from a monocentric city model.

In the next phase, employment sub-centre candidates are assessed on the basis of the number of commuters they attract (employment size) and their self-containment ratio. The idea is to concentrate on employment sub-centres that attract most traffic from other districts in the city with commuting trips usually made by non-local residents who use motorised modes of travel in their journey to work.

GIS tools are used to visualise those districts that lie above the upper quartile of a measure of the total number of commuters to each potential sub-centre candidate and below the lower quartile of the ratio of self-containment[9] at each district. Spatially clustered districts across the region are presented in Figure 2 as the identified employment sub-centres.

Figure 2 shows the four employment sub-centres identified for this purpose. Two main sub-centres in the west Dublin districts emerge from the analysis: Blanchardstown, located in the upper northwest corner, and Clondalkin-Tallaght to the southwest. Dublin Airport to the north and a cluster of districts along the national N11 road and the coastal electrified *DART* train line to the south, complete the set of employment sub-centres identified for the Dublin region. Some other districts are identified, but fail to qualify as employment sub-centres because they are not spatially clustered.

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[8] Those electoral districts with positive residuals that lie within Dublin inner city are left out because they are considered areas of influence of the CBD.

[9] Let T_{ji} be the number of commuting trips from j to i. $\sum_{j=1}^{n} T_{ji}$ will be the total number of jobs at i, including T_{ii}. The self-containment ratio is computed as $T_{ii} \Big/ \sum_{j=1}^{n} T_{ji}$

[Figure 2 Here]

The expansion of Dublin city to the West is the result of more than three decades of regional land-use planning. The so-called Myles Wright Plan[10] (1967) proposed to accommodate Dublin's urban growth westwards in four semi-self-contained "new towns", namely, Blanchardstown, Lucan, Clondalkin and Tallaght. The Myles Wright Plan also suggested the creation of restricted zones around Dublin Airport reserved for Airport service industries. Airports have been identified as employment sub-centres in some of the research published for US cities, such as Chicago and Los Angeles (McDonald and Prather (1994); Cervero and Wu (1998).

In spite of the existence of local employment sub-centres, the CBD still accounts for more than 40% of the total employment in the region, while all the identified sub-centres together represent the 15%. This confirms the existence of a highly centralised spatial distribution of employment by international standards. In the United States, the CBD employment rarely accounts for more than 8% of the total number of jobs of a metropolitan area (Ingram 1998). To explore this further, the second step in McDonald and Prather's (1994) methodology is followed to estimate the effects of the identified employment sub-centres on the overall spatial employment density. Polycentric city models of employment density as a function of distance to each employment sub-centre are estimated. None of the coefficients are statistically significant.

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[10] In 1965, Myles Wright was commissioned to prepare an "advisory Regional Plan and Final Report" for the Dublin region. The plan focused on four main issues: communication, housing, land-use and employment.

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3.2. Characterisation of employment sub-centres

Figure 3 shows the composition of employment for each sub-centre by industrial group[11]. The CBD and the N11 sub-centres offer a very similar profile. A relatively higher proportion of service-based (commerce) jobs are present in these areas together with a reduced presence of manufacturing industries and construction jobs.

Commerce classified employment is present in most of the sub-centres in a relatively large proportion. However, a further breakdown by subcategories is not provided in the dataset, making it difficult to extract major conclusions given the broad definition of commerce related industries.

[Figure 3 Here]

Manufacturing employment is found to be more decentralised than service-based employment. This is consistent with the spatial job location patterns found in the US, where in most big cities, manufacturing firms have followed a trend of moving further away from the centre in search of more space and better infrastructure (Ingram, 1998).

Some industrial groups seem to follow a predominant spatial location pattern in the region. Transportation, storage and communications industries are mainly clustered around Dublin Airport, while manufacturing industries show higher concentration patterns in the western sub-centres. Education, health and social work related

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[11] The definition of industrial group responds to the 2002 CSO classification of industries.

industries are mainly present in the N11 and the CBD, which coincide with the location of two of the main third level educational institutions in the country.

A salient feature of the spatial distribution of sub-centres shown in Figures 2 and 3 is their location adjacent to major transportation corridors (four radial national roads and the M50 orbital motorway). The fact that some industries such as manufacturing or transport and storage are heavily dependent on the access to transportation corridors for their daily activities may explain this pattern.

Parametric and non-parametric tests were carried out to evaluate whether there is a significant difference in the average sample employment across industrial groups within the identified employment sub-centres. The Bartlett's test of homogeneity of variance led to rejecting the assumption that no significant differences between the variances of the groups were present[12] (Bryman and Cramer, 2001). The Kruskal-Wallis non-parametric test was carried out and resulted in the rejection of the null hypothesis of non-significant differences in sample employment across industrial groups.

Figure 4 presents the socio-economic composition[13] by employment sub-centre. Again, the CBD and the N11 show a very similar profile in terms of the socio-economic make-up of their commuters, with a very low proportion of manual-skilled, semi-skilled and unskilled commuters present and the highest proportion of higher and lower professionals recorded in the region. Manual-skilled and semi-

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[12] In this case, we cannot use One-way Analysis of Variance (ANOVA) unless the data were transformed to make the variances equal. Non-parametric tests were used instead.
[13] Socio-economic group refers to the occupation and employment status of individuals as classified in the 2002 Irish Census of population

skilled classified commuters are found in larger proportions in the Western suburban employment sub-centres and around Dublin Airport.

