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Employment sub-centres and the choice of mode of travel to work in the Dublin region¹

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Abstract

Travel-to-work mode choice 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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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 decade³.

Very rapid and sustained increases in employment accompanied and facilitated high growth rates. A key feature of this employment growth has been 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).

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.

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.

This research 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 mode of travel-to-work across employment sub-centres. Results from the analysis carried out will confirm the existence of strong car dependencies in suburban employment sub-centres.

One of the most relevant trends in urban development across the world is employment decentralisation and the emergence of employment sub-centres (Ingram, 1998). The Greater Dublin Area is primarily monocentric and no evidence has been reported of the existence of a polycentric region (see POLYNET study for Ireland and Convery et al. (2006) for more details). However, analyses of origin-destination patterns from the 2002 Irish Census of Population have

³ 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)

shown certain tendency towards the decentralisation of activities in the Dublin region and the consequent emergence of the typical commuting behaviour that arise when jobs move away from the Central Business District (CBD).

It is not the intention in this paper either to argue in favour of the existence of a polycentric structure in the Dublin region or against it, but to provide a detailed analysis of the travel behaviour in the most congested areas of Dublin in the context of the choice of mode of travel to work across employment destinations.

The main source of data for the analysis is a unique 30% sample from the 2002 Census of population released by the Central Statistics Office (CSO) and revised by the Dublin Transportation Office (DTO). This database contains for the first time, information on origin-destination commuting trips, extended with revised travel times, distances and average speeds from the DTO.

In this paper, a number of methodologies are applied to the study of travel-to-work behaviour across employment sub-centres. Methodologies range from the use of regression analysis and Geographic Information System (GIS) tools, to the estimation of discrete choice models for travel mode choice.

The next section describes the main demographic trends and travel behaviour in the Greater Dublin Area (GDA) from analysis of the Small Area Population Statistics released by the CSO. It provides an overview of the context of the study area in terms of population, employment growth and commuting behaviour. Section 3 presents a detailed study of the origin-destination commuting patterns in the region and the identification and further characterisation of employment sub-centres within the four Dublin inner counties. In section 4, a binary logit model for the choice of travel-to-work mode is estimated and a comparative study across employment sub-centres is presented. Finally, section 5 outlines the main conclusions and significance of the analysis for future research.

2. Main demographic trends and travel behaviour

The Greater Dublin Area⁴ (GDA) accounts for a relatively high proportion of the total population of the Irish Republic. Dublin County was estimated to make up 29.2% of the national population in 2001, while the wider GDA comprised 39.6% of the total (Williams and Shiels, 2001).

⁴ The Greater Dublin Area consists of the counties of Dublin, Meath, Kildare and Wicklow. Dublin County is further divided into four local authority areas, called the counties of Fingal, South Dublin, Dun Laoghaire-Rathdown and Dublin City. In this paper, County Louth has also been included as part of the GDA.

Population in the region started to show significant levels of growth in the period 1991-1996. However, growth rates have not been equal across all the counties. The lack of affordable housing has forced many households to disperse into the Mid-East region with the consequent increase in the population of Dublin's adjacent counties and the expansion of the commuter belt. Figure 1 shows the location of the study region, the county boundaries and the main transportation networks within the region.

[Figure 1 Here]

Table 1 presents population growth rates by county in the GDA for the last three census periods 1986-1991, 1991-1996 and 1996-2002. The largest increase in population has taken place in the most recent census period 1996-2002 with an overall population growth of 9.31%. While Kildare and Meath have experienced the biggest increases with 21% and 22% respectively, Dun Laoghaire-Rathdown shows very low levels of growth between 1996 and 2002.

[Table 1 Here]

Dublin's adjacent counties have increased their population by 17% between 1996 and 2002, which reflects the process of suburbanisation and sprawl that the city is experiencing. Population in the four Dublin inner counties has grown at a much lower rate, with a 6.10% total increase in population in the 1996-2002 period and 3.23% average growth rate over the three census periods. Overall population growth in the four inner counties is mainly driven by Fingal County, with a 12% average growth rate over the last three census periods. This contrasts with other Dublin inner counties.

A more detailed picture of the population growth levels in the region is displayed in Figures 2 and 3. Figure 2 shows the population change for the smaller electoral district areas in the decade from 1991-2002. Figure 3 shows population change by electoral district in the 1996-2002 period. Since 1991, Dublin's Western and Northern districts have experienced significant increases in their population - in particular, the outer districts along the orbital M50 motorway and those districts along the Northern and Western train lines. The other eastern region towns of Dundalk and Drogheda and their metropolitan areas show the largest increases in population in this period together with Lucan, Swords and Blanchardstown.

[Figure 2 Here]

[Figure 3 Here]

Population has expanded ever further into the West crossing the border with adjacent counties, Meath and Kildare. Districts adjacent to Fingal along the N2 and N3 national roads and districts along the Western train line have experienced the most significant population growth levels.

The concept of the compact city and the promotion of higher urban densities have gained a political acceptance in Ireland in the last decade. The *Green Paper on the Urban Environment* published by the European Commission in 1990 addresses the issue of urban density and mixed land use and strongly encourages *dense developments* in order to achieve shorter trips to work and to other daily services. Progress has been made in Ireland in this regard with the publication of the *Planning Guidelines on Residential Density* (DOELG, 1999) and the *Strategic Guidelines for the Greater Dublin Area* (Brady Shipman Martin, 1999) where the need for increasing densities along transportation corridors and in the city centre is highlighted (McEldowney, Scott, and Smyth, 2003).

The changes in population density reflect the patterns of population growth discussed earlier, but illustrate the significant differences existing between the urban Dublin Counties and the surrounding counties. Figure 4 shows 2002 population density in the GDA by electoral district. The highest density levels are found in city districts as well as along the Western side of the M50 motorway (which was constructed in the late 1980s) and the Southwest of the city. In addition to Dublin city, several high-density urban centres are found along the Northern train line in Drogheda and Dundalk, Skerries, Swords, Portmarnock and Malahide and along the Southern coastal train line in Bray and Greystones.

[Figure 5 Here]

The unprecedented growth in travel demand that the Dublin region has experienced over the last decade has had a major impact on the use of the private car as the main mode of transport in the GDA. 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 is significantly below the European average⁵.

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.

Comparative figures for travel mode shares to work, school and college for the years 1996 and 2002 are presented in Table 2. Shares for car driver have significantly risen from 31.41% in 1996 to 38.20% in 2002. The highest rates of car use are found in Meath and Kildare. Surprisingly, South Dublin shows one of the largest increases of the region in car driver shares, growing from 31.72% to 42.17% between 1996 and 2002. This district would be considered relatively well-served by bus-based urban public transport.

[Table 2 Here]

In Dublin city, the *slow mode* (walking and cycling), is still the main mode of transport used to go to work, school and college and its mode share remains at a similar rate to 1996 levels. In terms of the use of public transport in the region, train shares have changed marginally between 1996 and 2002, in particular those for Fingal and Louth (along the Northern train line). On the other hand, bus shares have decreased in all counties, except for Dun Laoghaire-Rathdown, which shows just a 1% increase in the same period.

Dublin urban public transport consists mainly of bus services, with mainline suburban rail and the single coastal *DART* electrified line⁶. 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. The lack of significant east-west bus services reduces the attractiveness of public transport for many users. Residing in an area that is well serviced by public transport may still result in use of the car because the residential and employment locations may not be

⁵ The car ownership rate for the EU25 in 2004 was estimated to be 472 cars per 1,000 inhabitants (Eurostat, 2006).

