The impact of the great recession on Irish air travel: An intermodal accessibility analysis

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Abstract

This paper quantifies the changes in accessibility at small area scale arising from the combined effects of dramatic air traffic declines and a greatly expanded motorway network in Ireland during the period of the great recession. The subsequent policy decisions by government are assessed in light of the intermodal accessibility changes identified. The Irish Government engaged in an extensive motorway construction programme throughout the 2000s, greatly increasing the overall length of the inter-urban motorway network. The essential air transport services programme put in place in the 1990s to guarantee a minimum level of air access to disadvantaged regions was significantly reduced at the end of the 2008-2011 period, with only two of the six regional airports continuing to have any form of subsidised public service obligation for the period 2011e2014. In this study, small area datasets are used to measure the net impact of these changes on air transport accessibility in Ireland and the potential spatial inequalities that arise as a result of these changes. An inter-modal accessibility approach is used where the physical characteristics of the road transport network to airports and the network structure characteristics of the air transport system are taken into account to evaluate the levels of air transport accessibility at the small-area district level. Results from the analysis show that the improved surface access to the larger Irish airports (Dublin and Belfast) has enhanced the range of European and global locations directly accessible by air for many communities in Ireland. The net effect of these changes has been to concentrate air traffic at the largest Irish airports.

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1. Introduction

This paper quantifies the changes in accessibility at small area scale arising from the combined effects of dramatic air traffic declines and a greatly expanded motorway network in Ireland during the period of the great recession. The subsequent policy decisions by government are assessed in light of the intermodal accessibility changes identified. Changes to European Union (EU) air transport regulations now require analysis and assessment of Public Service Obligation (PSO) air route impacts, costs and 'proportionality', and this paper aims to demonstrate such an analysis and assessment in Ireland between 2005 and 2010.

The Irish government and European Union engaged in an extensive series of investment programmes in transport infrastructure during the 1990s and 2000s using EU structural funds and Irish government exchequer funding. These investment programmes aimed at greatly improving the roads network, airports and ports as well as some sections of the rail network. A series of Irish government documents set out 5-year plans for transforming the transportation infrastructure and achieving broad objectives of more balanced economic growth, increased employment and economic and social cohesion[1]. This paper will focus on the air and road transport networks and examine the changing policy context for enhancing air transport accessibility over a 20 year period.

The investment in Irish regional airports during the late 1980s and early 1990s resulted in a nine-airport network for the Irish Republic and a 12-airport network for the Island of Ireland by 1993. Along with the infrastructure investments, the Irish government put in place an *essential air transport policy* to ensure a basic minimum level of air service to the regional airports during the 1990s and 2000s in order to facilitate the development of tourism products and encourage industrial developments outside of the Dublin/Eastern region. The road investment programme was the largest investment programme undertaken by the Irish state, significantly increasing the total motorway length as well as upgrading significant portions of the national and regional road networks. This resulted in substantially lower travel times and higher travel speeds between the main urban centres in the country.

The aim of this paper is to measure the combined effects of the reduction in air transport services and the improvement in road transport accessibility for the 2005-2010 period and to examine the implications for transport policy in Ireland in the recovery period from 2010-2014. The long term policy implications will also be outlined. An inter-modal accessibility approach is adopted where the physical characteristics of the road transport network linking airports and the network structure characteristics of the air transport system are taken into account to evaluate the levels of air transport accessibility at the small-area district level. The paper contributes to the literature on air accessibility measurement, impact assessment and the leakage of traffic from small regional airports to larger airports (Lieshout, Malighetti, Redondi and Burghouwt (2015); Wei & Grubesic (2015); O'Connor (2003), Burghouwt (2013); Suau-Sanchez & Burghouwt (2011)).

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[1] See "*Operational programme on peripherality: roads and other transport infrastructure 1989 to 1993*", Government of Ireland and Commission of the European Communities, 1989; "*Operational programme for transport 1994 to 1999*", Government of Ireland, 1994; *Ireland National Development Plan 2000-2006 - Economic and Social Infrastructure Operational Programme*", 2000; *National Strategic Reference Framework 2007-2013*, Government of Ireland, 2007; *National Development Plan 2007-2013*, Government of Ireland, 2007.