[Figure 4 Here]

4. Travel mode choice model

In this section, the choice of mode of transport is modelled in the context of the journey to work. A comparative analysis of travel mode choice across employment sub-centres is presented. The objective is to give new insights into the linkages between the distribution of employment and the modal choice in the Dublin region and to illustrate the significance of studying both in an integrated manner.

The study area for the discrete choice analysis includes the four Dublin inner counties and the four adjacent counties of Kildare, Meath, Wicklow and Louth[14], the GDA. The decision makers are commuters into the previously identified employment sub-centres as shown in Figures 2, 3 and 4, i.e. Dublin Airport, Blanchardstown, Clondalkin-Tallaght, cluster of districts along the N11 national road and the CBD, with residential location in any of the counties included in the study area. Individuals who work at home or individuals who do not commute on a daily basis are not included in the analysis.

The data source for the analysis is a sub-set of the CSO – DTO 30% POWSAR sample with a total of 15,644 observations. Table 2 shows the mode availability shares, mode choice shares and sample statistics for the attributes of the alternatives.

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[14] Information was gathered for those electoral districts within the four adjacent counties for which the DTO records travel data.

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Random Utility Maximisation models (McFadden, 1973) have been broadly applied to model travel mode choice decisions. Utility maximisation theory assumes that an individual selects the alternative from his/her choice set that maximises his/her utility. The utility that the individual obtains from alternative j is decomposed into a systematic part, $V_{nj} = \left(x_{nj}, s_n \right)$ specified as linear in parameters and described as a function of the attributes of the alternatives and the decision-maker characteristics, and a random part ε_{nj}, which is the portion of utility that is unknown to the analyst. The utility function for each alternative is therefore defined as $U_{nj} = V_{nj} + \varepsilon_{nj}$ where the probability that the decision-maker chooses alternative i is

$$P_{ni} = \text{Prob}\left(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj}, \forall j \neq i \right) = \text{Prob}\left(\varepsilon_{nj} < \varepsilon_{ni} + V_{ni} - V_{nj}, \forall j \neq i \right).$$

The closed-form expression derived for the calculation of probabilities has made the logit model one of the most widely applied model structures to the study of modal choice.

In this paper we estimate a binary logit model for the choice of mode of travel to work. The logit model is obtained by assuming that each ε_{nj} is independently and identically distributed extreme value. The probability to choose alternative i is:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}}$$

Regarding the travel mode decision for the journey to work, the choice between the private car and public transport is modelled. Due to a lack of data on slow mode

commuting attributes (walking and cycling) for all of the Dublin electoral divisions, these modes are not included in the analysis. The extent to which this significantly affects the overall results for suburban employment destinations is not clear. Given the location of most of the suburban employment centres identified, i.e. along motorways in areas with low residential density, access by slow mode is expected to be less common than to the CBD. However, recommendations for further research include the examination of mode choice for individual employment sub-centres and the introduction of the "slow mode" where data is available (in most cases only for the CBD).

The availability of private car and public transport is taken into account and probabilities are computed accordingly. The systematic part of the utility function for each of the two choice alternatives, car and public transport, is given by the following expressions

$$V_{car} = \beta_1 * TravelTime_{car} + \beta_2 * TravelCost_{car} + \gamma_1 * Gender + \gamma_2 * NumberCars + \gamma_3 * Age2 \\ + \gamma_4 * Age3 + \gamma_5 * SEG1 + \gamma_6 * SEG3 + \gamma_7 * Sub-centre1 + \gamma_8 * Sub-centre2 \\ + \gamma_9 * Sub-centre3 + \gamma_{10} * CBD + \gamma_{11} * Emp\_density$$

$$V_{PT} = \alpha_0 + \beta_3 * TravelTime_{PT} + \beta_4 * TravelCost_{PT}$$

where all the coefficients for the characteristics of the decision maker are normalised to zero for the public transport alternative and the constant is normalised to zero for the car alternative. The attributes of the alternatives and the characteristics of the decision maker included in this model are those typically used for modelling travel mode choice.

A number of socio-economic variables are used for the analysis. These include gender, age, number of cars or vans available in the household and the socio-economic group. The classification by socio-economic group aims to bring together persons with similar social and economic statuses on the basis of the level of skill or educational attainment required[15]. The socio-economic group cannot be considered a proxy for income, but it is an appropriate indicator of the level of education and social status. Additional variables are the employment density calculated as the ratio of total employment per hectare in each electoral district and a series of dummy variables for each employment sub-centre. Table 3 provides the descriptions of the independent variables used.

[Table 3 here]

A test for taste variation is carried out to look for systematic variation of taste coefficients among sub-groups of individuals working in the various identified employment sub-centres[16]. The procedure consists in estimating the model for the full sample size and for a number of sub-samples corresponding to each of the employment sub-centres. A likelihood ratio test statistic is computed under the null hypothesis of no significant taste variations across employment sub-centres.