⁶ Suburban rail services in the GDA are provided by Iarnrod Eireann Suburban Rail Network. The current rail network is sparse with large sections of the region not covered by rail. The total length of the rail network in the GDA is approximately 150 Km in length and it consists of a radial network of four lines centred in Dublin City Centre and the *DART* line. (www.leda.ils.nrw.de)

easily accessible by public transport. Reynolds-Feighan and Durkan (2000) compared Dublin public transport services and subvention levels with 122 other European cities. Dublin had the third lowest subvention rate for urban bus services, and somewhat unusually, was majority-funded by national rather than local or regional government.

The principal mode of transport used for travel to work, school or college for persons aged 15 and over is mapped for the *car* (driver and passenger) in Figure 5 and for *public transport* (bus and rail) in Figure 6 by electoral district. There is a concentration of *high public transport use* in areas along the rail lines. Car use tends to be lower in the districts along the coastal *DART* rail line up to a certain distance. The same trend is observed in districts along the Western train lines. Relatively higher car use rates are found in Fingal and along the North and West districts of the M50.

[Figure 5 Here]

[Figure 6 Here]

The growth in car use for shorter journeys reflects the limited availability of public transport services as well as the employment growth and impact of rising incomes. This is particularly true for the outer suburbs and commuter zone counties, especially those areas tangent to the county border between Fingal and Meath, where public transport shares are the lowest in the region (<14%). Low shares of public transport use are also found in some areas of South Dublin and Dun Laoghaire-Rathdown (such as Firhouse, Ballyboden, Churchtown and Clonskeagh). All of these areas have relatively good provision of public transport, but the private car is still the main mode of travel used in the journey to work, school and college. This may reflect the demand for multiple trip-chaining associated with households with children in these areas and the lack of east-west oriented bus routes to service these needs.

The rate of car use for the journey to school has dramatically increased over the last decade. In the 2002 Census figures reported by the Dublin Transportation Office⁷, they show that 42% of school pupils were driven to school in Ireland. Car usage for school trips is particularly high for primary school children, with almost 50% of pupils driven to school in the counties of Dublin, Wicklow, Kildare and Meath.

⁷ Dublin Transportation Office, *Safer Routes to School. Next Steps*. May 2005 (www.dto.ie)

Figure 7 shows the declining average distance travelled per hour closer to the city centre reflecting the increased density of commuters and congested condition of the city centre road network. Residents from western suburban areas and from some areas in the Dublin mountains suffer levels of congestion as severe as in the city centre. These districts are located along the main arterial road routes into the city centre and will service local and non-local travel needs.

[Figure 7 Here]

Overall, the descriptive analysis presented in this section has shown that transportation links such as train lines and major national roads have a significant role as drivers of population growth and residential location patterns. Coastal train lines, in particular the Northbound, have appeared to motivate residents in adjacent districts to lower rates of car-based travel to work, school and college.

Regardless of the apparent relationship between mode choice and residential patterns, it has often been defined as a self-selection process where individuals with a strong preference for a specific mode of transport, train in this case, tend to look for residential locations that allow them to use that travel mode more intensively (Peng et al, 1996). Further statistical analyses that include other relevant variables such as the characteristics of alternative modes of transport and the socio-economic attributes of travellers would be needed to give insight into the nature of this relationship in a Dublin context.

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 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 (Murphy, 2004). Traditional urban public transport networks with a radial structure may not be sufficient to cover the transportation needs of more suburbanised

cities⁸ (Modarres, 2003). This may have enormous consequences in terms of commuting and travel behaviour.

In this section, we identify and characterise a series of employment sub-centres in the Dublin region on the basis of the traffic they generate at the regional level and their composition by industrial group.

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).

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 (1990) 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.

Over the last decade, more sophisticated approaches have introduced regression analysis to identify employment sub-centres (McDonald, 1987; McMillen and McDonald, 1998 and McDonald and Prather, 1994)). One of the main advantages of the regression 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. Latest studies offer non-parametric procedures (Craig and Ng, 2001; McMillen, 2001) and the use of contiguity matrices (McMillen, 2003) to identify employment sub-centres.

⁸ 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.

To our knowledge, a detailed analysis of employment sub-centres in the Dublin region has not been published. A simple procedure for the identification of employment sub-centres is presented here, where the main focus is on the level of attraction (measured as number of commuting trips) of each of the potential sub-centre candidates. Most of the procedures reviewed on the identification of employment sub-centres follow the systematic methodology of first, identifying candidates to employment sub-centre, and then evaluating whether these candidates 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 will become clear in the next section, this aspect is considered to be crucial for the analysis of travel mode choice presented in this chapter.

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 in order to (i) identify candidates to employment sub-centre in the Dublin region and (ii) assess whether these sub-centre candidates are relevant for the analysis on the basis of their employment size and their employment self-containment ratio⁹. In general, relevant employment sub-centres are those that attract the largest number of commuters and in particular, those that attract the largest number of commuters from other areas.

The data used for the analysis is a 30% sample from the 2002 Irish Census of Population. This dataset was prepared by the CSO and it includes information from individuals who at the time of the census were

- enumerated in a private household;
- 15 years old or over;
- indicated that their current status was working for payment or profit.

⁹ The ratio of work trips to each employment sub-centre candidate within each itself relative to work trips to the same employment sub-centre from other electoral districts

It provides socio-economic information on these individuals and the characteristics of the households, means of travel, distance and journey times to work as well as place of residence and place of work¹⁰.

This is a unique data set in the sense that it provides for the first time information on origin-destination trips within the Dublin region. 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.

This data set is a powerful source of information to identify employment sub-centres and to relate them to other relevant travel and socio-economic variables. Walsh, J. Foley, R. Kanavanagh, A. and McElwin, A. (2005) recently presented an extensive analysis of origin-destination commuting patterns using the Place of Work Sample of Anonymised Records (POWSAR). This data set was released by the CSO in the same format as the data set we are using here, but for the entire country and without the adjustments made by the DTO in terms of travel related variables. The POWSAR database does not give the work location by household in the sample.

The analysis carried out in this section 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 region¹¹ 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 3 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 3 Here]

¹⁰ Census of Population 2002 Place of Work Sample of Anonymised Records (POWSAR) User Guide. (www.cso.ie/census/documents/PlaceofWork-SARUserGuide2002.pdf)

¹¹ Figure 7 presented a picture of the congestion levels in the Dublin region measured as the average distance travelled by commuters per hour. Dublin inner counties showed the lowest figures in the region.

McDonald and Prather's (1994) procedure is followed to identify potential candidates to employment sub-centre. 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.

A negative exponential function of employment density as a function of distance x from the CBD is estimated with D_o and β as positive constants, where β is the density gradient and μ is the random error term.

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

Initially, the log version of the model is estimated using ordinary least squares (OLS), but it failed the Breusch-Pagan test for heteroscedasticity. The same log version of the model is estimated again using weighted least squares (WLS), which solves the problem of heteroscedasticity present in the OLS estimated model¹². As expected, a negative significant coefficient for distance to CBD is obtained. The idea behind McDonald and Prather's (1994) procedure is that by analysing the residuals of the estimated equation, we are able to identify spatially contiguous areas that show employment density values much higher than those predicted from 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 estimated values of the natural log of employment density¹³, i.e. the employment density is greater than what it would be expected from the monocentric model, which is considered a sign of polycentrism.

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-centre 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.

We use GIS tools 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

¹² 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).

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

¹³ Those electoral districts with positive residuals that lie within Dublin inner city are left out for being areas of influence of the CBD.

of the ratio of self-containment¹⁴ at each district. Spatially clustered districts across the region are presented in Figure 8 as the identified employment sub-centres.

Figure 8 shows the four employment sub-centres identified for the purpose of this paper. Two main sub-centres in the Dublin Western 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.

[Figure 8 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 Plan¹⁵ (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%.

Figure 9 shows the composition of employment for each sub-centre by industrial group¹⁶. The CBD and the N11 sub-centres offer a very similar profile. A relatively higher proportion of commerce related jobs are present in these areas together with a reduced presence of manufacturing industries and construction jobs.