The next section of the paper sets out the background to the development of the Irish air and road transport networks and details the policy implications for the shifting time-space geography resulting from these evolving networks. The dramatic changes in Ireland's economic circumstances from 2008 are also briefly outlined as this resulted in strong pressure to cut government expenditure and rationalise many assistance programmes including the essential air services programme. The wider European airports network is also described in this section. Section 3 summarises the methodological framework adopted to model both accessibility at the local level and at the international level. In Section 4, the results of this analysis are presented for 2005 and 2010; in this section, the policy impacts arising from reduced travel times by road are highlighted and the increasing costs of continuing to fund public service obligation air routes are detailed. The policy changes introduced in the 2010-2014 recovery period are examined and evaluated in light of the intermodal accessibility results. Section 5 presents an analysis of the inequality in accessibility for the surface and air transport networks. Section 6 summaries the key findings and discusses the implications for further analysis.

2. Irish economic development and transport infrastructure investment policies 1990-2010

European Community regional development policies changed significantly during the 1980s with the accession of Spain, Portugal and Greece in 1986. Under the greatly expanded European Regional Policy of the late 1980s and 1990s, substantial EU funds were made available to economically lagging regions in order to reduce the disparities that existed between the regions of the then 15 member states. The structural funds provided large scale funding for programmes of investment in infrastructure, education and training in order to enable economic growth and development and reduce unemployment. In Ireland, the government in conjunction with the European Commission set out a series of 5-year regional development planning programmes beginning in 1989 with the *Operational Programme on Peripherality*. Subsequent programmes were agreed and published in 1994, 2000 and 2007. The transport component of these plans aimed at greatly improving the roads network, airports and ports as well as some sections of the rail network. These plans represented a new commitment to the process of medium term regional and national planning by the Irish state.

Roads Network

The Irish road network changed dramatically between 2000 and 2010 as the substantial government investment programmes (National Development Plan 2000-2006 and National Development Plan 2007-2013) delivered a greatly increased total motorway length thereby substantially reducing travel times and increasing travel speeds between the main urban centres in the country. The earlier programmes had focused on upgrading sections of the national primary and secondary road networks (in many cases to dual carriageway standard), removing bottlenecks, by-passing small towns and villages and removing curves and grades that significantly impacted on driving speeds. The total national road network measured 5,306km in 2014 of which 897km was motorway (NRA *National Route Lengths as* *of 31/12/2013*)[2]. In this study, the road transport network for the island of Ireland is utilised. The network consists of the motorways, national primary and secondary routes, and regional and county roads networks in the Republic of Ireland and Northern Ireland. The length of motorway in Northern Ireland was 115km in 2014, with 2,290km of primary roads ('A'- class single and dual carriageway roads)[3]. Table 1 shows the total road length of the road network under study and the corresponding average speed by road type. Average speed levels were used to compute average travel times by road type and section to each airport under study (see next section for details).

There was a dramatic increase in the total road length of the motorway network in the 2005-2010 period in the Republic of Ireland. Figure 1 shows the total motorway length between 1999 and 2013 as recorded by the National Roads Authority[4] and highlights the fact that most of the motorway length came on stream after 2008. The motorway network changed by less than 1km in the same period in Northern Ireland. The 2007-2013 NDP included a budget of €13.3 billion for completion of the interurban motorway network and the upgrading of key national primary and secondary routes particularly where bottlenecks had resulted in increased travel costs for road users. The motorway network consisted of the upgrading (via widening, realignment and separation of existing lanes and construction of additional lanes) of many sections of the existing national primary and secondary routes, along with significant new road construction (roughly 25% of the total length of motorway). Where new road sections were constructed, pre-existing routes were reclassified. To illustrate the impact of road network changes, the travel times and changes in travel times between each electoral district (ED) and Dublin Airport were mapped. Figure 2 shows the average free flow travel time in 2010 in minutes between the centroid of each Electoral District (ED) and Dublin Airport. Figure 3 illustrates the change in average free flow travel time between 2005 and 2010 using the average speed levels set out for each road class in Table 1. The greatest reductions in travel time to Dublin Airport have been achieved in the northwest, west and southwest of the island.