The null hypothesis is rejected at the 95% confidence level. Further exploration of the individual coefficients for each employment sub-centre is carried out to

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[15] The socio-economic group of persons aged 15 years or over who are at work is determined by their occupation and employment status. Unemployed or retired persons aged 15 years or over are classified according to their former occupation and employment status. Persons on home duties or at school/college, who are members of a family unit, were classified to the socioeconomic group of the person in the family on whom they were deemed to be dependent (www.cso.ie/census/)

[16] Taste variation can only be partially captured by logit models. Taste variation in relation to observed variables, or systematic taste variation, can be tested for and incorporated into logit models. However, when taste variation is random, that is, when tastes vary with unobserved variables, other model structures such as random coefficient models need to be estimated instead.

investigate which particular coefficients are responsible for the rejection of the null hypothesis. Following Ben-Akiva and Lerman (1985), asymptotic *t-tests* of equality of coefficients between market segments are computed. Significant differences are found between the estimated coefficients of some of the travel variables; however, these differences only apply to a limited number of pairs of employment sub-centres. Attempts to incorporate systematic taste variation in the pooled data model are made, resulting in poorer fits than the model initially estimated.

Table 4 shows the estimation coefficients and marginal effects. Likelihood ratio tests rejected a generic specification for travel time and cost in favour of a specification with alternative-specific attributes. All the parameters are significant and present the expected signs.

[Table 4 here]

As expected, travel time and travel cost present negative marginal effects. Although statistically significant, the marginal effects are found to be small for car travel time and for public transport travel costs. These effects are later explored in this section with the computation of aggregate elasticities by employment sub-centre.

Results for the socio-economic characteristics of the commuters show that older commuters are more likely to use the private car than those under 35 years old. Another expected result refers to the number of available cars in the household, which shows a positive effect on car choice probabilities.

Gender effects are found for car use, with small negative marginal effects for female commuters, who are found to be less likely to use the private car in their journey to work. These results are supported by Nolan (2003) where significant gender effects were found for public transport and in particular for bus use in the Dublin Area.

Commuters classified as employers, managers and professionals and those classified as part of the socio-economic group 3, i.e. manual skilled, semi-skilled and unskilled occupations, are more likely to drive to work than those classified within the non-manual socio-economic group 2. The largest numbers of socio-economic group 3 commuters are found in suburban employment sub-centres, which have a limited supply of public transport from areas other than the city centre. For these suburban sub-centres, no travel alternative is frequently available other than the private car.

In terms of employment destinations, results form Table 4 show that commuters to the CBD are and the N11 are less likely to use the private car than those commuting to further away suburban areas in the west of the region. In terms of employment density, estimation results show small negative marginal effects on the choice probability for car use.

Table 5 shows the computed aggregate direct and cross elasticities with respect to travel time and travel cost by employment sub-centre. These elasticities have been referred in the literature as mode-choice demand elasticities because they express the change in demand for one travel mode given a fixed level of traffic demand for the other mode (Nijkamp and Pepping 1998). Oum et al. (1992) also classify the

type of elasticities presented here as "without non-travellers in the data". This refers to the absence of the option of not making the trip in the users' choice set.

[Table 5 here]

Direct elasticities with respect to travel times are remarkably low for car use. This is more pronounced in the western suburban employment sub-centres, where the sensitivity to changes in car travel times is found to be particularly low. Car choice probabilities to the CBD show the largest sensitivity to changes in car travel costs, followed by the N11, which is also the most centrally located employment sub-centre. The elasticities with respect to car travel costs refer to changes in vehicle operating (out-of-pocket) costs and include petrol and parking costs and road tolls. In the case of the CBD, these are consistent with those presented by Oum et al. (1992) for the US and Australia and with other more recent studies for the Netherlands (Oum et al. (1996)). Elasticities for the CBD are also consistent with the recently reported elasticities with respect to car travel costs and travel times by de Jong and Gunn (2001) within the TRACE project. Elasticities obtained for suburban destinations are remarkably low by international standards.

In general, commuters show very low sensitivities to changes in car travel times. The opposite happens when we look at public transport time elasticities. Commuters to suburban employment sub-centres are particularly sensitive to public transport travel times, with Dublin Airport showing the largest elasticity measure. Travel cost direct elasticities are found to be larger for public transport than for car use in the case of suburban employment sub-centres. In other words, public transport commuters to suburban employment sub-centres are found to be more sensitive to travel cost changes than car commuters. Car commuters to central

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employment locations are more sensitive to changes in travel cost than public transport commuters.

Most studies that include public transport elasticities tend to differentiate between public transport modes such as rail and bus (Oum, Waters and Yong (1992); Goodwin (1992) and Wardman and Shires (2003)). Kain and Liu (1999) identify a number of factors affecting public transport use. They report direct elasticity figures of public transport use with respect to fares, which result in values larger than in Table 5, i.e. -0.32.