¹⁴ 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 $\frac{T_{ii}}{\sum_{j=1}^n T_{ji}}$

¹⁵ 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.

¹⁶ The definition of industrial group responds to the 2002 CSO classification of industries.

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 9 Here]

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 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 8 and 9 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.

Non-parametric tests were carried out to evaluate whether there is a significant difference in the average sample employment size across industrial groups within the identified employment sub-centres. Results suggest non-significant differences in sample employment across industrial groups¹⁷.

Figure 10 presents the socio-economic composition by employment sub-centre¹⁸. 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-skilled classified commuters are found in larger proportions in the Western suburban employment sub-centres and around Dublin Airport.

¹⁷ 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. The Bartlett's test of homogeneity of variance led to the rejection of the assumption that no significant differences between the variances of the industrial groups were present (Bryman and Cramer, 2001). The Kruskal-Wallis non-parametric test was carried out and resulted in the rejection of the null hypothesis

¹⁸ Socio-economic group refers to the occupation and employment status of individuals as classified in the 2002 Irish Census of population

[Figure 10 Here]

The analysis presented in this section shows a snap shot of 2002 Census employment job destinations for the Dublin region. Further work should be done on the definition of employment sub-centres according to the most recent methodologies presented in the literature and in particular, in relation to the forthcoming 2006 Census data.

4. Travel to work modal choice by employment sub-centre

The choice of the mode of travel is one of the most important elements of transport planning and policy making. Modal choice modelling has been largely applied to evaluate the effectiveness of transportation policies aimed at changing car-based travel behaviour.

The process of low-density residential sprawl that the Dublin region has experienced over the last decades had very significant consequences for the travel patterns, which resulted in increasing car dependency and long distance commuting (Williams and Shiels, 2001).

Previous studies on travel behaviour in Dublin have acknowledged the negative effect that dispersed residential location had for the process of providing a comprehensive public transport system in the region, where bus-based public transport remains as the most viable alternative to the use of the private car (McCarthy, 2004). Nolan (2003) presents a detailed study of the determinants of households travel decisions in the Dublin Area¹⁹. Non-availability of public transport is identified as one of the main determinants of the use of the private car. Increasing employment participation in the household was also identified as a significant variable, suggesting the positive effect of commuting on car use at the household level.

In terms of the effects of employment suburbanisation on travel behaviour, research in the US has shown the limited impact that job decentralisation had on commuting patterns (see Cervero and Wu (1998) for the effects of commuting distance and travel times). Increasing job mobility has been identified as a contributor to this reduced effect, with households selecting convenient residential locations to access a wide range of potential job destinations (Anas et al., 1998).

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 a new insight into the linkages between the distribution of

¹⁹ Here the Dublin Area refers to the four Dublin inner counties.

employment and the modal choice in the Dublin region and to illustrate the significance of studying both in an integrated manner.

Discrete choice models of travel mode choice: 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, $V_{nj} = (x_{nj}, s_n)$ 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

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

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:

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

The well-known IIA property of the logit model states that the ratio of the probabilities of choosing two alternatives does not depend on the attributes of any other alternative. In other words, the unobserved proportion of one alternative is independent to the unobserved proportion of another alternative²⁰.

²⁰ See Ben-Akiva and Lerman (1985) and Train (2003) for more details

The study area for the discrete choice analysis is shown in Figure 1. It includes the Dublin inner counties and the four adjacent counties of Kildare, Meath, Wicklow and Louth²¹, the GDA. The decision makers are commuters into the previously identified employment sub-centres as shown in Figures 8, 9 and 10, 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.

Regarding the travel mode decision for the journey to work, we model the choice between the private car and public transport. Due to a lack of data on slow mode commuting attributes (i.e. walking and cycling) for all of the Dublin electoral divisions, these modes are not included in the model presented²². Availability of private car and public transport is taken into account and probabilities are computed accordingly to the existence of these modes available for the commuter.

The data source for the analysis is a sub-set of the CSO – DTO 30% sample with a total of 15,644 observations. Table 4 shows the mode availability shares, mode choice shares and sample statistics for the attributes of the alternatives.

[Table 4 Here]

The systematic part of the utility function for each of the two choice alternatives, car and public transport respectively, is given by the following two expressions. 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. Table 5 provides the descriptions of the independent variables used in the model.

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

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

²¹ Information was gathered for those electoral districts within the four adjacent counties for which the DTO records travel data.

²² Further research will examine mode choice for individual employment sub-centres and will model ‘slow mode choice’ where these data are available (for example, in the Central Business District).

A test for taste variation is carried out to look for systematic taste variation of taste coefficients among sub-groups of individuals working in the various identified employment sub-centres²³. The procedure used is known as *market segmentation* (see Ben-Akiva and Lerman (1985) for details) and it consists of first, estimating the above model for the subset data by employment sub-centre and second, computing a likelihood ratio test statistic 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 followed in order to know which particular coefficients are responsible for the rejection of the null hypothesis. Following Ben-Akiva and Lerman (1985), asymptotic *t-tests* between market segments are computed under the null hypothesis of equality of individual coefficients. Significant differences are found among the estimated coefficients for some of the travel variables in some employment sub-centres such as Airport, CBD and Tallaght. Unsuccessful attempts to incorporate systematic taste variation in the pooled data model were made, resulting in worse fitted models than the model initially estimated.

Table 6 shows the estimation coefficients and the 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.

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 will be further explored 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 and public transport, with the small negative marginal effects for female commuters, who are found to be less likely to drive to work. Interaction variables for Age and Gender were estimated in previous versions of the model resulting in similar negative

²³ Taste variation can be only 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 coefficients models need to be estimated instead.

marginal effects. 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 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 other travel alternative is frequently available, but to use the private car.

Employment trip destination dummy variables with Airport as the reference category show strong car dependencies for suburban trips, in particular for those ending at Western employment sub-centres. In terms of employment density, estimation results show small negative marginal effects on the choice probability for car use.

Table 7 shows the computed aggregate direct and cross elasticities with respect to travel time and travel cost by employment sub-centre. Direct elasticities with respect to travel times are remarkably low for car use. This is more pronounced in Western suburban employment sub-centres where the sensitivity to changes in car travel times is found to be particularly small. Low direct elasticities are also found for car travel costs. 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.

In general, commuters show very low sensitivities to changes in car travel variables. The opposite happens when we look at public transport time direct elasticities. Commuters to suburban employment sub-centres are particularly sensitive to public transport travel times, with Dublin Airport showing the largest elasticity measure. Travel costs 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 employment locations are more sensitive to changes in travel cost than public transport commuters.

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 8 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.

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.

Cross elasticities for public transport use due to changes in car travel costs are generally low across all the employment destinations.

Overall, car choice probabilities are more sensitive to changes in travel cost than to changes in travel time in central employment destinations and vice-versa in suburban employment destinations. Public transport choice probabilities are significantly more sensitive to changes in travel times than in travel costs, in particular for those employment sub-centres such as Airport and Clondalkin-Tallaght. The results shown in Table 7 reflect the extent to which travel mode choice elasticities vary across the various commuting trip destinations and illustrate the implications of imbalances in public transport provision to suburban employment centres, which have emerged without strong investment in public transport infrastructure to facilitate access to them.

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 with 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 transportation 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 was 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).

5. 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. McDonald and Prather's (1994) method is partially 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.

Conclusions from this study become particularly relevant in the context of *Transport 21*²⁴, 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*²⁵ 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.

A systematic methodology for identifying employment sub-centres together with the integrated analysis of the associated travel behaviour is necessary in order to provide a sound public transport system and to assist to the efficient management of the current transportation network in the Dublin region. A further comparative analysis would be desirable with the release of the new 2006 Irish Census of Population²⁶.