[Table1]

[Figure 1]

[Figure 2]

[Figure 3]

Airports network in Ireland: The Republic of Ireland's civil airports network consists of three state-owned airports and six privately-owned regional airports. The state owned airports are Dublin (DUB), Cork (ORK) and Shannon (SNN) airports. Dublin and Cork are operated by the Dublin Airports Authority (the DAA), while Shannon Airport was separated from DAA and became an independent company on December 31st 2012.The six regional airports

[2] The regional and county roads network consists of approximately 87,000km of paved roads and is under the remit of the Department of Transport, Tourism & Sport.

[3] See *Northern Ireland Transport Statistics - 2011-2012*, HMSO (2012); (available at www.drdni.gov.uk/index/statistics/stats-catagories/ni_transport_statistics.htm).

[4] National Roads Authority *National Route Lengths* 2006, 2007, 2008, 2009, 2010 (available at www.NRA.ie).

consist of two airports with jet aircraft capabilities, Kerry County (KIR) and Knock (NOC) airports, and four with turbo-prop capabilities, Sligo (SXL), Galway (GWY), Waterford (WAT) and Carrickfinn (CFN) airports. The regional airports were developed during the 1980s with Irish exchequer and European Union structural funds. The regional airports are located in areas that were considered to be peripheral in an Irish and European context. Surface transport access to towns in the northwest, west and southwest of Ireland during the 1980s was considered to be of poor quality as much of the national road network passed through small towns and villages and had an effective travel time of 67km (42 miles) per hour[5]. Government investment during the late 1980s put in place this network of regional airports in order to facilitate fast access to the regions and thereby enable industrial development and the development of new tourism products. The airport hinterlands overlap to a considerable degree, and most are located close to coastline so that the effective hinterlands are quite small. Figure 4 illustrates the extent of the overlap in 2010 by showing the one-hour driving catchment areas from each of the airports included in the study.

[Figure 4]

In Northern Ireland, the two airports at Belfast (Aldergrove (BFS) and George Best Belfast City Airport (BHD), and Eglinton City of Derry Airport (LDY) make up the balance of Island of Ireland's 12-node airports network.

In order for the investment in air transport infrastructure to yield benefits to the region in which the airports are located, air services need to be initiated by air carriers. During the early 1990s, it became clear that the Irish regional airports would not experience continuity of air services without some government intervention (Reynolds-Feighan, 1995a). A series of measures were developed to aid the regional airports and deliver continuity of air services in the regions. These measures have evolved during the 1990s, 2000s and 2010s as changes in European Union regulations relating to competition and state aid, and, economic regulation of air transport have been made. The Irish Government's *Regional Airports Programme 2008-2011* consisted of three support schemes for capital expenditure grants, operational expenditure subvention and the *Public Service Obligation* (PSO) air routes scheme for subsidising air services operating between Kerry, Galway, Knock, Sligo, Donegal and Derry Airports and Dublin Airport[6].

Before 2006, European Union member states provided grants for marketing and promotion as well as for safety and security measures at regional airports. However in December 2005, the European Commission changed the approach to financing and funding of regional airports[7]. The overarching concern was that payments to airports could be considered to be state aid and thus potentially distortionary of competition. An airport classification scheme was presented which identified 'large regional airports' and 'small regional airports' in an EU

[5] Estimated travel times by roads reported in Reynolds-Feighan (1993) Reynolds-Feighan, A.J. Assessment of Performance and Prospects for the Irish Regional Airports, Commissioned report submitted to the Irish Department of Transport, May 1993.

[6] Payments under this programme amounted to €21.1m in 2007; €27.1m in 2008 and €22.8m in 2009 (see *Value for Money Review of Exchequer Expenditure on the Regional Airports Programme*, Irish department of Transport, June 2010).

[7] European Commission Communication of 9 December 2005 "Community guidelines on financing of airports and start-up aid to airlines departing from regional airports" (available here: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52005XC1209(03)).

context. The Commission set out requirements linking funding of regional airports with formal PSO contracts.