Aggregate cross elasticities are defined as the percentage change in car (public transport) probability choice due to a 1% change in public transport (car) travel costs or travel times. Table 5 shows significantly lower cross time elasticities for car use than for public transport. This implies that commuters by public transport to both central and suburban employment sub-centres are sensitive to variations in car travel times, with Dublin Airport and N11 showing the largest cross elasticities. In other words, a given increase in car travel times due to severe congestion will affect public transport use in a positive way. Car choice probabilities are much less sensitive to changes in public transport travel times. In general, commuters by car are more willing to keep using their chosen mode of transport in spite of improvements in public transport times, i.e. frequency, in-vehicle time or walk time to stop/station.

Results are consistent with those reported in de Jong and Gunn (2001) where the cross elasticities for the impact of car travel costs in public transport use is generally low across all the employment destinations. As shown in Table 5, de

Jong and Gunn (2001) report that the cross elasticities for changes in car travel times are greater than the cross elasticities for changes in car travel costs.

Variations in public transport costs seem to have a larger positive effect on car choice probabilities, specifically for those commuting trips to central employment locations. In absolute terms, cross elasticities are found to be larger than direct elasticities for car use. This is particularly relevant for commuting trips to the CBD where a decrease in public transport fares will have a greater effect in reducing car use than an increase in car costs.

Overall, car choice probabilities are more sensitive to changes in travel cost than to changes in travel times for central employment destinations and vice-versa for suburban employment destinations. Public transport choice probabilities are significantly more sensitive to changes in travel times than to changes in travel costs, in particular for those employment sub-centres such as Airport and Clondalkin-Tallaght. The direct and cross elasticities reported in this paper are generally consistent with other studies in Europe, Australia and the US.

It has been argued that given the diversity in travel modes, the type of data used in the various studies and the estimation methods, travel demand elasticities are not directly comparable across studies (Nijkamp and Pepping 1998). However, this is common practice and recent papers keep publishing reviews on travel demand elasticity estimates (Graham and Glaister 2004).

The results shown in Table 5 reflect the extent to which travel mode choice elasticities vary across the various commuting trip destinations. They illustrate the implications of imbalances in public transport provision to suburban employment

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centres, which emerged due to a lack of strong investment in public transport infrastructure to those areas.

Modarres (2003) found similar patterns of public transport provision for Los Angeles County, where a significant proportion of new employment sub-centres were found to be inadequately served by public transport.

Differences in computed direct elasticities for car use for central and suburban employment locations provide a pessimistic picture for those hoping to attain car use reduction levels across the Dublin area by implementing transport demand management strategies such as road pricing without first providing for a comprehensive public transport infrastructure to suburban employment sub-centres.

The analysis presented in this section offers a simplified picture of the travel behaviour in Dublin at the time when the data were gathered. Further research on travel mode choices that take into account residential location patterns would be desirable to reach a more complete representation of the relationship between travel behaviour and the urban structure in the Dublin region. Detailed modelling of travel mode choice for individual employment sub-centres may also generate a more refined analysis of travel behaviour and mode choice where the set of travel options may be more precisely specified (for example, along the *DART* line).

6. Conclusions and discussion

This study focuses on two related topics: the spatial distribution of employment across the Dublin region and the extent to which this spatial distribution of employment affects travel behaviour. The main motivation is to identify a number of key employment sub-centres in the region and to illustrate the variations in

travel mode choice across the sub-centres. In this way, the importance of integrated urban modelling and the role of trip destination (employment) as a main driver of travel behaviour are highlighted, which contrasts with the attention that is usually given to trip origin in travel modelling.

Demographic and economic factors have contributed to the emergence of unprecedented levels of car-based travel and traffic congestion in Dublin. Rising house prices have increased the pace of urban sprawl, and this has had enormous consequences for commuting patterns.

A new 30% sample from the 2002 Irish Census of Population is used to identify key employment sub-centres in the Dublin region. A version of McDonald and Prather's (1994) method is applied to identify electoral districts that act as key employment sub-centres. Four employment sub-centres are identified and used as the key trip destinations in the estimation of a binary logit model for the choice of the mode of travel to work. Further characterisation of these employment sub-centres has shown concentration patterns of particular industries across the identified sub-centres, often located close to the main transportation corridors, and displaying a significant variation in the average employment across different industrial groups.

Elasticities with respect to travel times and costs are computed and compared across employment sub-centres. Significant differences are revealed in the public transport choice probabilities for the CBD compared to suburban employment sub-centres. In general, elasticities are remarkably low by international standards for car use and significantly greater for public transport, particularly with respect to travel times.

Differences in travel mode choice probabilities between central and suburban employment locations reflect the relatively poor provision of public transport to non-central employment sub-centres, making it difficult for commuters to switch modes of travel to work from the private car to public transport at those employment destinations.

Results from this analysis suggest that elasticities of demand for car and public transport vary according to the spatial distribution of employment. However, this is in turn the result of lower car travel costs, which motivated the development of new employment sub-centres in the first place. Recent research paper have suggested that the fixed costs of new employment sub-centres are mainly due to the provision of public transport to access them (Glaeser and Khan (2003); Nechyba and Walsh, 2004). As individuals switch from public transport to car due to reduced car travel costs, the need to provide public transport to employment sub-centres decreases, making the development of new suburban job centres more attractive.