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 strengthen the need for integrated urban modelling when addressing new transportation and land-use planning projects and the development of effective policies of land use and transportation interaction in the Dublin region.

²⁴ See <http://www.transport21.ie/>

²⁵ *LUAS* is Dublin's light rail system consisting of two routes opened in June 2004.

²⁶ Expected release in 2007

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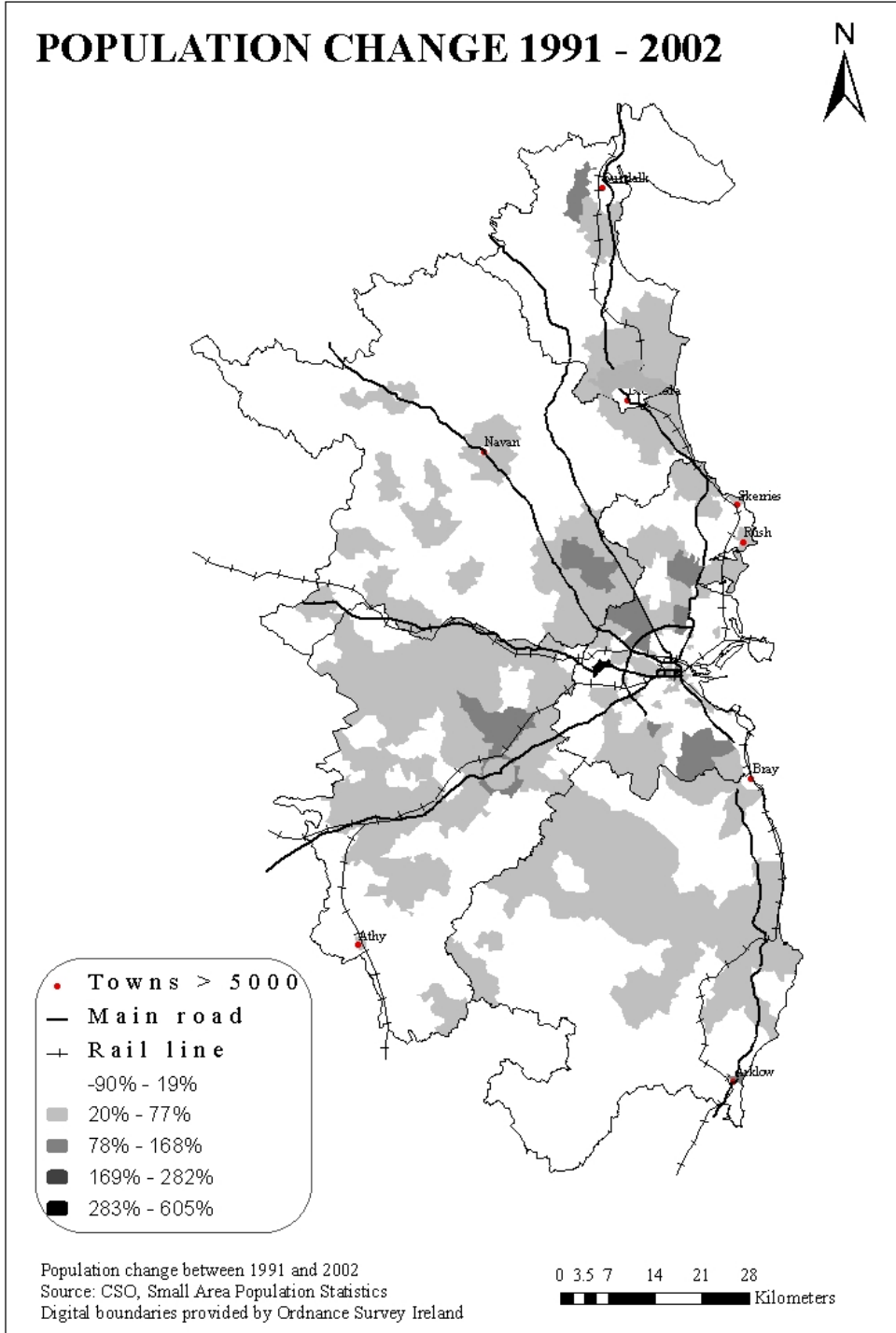
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Figure 2: 1991-2002 Population change



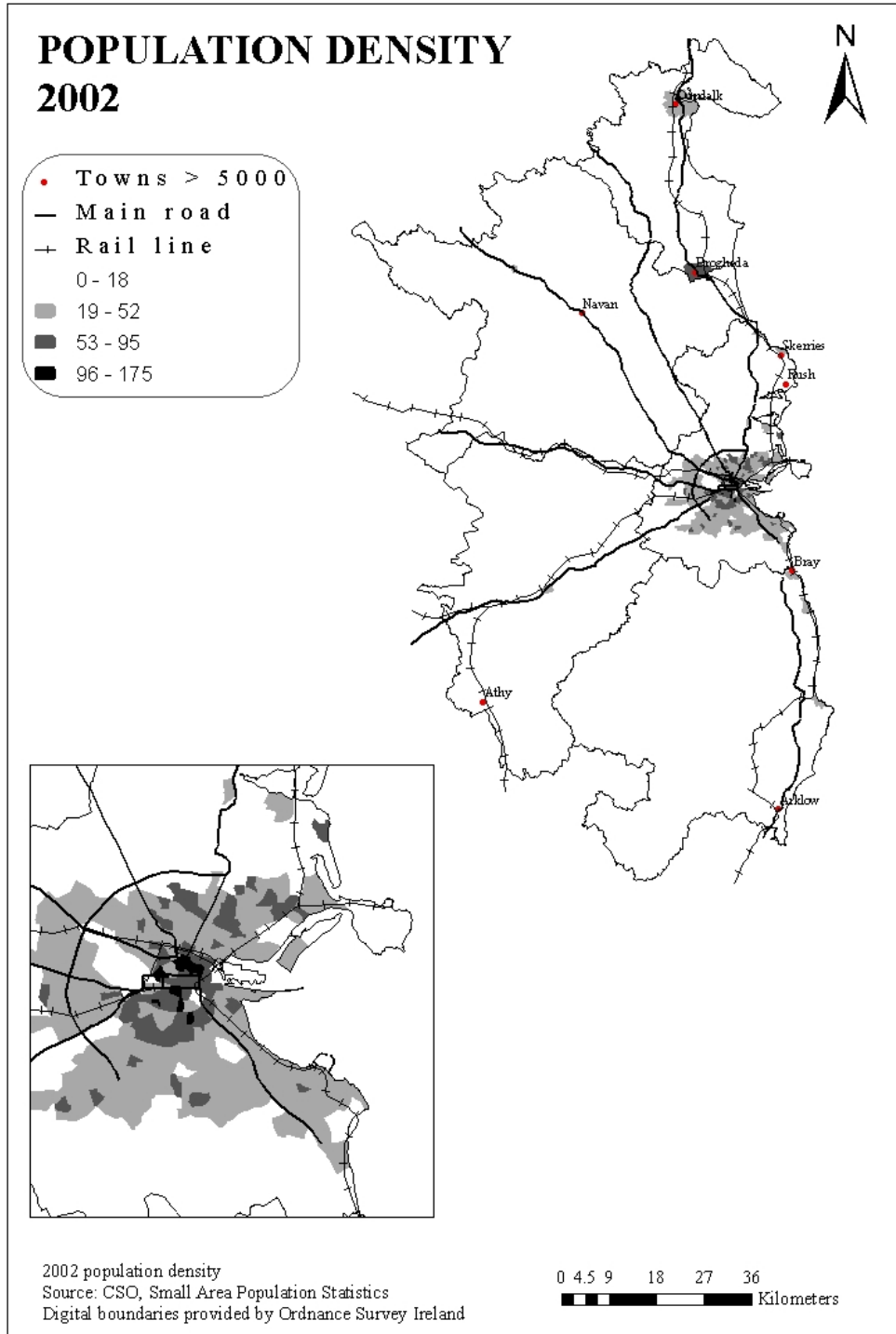
Source: Authors' calculations based on Irish Central Statistics Office data.
 Small Area Population Statistics in years 1991, 1996 and 2002.