The economic regulation of air transport in Europe was set out in the so-called 'Third Package' of EU air transport liberalisation measures, which came into effect on January 1 1993. The package of measures included provision for the Member States to impose and subsidise if necessary 'public service obligations' (PSOs) on low-density routes which were deemed necessary for the purposes of regional development (Council Regulation N° 2408/92). The regulations governing PSOs were changed in 2008 when Europe's air transport regulations were overhauled, updated and consolidated[8]. Much of the detail on the functioning of the PSO regulations was not changed from the 1993 regulation; however the new regulation required member states to periodically review and justify the continued imposition and funding of PSO air routes[9].

The PSOs may be imposed by Member States in relation to scheduled air services, and relate to airports serving peripheral or development regions within the state, or on thin routes to any regional airport where the route is considered vital for the economic development of that region (Williams et al (2004); Bråthen & Halpern (2012)). The EU PSOs are defined and operated in terms of routes (rather than airports). The European Council did not put any financial instrument in place, nor were specific guidelines set out for the operation of such a programme, other than a requirement that there be a public tender for award of the PSO contract[10]. Compensation paid to carriers under these PSOs comes from the individual member state concerned. The Irish government was the first EU member state to implement these provisions in the Third Package (see Reynolds-Feighan (1995a & 1995b)). PSOs were imposed on routes between five of the six regional airports in the Republic of Ireland and also on the Derry-Dublin air route[11]. The total amount of payments in the 2008-2011 period for the 6 regional airports[12] with PSO air routes was €44.8m.

Following the economic downturn beginning in 2008, the Irish Government sought to cut expenditure across all sectors and programmes, including the PSO air route programme[13]. In the 2011-2014 period, only two PSO routes were funded: Dublin – Donegal (justified on the basis of the surface travel time to Dublin) and Dublin-Kerry (justified on the basis of the importance of tourism in the locality). These PSOs were renewed in November 2014 with new contracts to run until January 2017. The reduced travel times resulting from

[8] Regulation (EC) No 1008/2008 of the European Parliament and of the Council, Articles 16-18, (24th September 2008).

[9] Article 16(3) of EC 1008/2008 now requires a member state to assess the necessity and adequacy of a PSO service having regard to : "*(a) the proportionality between the envisaged obligation and the economic development needs of the region concerned; (b) the possibility of having recourse to other modes of transport and the ability of such modes to meet the transport needs under consideration, in particular when existing rail services serve the envisaged route with a travel time of less than three hours and with sufficient frequencies, connections and suitable timings; (c) the air fares and conditions which can be quoted to users; (d) the combined effect of all air carriers operating or intending to operate on the route.*"

[10] A listing of current PSO routes in the European Union may be found on the Commission's website: http://ec.europa.eu/transport/modes/air/internal_market/pso_en.htm

[11] The allocation and cost of the Irish PSOs is reviewed in the Irish Department of Transport report "*Value For Money Of Exchequer Expenditure On The Regional Airports Programme*" (Revised), Department of Transport, June 2010. (available here: http://www.dttas.ie/sites/default/files/node/add/content-publication/June%202011%20Value%20for%20Money%20Review%20of%20Exchequer%20Funding%20on%20the%20Regional%20Airports%20Programme.pdf)

[12] The PSO routes in the 2008-2011 period were Galway-Dublin; Kerry-Dublin; Knock-Dublin; Derry-Dublin; Donegal-Dublin; Sligo-Dublin. Derry (Eglinton Airport) is located in Northern Ireland.

[13] See McCarthy, Colm; McNally, Donal; McLaughlin, Pat; O'Connell, Maurice; Slattery, William; Walsh, Mary (2009) "Report of the Special Group on Public Service Numbers and Expenditure Programmes", Department of Finance, July 2009.

improvements in the roads network, improvements in surface public transport options and the escalating levels of subsidy per passenger were the main justifications given for cutting most of the other PSO air services[14]. Sligo and Galway Airports closed in 2011 and 2013 respectively following withdrawal of all scheduled air services. Knock Airport benefited from these closures by becoming the focus for west of Ireland air transport development. Table 2 shows details on the number of movements in 2010 and 2014, the percentage change in the number of movements between 2005 and 2010, and the average stage length for each of Ireland's airports.