In a polycentric city model, an increase in the number of employment sub-centres due to lower transport costs, and the consequent switch from public transport to car use, enormously reduces the cost of employment suburbanisation.

Results from this research are consistent with previous research on employemtn suburbanisation in relation to the link between the emergence of new suburban employment sub-centres, the importance of the private car as the main driver of decentralisation and the existence of poor provision of public transport to the new suburban job sub-centres.

Conclusions from this study become particularly relevant in the context of *Transport 21*[17], the new capital investment framework for the development of the transportation system in Ireland over the period 2006-2015. Investment in the GDA is one of the key priorities in Transport 21. The investment programme includes a proposal for at least one metro line, extensions to the *LUAS*[18] light rail system and integration of light and heavy rail lines through a central city public transport hub. An upgrade of the M50 orbital motorway is also proposed.

The analysis presented in this paper contributes to the understanding of the relationship between land use and travel behaviour in the context of the journey to work in Dublin. The identification and analysis of suburban employment sub-centres along with the CBD allows for a more detailed assessment of mode choice behaviour in the context of Dublin commuting patterns in 2002. The results contribute to the literature on employment suburbanisation and the effects of travel costs on travel mode choice under various spatial patterns of job destination. They also strengthen the need for integrated urban modelling when addressing new transportation and land-use planning projects in the Dublin region.

This study can be extended further in several directions. The relationship between travel mode choice and the location of employment can be explored in detail to include recently introduced public transport modes such as the *LUAS* and newly developed employment sub-centres in the city of Dublin. The release of the new 2006 Irish Census of Population[19] will facilitate the study of the effects of improved public transport provision in new employment sub-centres.and the effect

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[17] See http://www.transport21.ie/
[18] *LUAS* is Dublin's light rail system consisting of two routes opened in June 2004.
[19] Expected release in November 2007

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on the overall use of the private car to these areas. Another direction to extend this research is to include the choice of residential location combined with the choice of travel mode under central and suburban employment patterns.

APPENDIX

REGRESSION ANALYSIS MONOCENTRIC CITY MODEL

[Table A1 Here]

Tables and Figures

Table 1 Spatial concentration measures			
Variable	**Gini Index (Bootstrap Standard Error)**	**Theil Entropy (Bootstrap Standard Error)**	**Coefficient of Variation**
Employment Density	0.710 (.025)	1.07 (0.099)	2.204
Employment per Head of Population	0.696 (.051)	1.25 (0.292)	3.428
Source: Authors' calculations based on Irish Central Statistics Office data. 2002 Small Area Population Statistics			

Table 2: Sample statistics				
Mode	Availability shares	Mode choice shares	Total travel time (in seconds)[20]	Total travel cost (in cents)
Car	0.923	0.593	48.916 (34.343)	93.771 (73.432)
Public transport	0.933	0.407	72.706 (40.334)	152.182 (162.461)

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[20] Average travel times and travel costs with standard deviation (parenthesis)

Table 3: Variables in the model	
Name	**Description**
Attributes of the alternatives	
Total travel time for car and public transport in hours	In-vehicle travel time for car provided by the DTO Walking time to station/stop, waiting time at station/stop and in-vehicle time for public transport provided by the DTO
Total travel costs for car and public transport in euro	Travel costs for car and public transport fares provided by the DTO
Socio-economic and land use characteristics	
Gender	Female commuter =1
Age group 2	Individuals between 35 and 54 years old (reference category: individuals between 15 and 34 years old)
Age group 3	Individuals over 55 years old (reference category: individuals between 15 and 34 years old)
Socio-economic group 1	Education and employment status (socio-economic group as defined by CSO). Employers, managers and professionals (reference category: non-manual)
Socio-economic group 3	Education and employment status (socio-economic group as defined by CSO). Manual skilled, Semi-skilled and Unskilled (reference category: non-manual)
Number of cars	Car availability for use in the household
Employment sub-centre	Dummy variable for each identified employment sub-centre, i.e. Blanchardstown, CBD, Clondalkin-Tallaght and N11 (reference category: Airport)
Employment density	Gross employment density computed as the number of total employment per hectare in each electoral district.

Table 4: Logit model estimation results (public transport as reference category)		
Variables	**Coefficient (t-stat)**	**Marginal effects**
Mode constant		
Car		
Public transport	-0.36 (-3.50) **	
Total Travel Time (in hours)		
Car	-0.15 (-2.08) **	-0.02
Public Transport	-0.88 (-12.81) **	-0.13
Total Travel Cost (in euro)		
Car	-0.71 (-10.50) **	-0.10
Public transport	-0.16 (-6.68) **	-0.02
Age group 2	1.07 (24.91) **	0.16
Age group 3	1.01 (13.79) **	0.15
Socio-economic group 1	0.60 (13.55) **	0.09
Socio-economic group 3	0.48 (6.30) **	0.07
Number of cars	0.57 (19.12) **	0.08
Gender	-0.28 (-6.73) **	-0.04
Dummy Blanchardstown (Airport base)	1.33 (3.76) **	0.19
Dummy CBD (Airport base)	-1.13 (-10.95) **	-0.16
Dummy Clondalkin-Tallaght (Airport base)	0.40 (3.42) **	0.06
Dummy N11 (Airport base)	-0.64 (-7.66) **	-0.09
Employment density	-0.01 (-9.44) **	-0.00
Number of estimated parameters:	16	
Number of observations:	17,081	
Null log-likelihood:	-10,034	
Final log-likelihood:	-7,458.29	
Adjusted Rho-square:	0.25	