Figure 3: 1996-2002 Population change



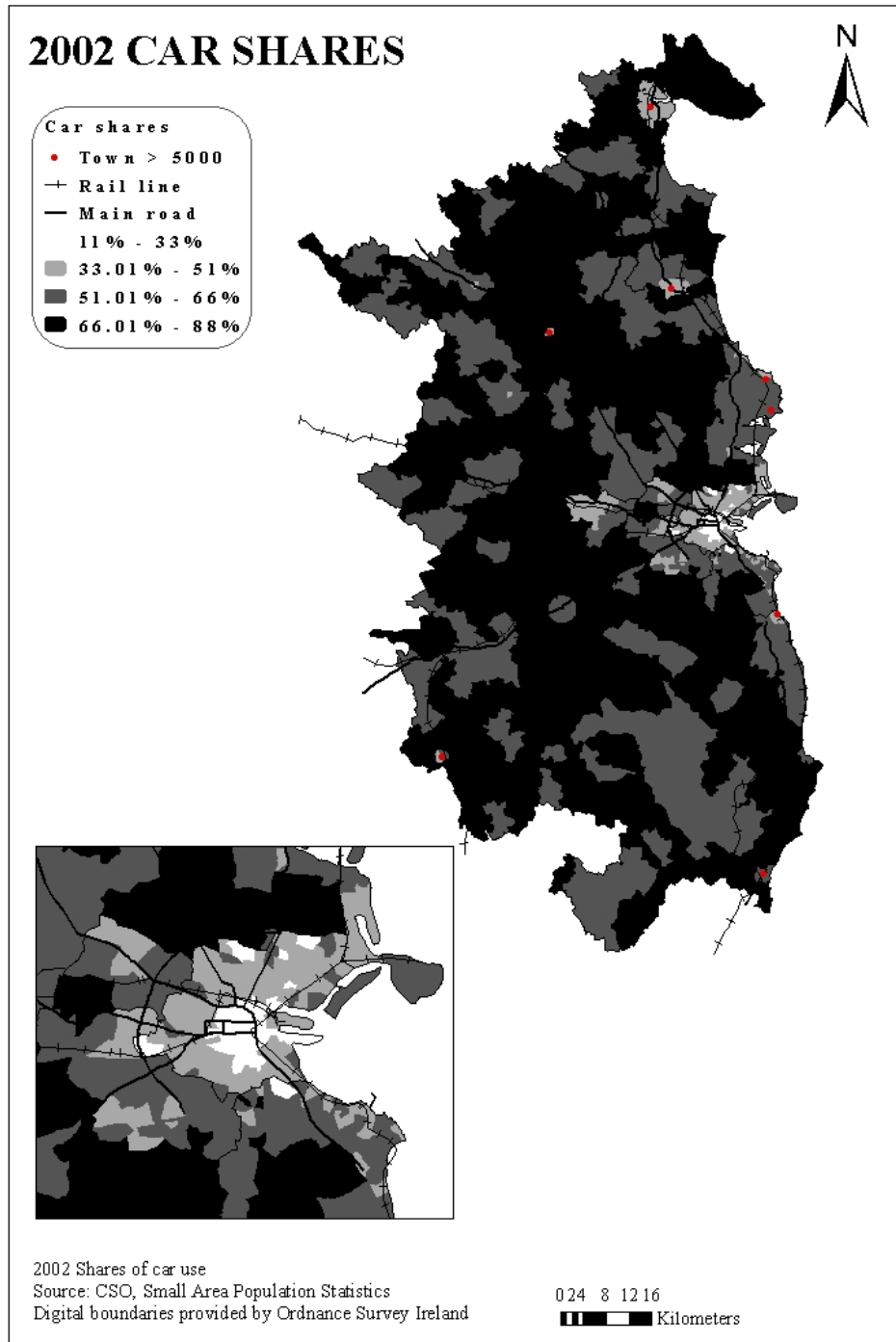
Source: Authors' calculations based on Irish Central Statistics Office data
 Small Area Population Statistics in years 1991, 1996 and 2002.

Figure 4: 2002 average population density



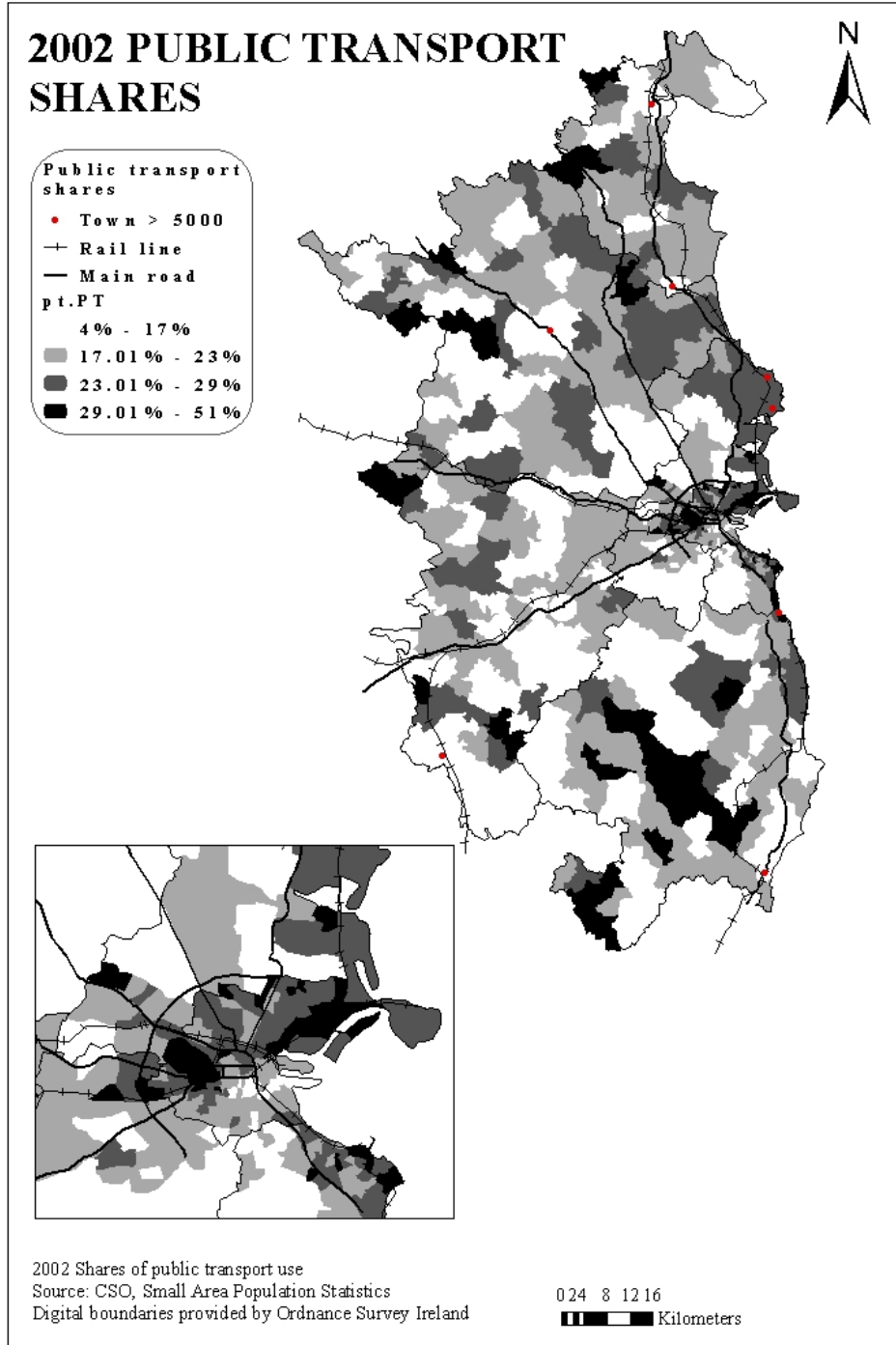
Source: Authors' calculations based on Irish Central Statistics Office data
2002 Small Area Population Statistics