[Table 2]

The impact of the downturn, the banking crisis and subsequent public debt crisis resulted in dramatic falls in air traffic activity between 2008 and 2010 for all of the Irish airports. Figure 5 shows the total number of air routes to and from Ireland and Dublin Airport between the longer time period of 1996-2014. In 2014 traffic levels had increased at Dublin, Shannon and Knock airports, but were still below 2008 levels at all of the airports. Most of the airports continue to struggle in generating revenue and increasing traffic despite the more favourable economic climate.

The critical period influencing the long term sustainability of the Irish airports occurred between 2005 and 2010. Air traffic peaked in 2008 with dramatic falls following the onset of the global financial crisis. At the same time, the road network improvements resulted in a structural change in the time-space geography of Ireland and permanently altered the viability of all of Ireland's airports. The inter-modal accessibility approach outlined in the next section quantifies at local level, the combined effects of the roads infrastructure improvements and the air traffic changes.

[Figure 5]

(ii) International Airports networks: The international air transport network analysed in this study consisted of the Irish, Northern Irish and UK airports and the airports in the IATA European Region[15].

The European airports network (including the Irish and UK airports) consisted of 675 airports receiving air services in 2010. This network of airports is illustrated in Figure 6. The largest 14 European airports had 111,082 or more departure movements. In the UK and Ireland, only London Heathrow Airport (LHR) has this traffic threshold. The European airports network is hierarchical in the sense that at the larger airports, carriers are more focused on long-haul routes with less short-haul commuter routes; at the medium and smaller airports,

[14] Department of Transport (2010) "Value for money of exchequer expenditure on the regional airports programme" (Revised), Department of Transport, June 2010. (available here: http://www.dttas.ie/sites/default/files/node/add/content-publication/June%202011%20Value%20for%20Money%20Review%20of%20Exchequer%20Funding%20on%20the%20Regional%20Airports%20Programme.pdf)

[15] Europe is broadly defined and includes Austria, Belgium, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, Cyprus, Turkey, Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Belarus, Croatia, Czech Republic, Estonia, Georgia, Hungary, Latvia, Lithuania, Macedonia (Former Yugoslav Republic), Moldova Republic of, Montenegro, Poland, Romania, Russian Federation (west of the Urals), Serbia, Slovenia, Slovakia, Ukraine. This categorization of Europe is based on IATA definitions of the region.

carriers service a mix of short haul commuter/regional traffic as well as some short/medium haul heavier trafficked routes where jet aircraft are utilised. At London Heathrow Airport for example, UK regional services were gradually withdrawn during the 1980s and 1990s, with long-haul services making use of the scarce airport take-off and landing slots. The range of connections available at an airport facilitates connectivity within the entire network; the largest airports tend to have large numbers of direct connections and substantial capacity in terms of number of departures and seats available. The importance of a route can be captured by taking into account the extent to which each airport is directly connected to other airports, and, the importance of those other airports in terms of their connectivity in the overall network (see for example Rendondi et al (2011); Guimerà et al (2005)).

[Figure 6]

In modelling accessibility, data on the number of non-stop routes, the number of movements and the seating capacity were collated in order to generate metrics of airport traffic volumes, attractiveness and connectivity. Table 3 shows the relationship between the variables used in modelling accessibility between 2005 and 2010 for Ireland, the UK and the rest of Europe.

[Table 3]

There is a strong correlation between flight frequency levels in Ireland and the UK in the period under study; this relationship is still present in the case of the total number of European routes departing from Irish and UK airports. Correlation is positive in the case of the number of movements for Ireland and the rest of Europe; however, there is no relationship between both variables in the case of seating capacity and number of routes. While these variables have experienced a significant decline since 2005 in Ireland, they have increased in the case of other European airports.

3. Methodology

The concept of accessibility has been well-known in the regional science and transport literature since the mid-20th century with the seminal works of Hansen in the 1950s and Weibull in the 1980s. Accessibility has often been defined as the potential of opportunities for interaction (Hansen, 1959) as well as a general concept to encapsulate all the potential benefits that transport investment produce (Banister and Berechman, 2001). The importance of accessibility from a regional economic perspective relies on the general idea that changes in accessibility resulting from new transport infrastructure investments are likely to cause a redistribution of economic activities between regions (Banister and Berechman, 2001).