Table 5: Logit mode choice aggregate direct and cross elasticities

| Employment sub-centre | AGGREGATE DIRECT ELASTICITIES | | | | AGGREGATE CROSS ELASTICITIES | | | |
| | Car | | Public Transport | | Car | | Public Transport | |
	Car Time	Car Cost	PT Time	PT Cost	Car Time	Car Cost	PT Time	PT Cost
Airport	-0.012	-0.081	-0.629	-0.159	0.023	0.146	0.331	0.088
N11	-0.027	-0.138	-0.511	-0.119	0.037	0.216	0.372	0.076
CBD	-0.055	-0.269	-0.351	-0.087	0.070	0.437	0.278	0.054
Clondalkin-Tallaght	-0.005	-0.047	-0.573	-0.123	0.013	0.070	0.224	0.083
Blanchardstown	-0.003	-0.025	-0.315	-0.071	0.007	0.038	0.144	0.046

Table A1: Regression analysis of gross employment density

INDEPENDENT VARIABLE	DEPENDENT VARIABLE
	Employment density
	Coefficient
Constant	1.88
Distance to CBD	-0.28 (-16.36)
R^2	0.46
Sample size	315

* t value in parenthesis

Figure 1: Study area

EMPLOYMENT SUB-CENTRES

Employment sub-centres is the
Dublin region.
Data source: CSO 30% sample
provided by the DTO from the 2002
Irish Census of population.
Digital boundaries provided by
Ordnance Survey Ireland