Figure 5: 2002 Car shares



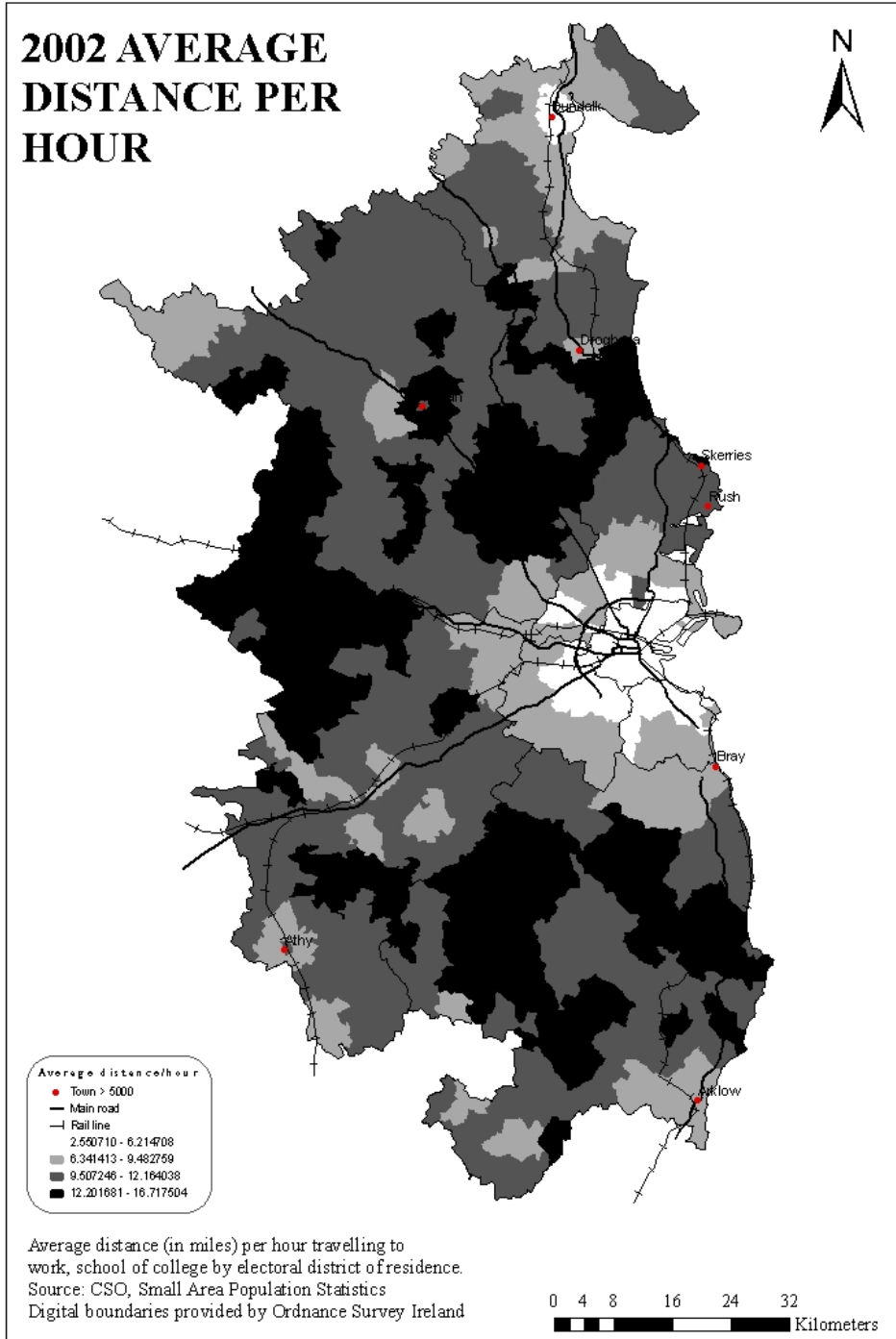
Source: Authors' calculations based on Irish Central Statistics Office data
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Figure 6: 2002 Public transport shares



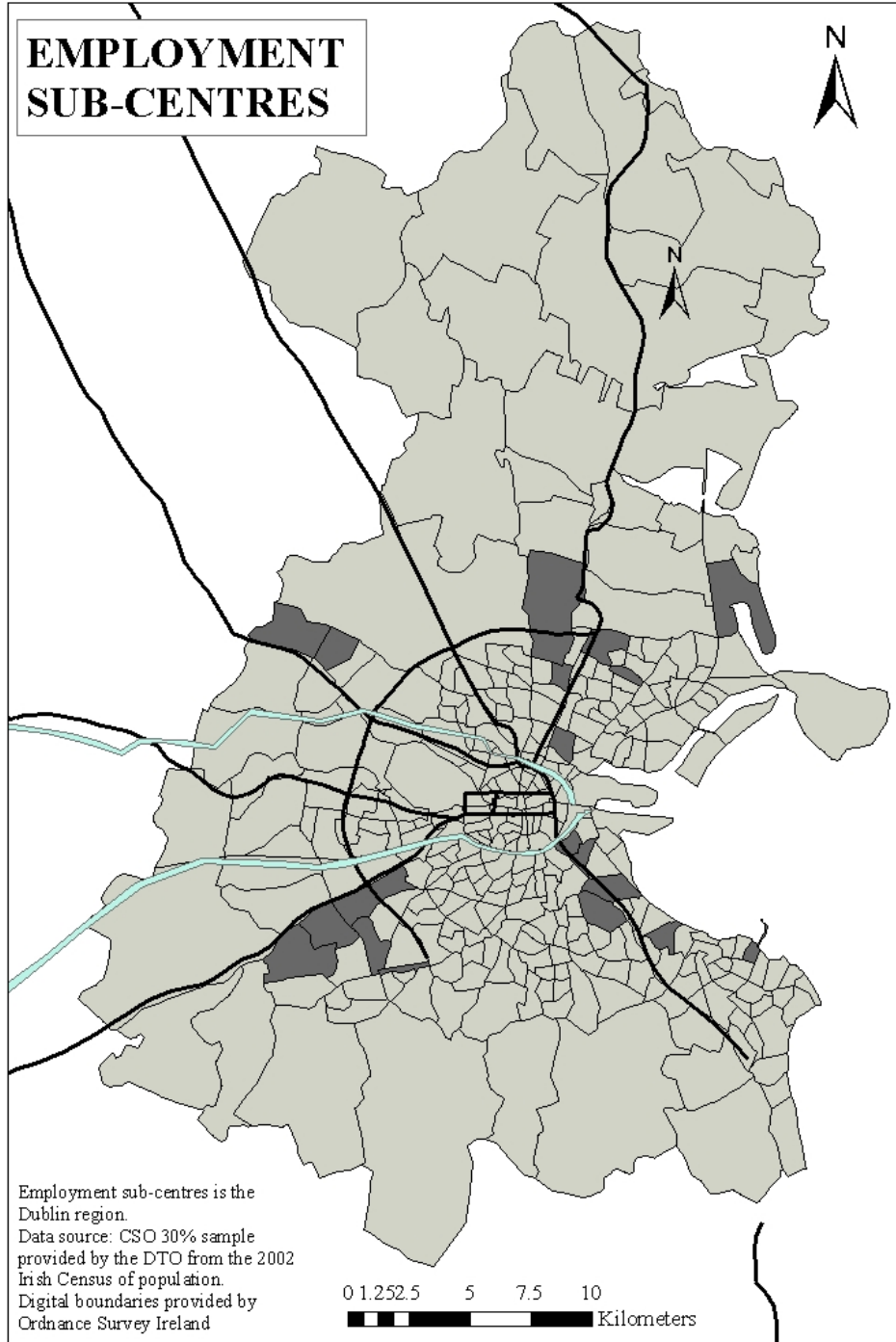
Source: Authors' calculations based on Irish Central Statistics Office data.
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Figure 7: 2002 Average distance per hour



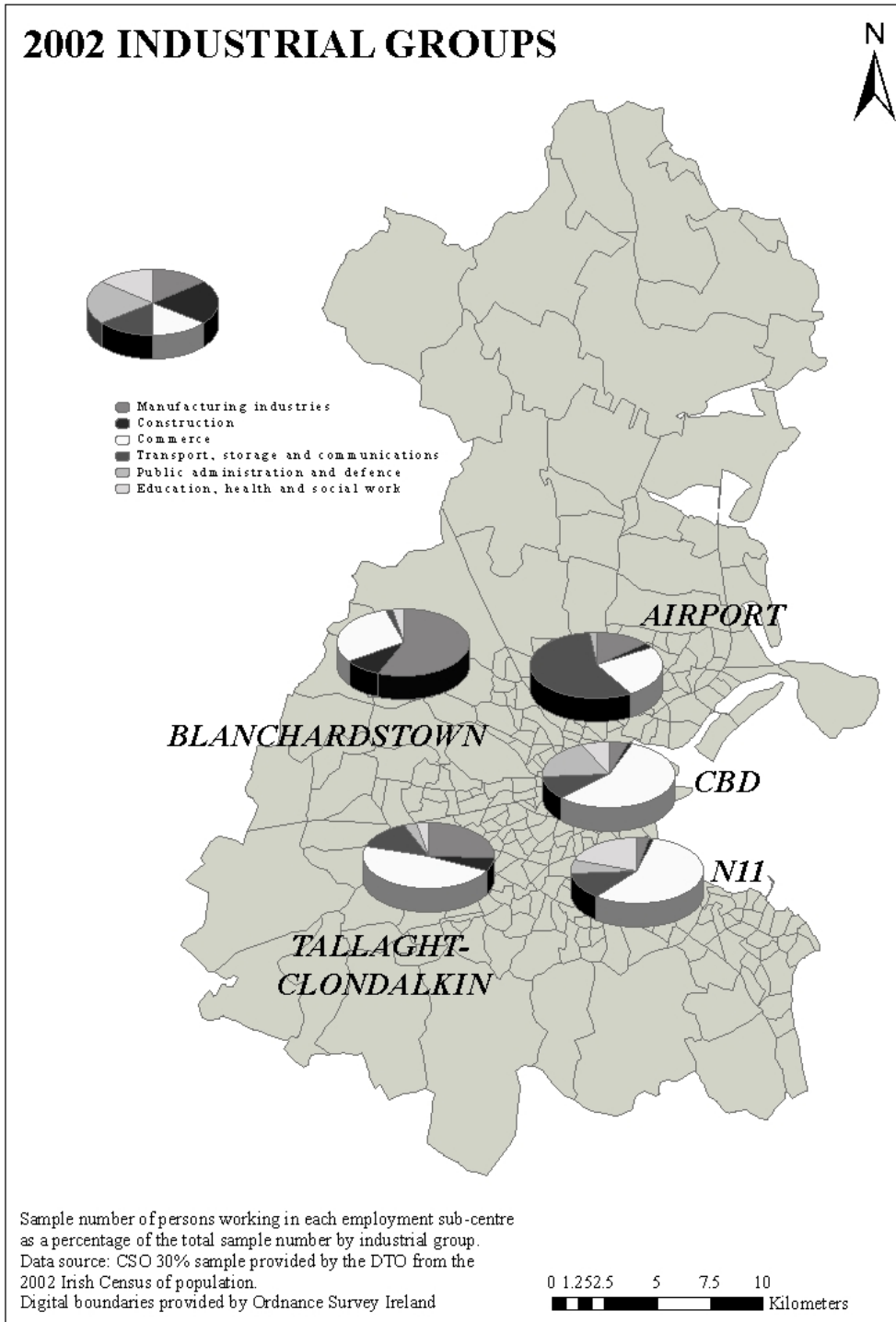
Source: Authors' calculations based on Irish Central Statistics Office data.
 2002 Small Area Population Statistics

Figure 8: Employment sub-centres within the four Dublin inner counties



Source: Authors' calculations based on CSO and DTO data.
30% anonymised sample from the 2002 Census of population

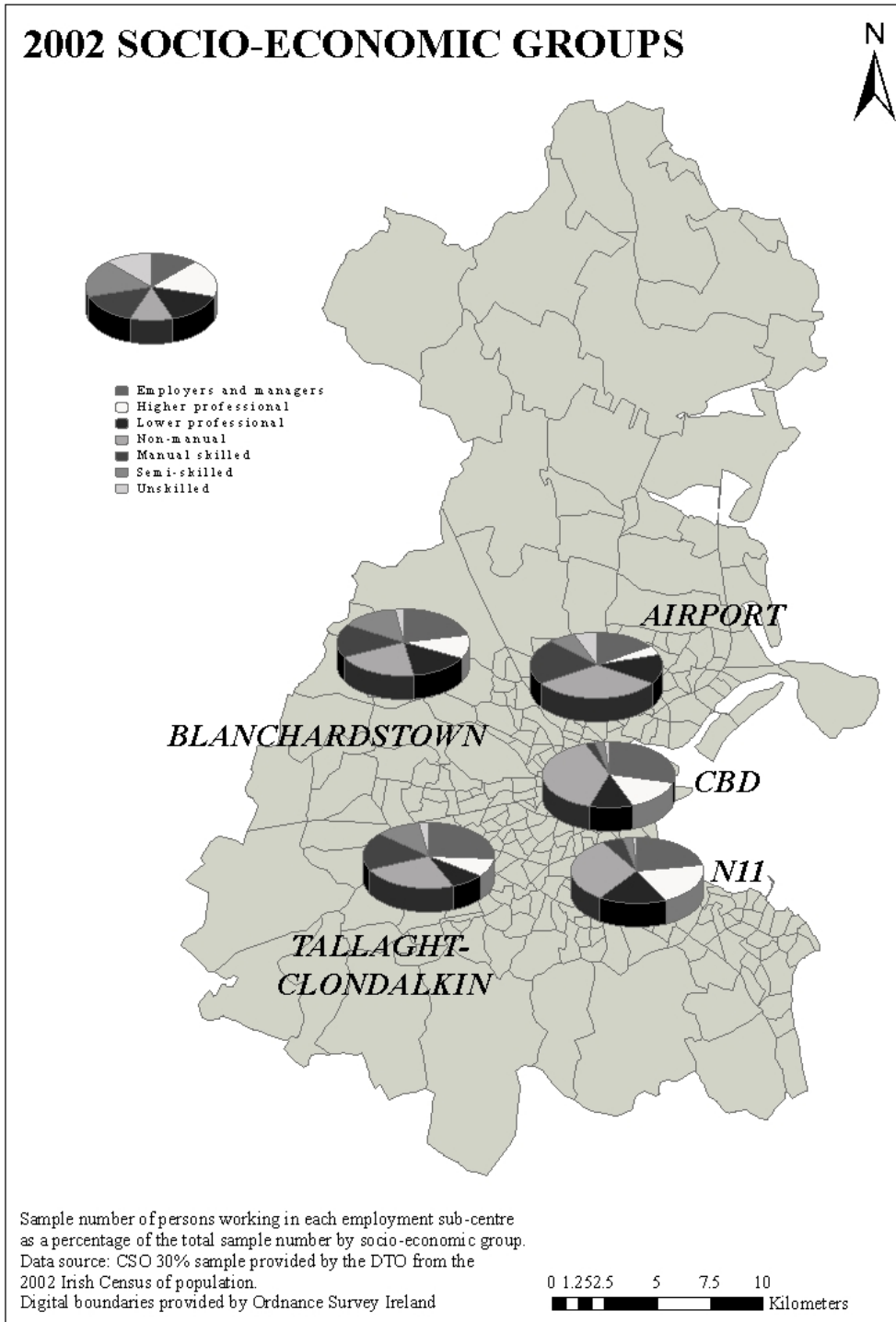
Figure 9: Travel-to-work areas by industrial group



Source: Authors' calculations based on data from the Irish Central Statistics Office and the Dublin Transportation Office.