0 1.25 2.5   5   7.5   10
Kilometers
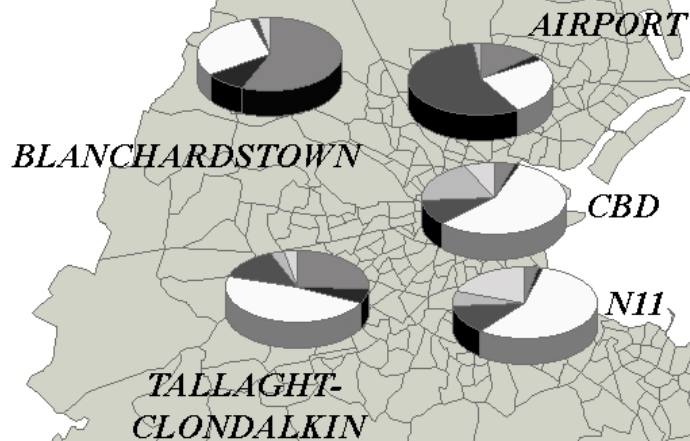
Figure 2: Employment sub-centres within the four Dublin inner counties
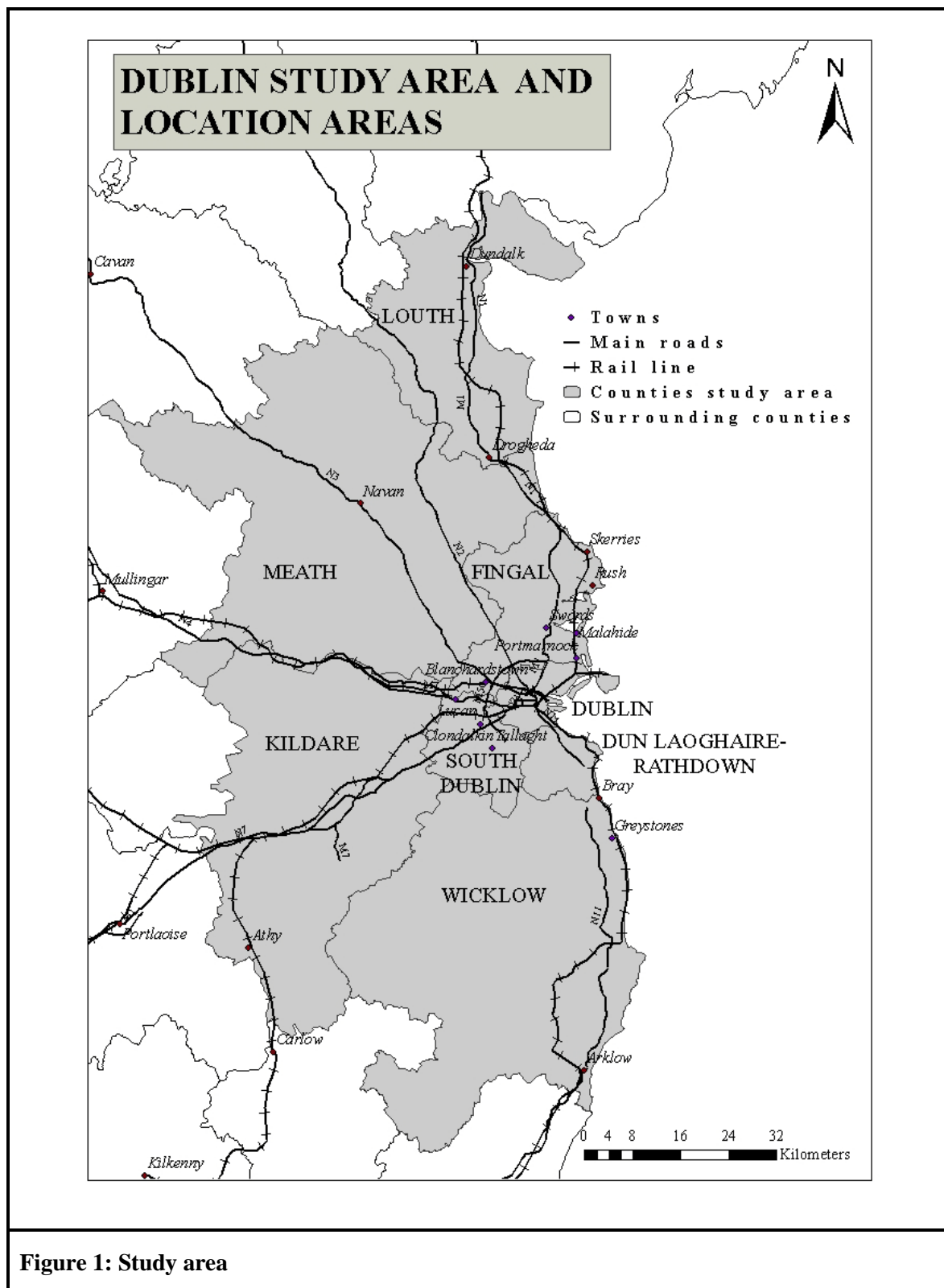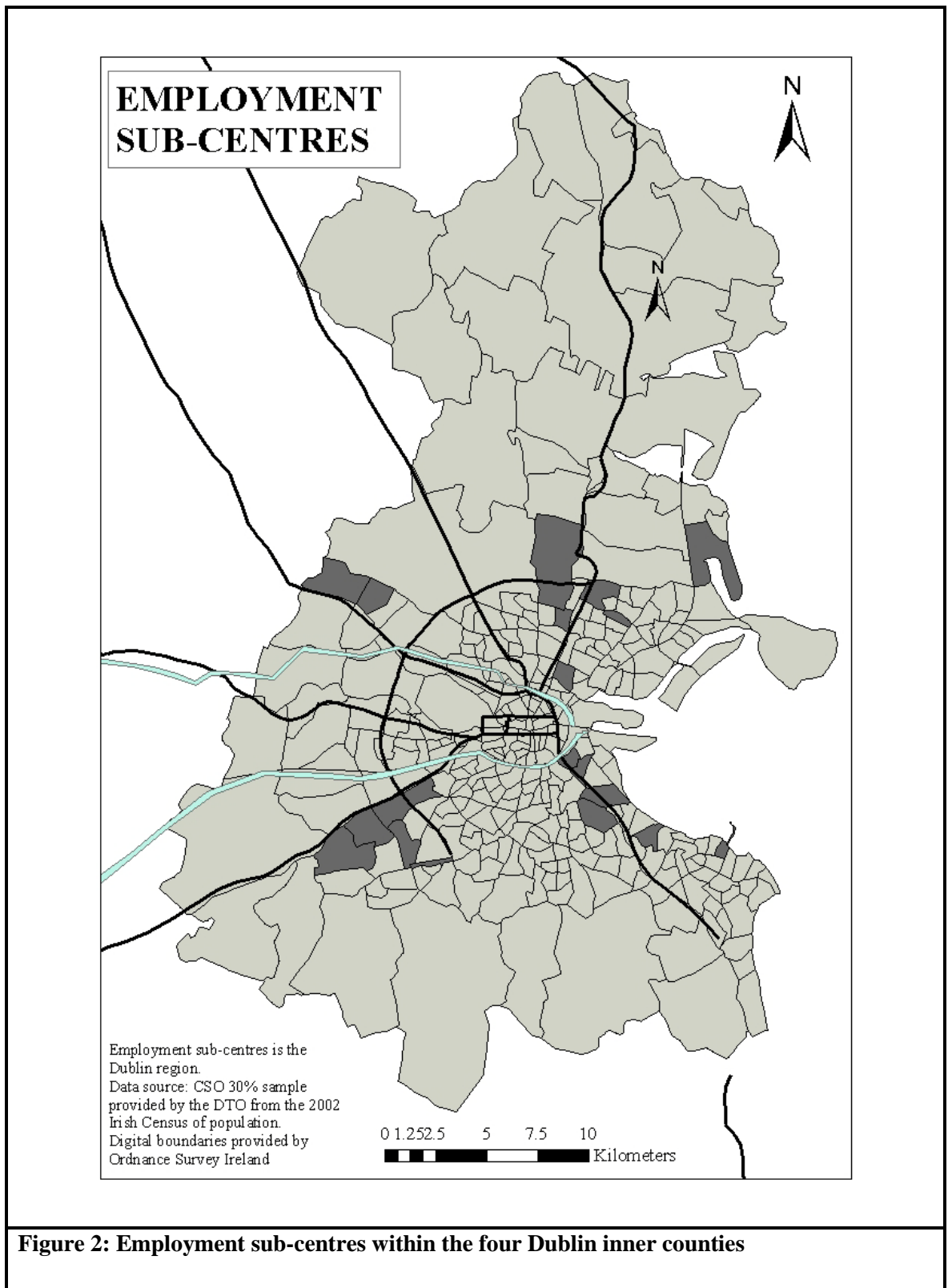
2002 INDUSTRIAL GROUPS