30% Anonymised sample from the 2002 Census of population

Figure 10: Travel-to-work areas by socio-economic group



Source: Authors' calculations based on data from the Irish Central Statistics Office and the Dublin Transportation Office.

30% Anonymised sample from the 2002 Census of population

County	1986 - 1991	1991 - 1996	1996 - 2002
<i>Dublin City</i>	-4.85%	0.72%	2.89%
<i>South Dublin</i>	4.61%	4.79%	9.19%
<i>Fingal</i>	10.32%	9.76%	17.13%
<i>Dun Laoghaire - Rathdown</i>	2.62%	2.48%	0.94%
<i>Kildare</i>	5.51%	10.06%	21.45%
<i>Louth</i>	-1.18%	1.59%	10.48%
<i>Meath</i>	1.43%	4.14%	22.12%
<i>Wicklow</i>	2.88%	5.57%	11.68%
<i>TOTAL REGION</i>	0.94%	3.92%	9.31%
Table 1: Population growth in the GDA by county Source: Authors' calculations based on Irish Central Statistics Office data. Small Area Population Statistics in years 1986, 1991, 1996, and 2002.			

MODE	Dublin		South Dublin		Fingal		Dun Laoghaire-Rathdown		Kildare		Meath		Louth		Wicklow		TOTAL GDA	
	1996	2002	1996	2002	1996	2002	1996	2002	1996	2002	1996	2002	1996	2002	1996	2002	1996	2002
Foot	30.50%	30.67%	27.49%	19.49%	22.27%	17.18%	14.77%	14.53%	21.97%	16.70%	15.09%	13.44%	24.26%	20.36%	24.33%	17.67%	24.26%	21.02%
Bicycle	8.89%	6.29%	5.14%	3.49%	2.99%	2.02%	6.49%	4.62%	5.88%	2.37%	3.24%	1.15%	6.63%	2.73%	2.16%	1.09%	6.01%	3.75%
Bus	22.53%	20.98%	22.25%	18.81%	17.92%	14.42%	14.21%	15.24%	17.72%	13.20%	23.48%	16.93%	19.63%	14.60%	15.96%	12.28%	19.84%	17.05%
Train	3.22%	3.56%	0.19%	0.21%	7.41%	9.30%	7.39%	7.35%	2.19%	3.87%	0.80%	1.36%	1.19%	3.20%	6.62%	6.84%	3.65%	4.30%
Motorcycle	0.89%	1.35%	0.97%	1.89%	0.61%	1.08%	0.76%	1.47%	0.62%	0.99%	0.58%	0.64%	0.49%	0.66%	0.70%	0.97%	0.77%	1.26%
Car driver	25.39%	28.54%	31.72%	42.17%	33.91%	41.57%	38.27%	40.00%	34.36%	44.51%	35.79%	46.49%	29.53%	38.90%	32.18%	41.43%	31.41%	38.20%
Car passenger	8.57%	8.62%	12.26%	13.93%	14.89%	14.43%	18.11%	16.80%	17.26%	18.37%	21.02%	19.98%	18.26%	19.55%	18.05%	19.70%	14.07%	14.43%

Table 2: Mode share in the GDA: 1996 vs. 2002

Source: Authors' calculations based on Irish Central Statistics Office data.
Small Area Population Statistics in years 1996 and 2002.

<i>Variable</i>	Gini Index (Bootstrap Standard Error)	Theil Entropy (Bootstrap Standard Error)	Coefficient of Variation
<i>Employment Density</i>	0.710 (.025)	1.07 (0.099)	2.204
<i>Employment per Head of Population</i>	0.696 (.051)	1.25 (0.292)	3.428

Table 3: Spatial concentration measures
Source: Authors' calculations based on Irish Central Statistics Office data.
2002 Small Area Population Statistics

<i>Mode</i>	Availability shares	Mode choice shares	Total travel time (in seconds)²⁷	Total travel cost (in cents)
<i>Car</i>	0.923	0.593	48.916 (34.343)	93.771 (73.432)
<i>Public transport</i>	0.933	0.407	72.706 (40.334)	152.182 (162.461)

Table 4: Sample statistics

²⁷ Average travel times and travel costs with standard deviation (parenthesis)

Name	Description
<i>Attributes of the alternatives</i>	
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
<i>Socio-economic and land use characteristics</i>	
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 5: Variables in the model	

Variables	Coefficient (t-stat)	Marginal effects
<i>Mode constant</i>		
Car		
Public transport	-0.3615 (-3.4999)	
<i>Total Travel Time (in hours)</i>		
Car	-0.15147 (-2.0823)	-0.0222
Public Transport	-0.88453 (-12.8144)	-0.1295
<i>Total Travel Cost (in euro)</i>		
Car	-0.70840 (-10.5041)	-0.1037
Public transport	-0.16391 (-6.6787)	-0.0240
Age group 2	1.0694 (24.9057)	0.1565
Age group 3	1.0133 (13.7870)	0.1483
Socio-economic group 1	0.6039 (13.5485)	0.0884
Socio-economic group 3	0.4806 (6.3049)	0.0704
Number of cars	0.5675 (19.1189)	0.0831
Gender	-0.2840 (-6.7272)	-0.0416
Dummy Blanchardstown (Airport base)	1.3292 (3.7569)	0.1946
Dummy CBD (Airport base)	-1.1263 (-10.9503)	-0.1649
Dummy Clondalkin-Tallaght (Airport base)	0.4048 (3.4169)	0.0593
Dummy N11 (Airport base)	-0.6449 (-7.6568)	-0.0944
Employment density	-0.0022 (-9.4358)	-0.0003
<i>Number of estimated parameters:</i>	16	
<i>Number of observations:</i>	17,081	
<i>Null log-likelihood:</i>	-10,034	
<i>Final log-likelihood:</i>	-7,458.29	
<i>Adjusted Rho-square:</i>	0.255	

Table 6: Logit model estimation results (public transport reference category)

	Aggregate direct elasticities				Aggregate cross elasticities			
	Car		Public Transport		Car		Public Transport	
	Time	Cost	Time	Cost	Time	Cost	Time	Cost
<i>Employment sub-centre</i>								
<i>Airport</i>	-0.012	-0.081	-0.629	-0.159	0.023	0.146	0.331	0.088
<i>N11</i>	-0.027	-0.138	-0.511	-0.119	0.037	0.216	0.372	0.076
<i>CBD</i>	-0.055	-0.269	-0.351	-0.087	0.070	0.437	0.278	0.054
<i>Clondalkin-Tallaght</i>	-0.005	-0.047	-0.573	-0.123	0.013	0.070	0.224	0.083
<i>Blanchardstown</i>	-0.003	-0.025	-0.315	-0.071	0.007	0.038	0.144	0.046

Table 7: Logit mode choice aggregate direct and cross elasticities