N

Manufacturing industries
Construction
Commerce
Transport, storage and communications
Public administration and defence
Education, health and social work

AIRPORT

BLANCHARDSTOWN

CBD

N11

TALLAGHT-
CLONDALKIN

Sample number of persons working in each employment sub-centre
as a percentage of the total sample number by industrial group.
Data source: CSO 30% sample provided by the DTO from the
2002 Irish Census of population.
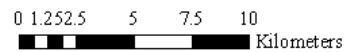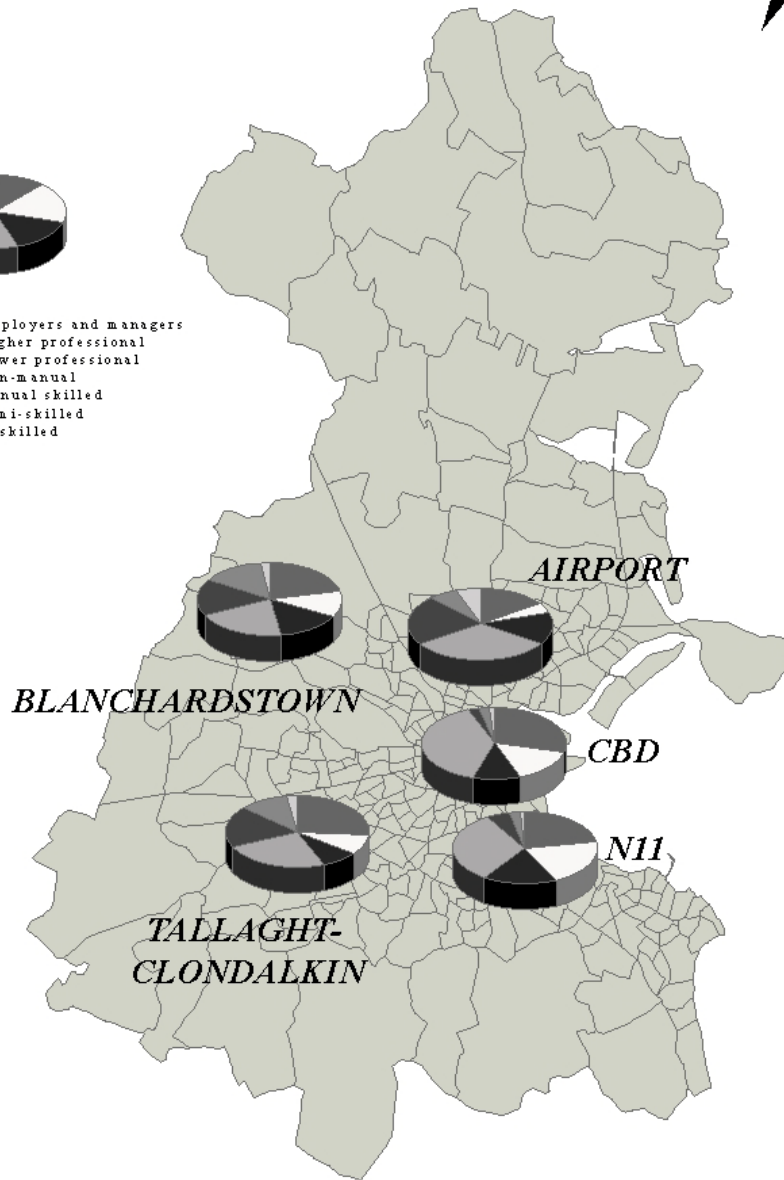Digital boundaries provided by Ordnance Survey Ireland

0 1.25 2.5   5   7.5   10
                                              Kilometers

Figure 3: Dublin employment sub-centres by industrial group

2002 SOCIO-ECONOMIC GROUPS

Employers and managers
Higher professional
Lower professional
Non-manual
Manual skilled
Semi-skilled
Unskilled

AIRPORT

BLANCHARDSTOWN

CBD

N11

TALLAGHT-
CLONDALKIN

Sample number of persons working in each employment sub-centre
as a percentage of the total sample number by socio-economic group.
Data source: CSO 30% sample provided by the DTO from the
2002 Irish Census of population.
Digital boundaries provided by Ordnance Survey Ireland

0 1.25 2.5   5   7.5   10
                                     Kilometers

Figure 4: Dublin employment sub-centres by socio-economic group

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