More recently, some authors have addressed the importance of the role of accessibility in the network framework (see Reggiani, 2011). Accessibility should capture spatial structure effects and network configuration properties such as connectivity (Reggiani et al., 2010) since it relates to all the nodes in the spatial economic system under analysis (Weibull, 1980; Reggiani et al., 2010).

There is a wide range of approaches and methodologies to measure accessibility (see comprehensive reviews in Handy and Niemeier, 1997; Geurs and Ritsema van Eck, 2003; Halden, 2002; Geurs and van Wee, 2004; Martin and Reggiani, 2007; Willigers et al., 2007). Overall, the definition and mathematical formulation of accessibility depends on the objectives of the particular study for which the accessibility measure is intended for (Borzacchiello et al., 2010). Several formulations of accessibility may lead to different results for the same transport network and land use context (Barzacchiello et al. 2010). In the regional economics literature, accessibility has often been measured as 'economic potential', as follows:

$$A_i = \sum_j D_j f\left(c_{ij}\right) \tag{1}$$

where A_i is the accessibility of zone *i*; D_j is a measure of opportunities or activities in zone *j*; and $f(c_{ij})$ is the impedance function to measure the spatial separation between origin *i* and destination *j*. A number of versions of Equation 1 have been used in previous studies to measure accessibility patterns (see Reggiani, 1998 for details). The popularity of this analytical form in the scientific literature is partly due to two convenient properties: Equation 1 corresponds to the inverse of the calibration factor in an origin-constrained *Spatial Interaction Model* (Reggiani, 1998). In the context of random utility theory, Equation 1 has also been interpreted as the benefit or expected utility to an individual in a spatial choice situation (Ben-Akiva and Lerman, 1985). The accessibility formulation above has been regarded as a fundamental linking tool between spatial economics and network analysis as it contains the network connectivity structure in the cost matrix c_{ij} as well as the behavioural response to the location of economic activities by means of the cost-decay parameter embedded in the impedance function (Reggiani et al, 2011).

In this paper, an inter-modal measure of accessibility is used, following recent research by Matsziw and Grubesic (2010) on the measurement of locational accessibility for the US air transport system. Assuming an economic or market potential accessibility measure, the index of accessibility is computed as a ratio between the volume of activity of the destination *j* and the cost of reaching *j* from demand location *i*. The methodology suggested here extends Matsziw and Grubesic's (2010) method to better fit the research objectives of this study for Ireland, where the relative importance of internationally connected destination airports plays a relevant role given the nature and size of the study area.

The accessibility indicator takes the analytical form of a composite measure where the first term measures the level of surface accessibility to airports - road network accessibility to the entry points of the air passenger transport system – and the second term measures the level of accessibility within the air passenger transport system for each Irish airport. Thus, the overall levels of air transport accessibility measured at the local – electoral district – level take into account not only the surface level of accessibility to each Irish airport, but also the level of air transport accessibility that can be potentially obtained from each airport, given the air transport network under analysis. In this study, the analysis focuses on the European air passenger transport network.

Given a set of demand locations (i.e., electoral districts), a set of facilities (i.e., airports) as well as data on the air passenger travel network structure (i.e., connections between airports), the level of accessibility is computed as follows:

$$A_i = \left(\sum_{j \in J} D_j f(t_{ij})\right) + \sum_{m \in M} \delta_m f(c_{jm}) \tag{2}$$

where A_i is the level of accessibility of electoral district *i* to the entire air passenger travel network, assuming entry to all service facilities or airports *j*. A weighted measure of air traffic at each airport is used to describe the level of service *Dj* at each Irish airport and the level of service δ_m at each connected destination airport. The weight measures the relative importance of the destination airport in terms of the regional passenger air traffic hierarchy (see Reynolds-Feighan and McLay, 2006 for details). The motivation for using these weighted measures of air traffic is based on results from previous research carried out by the authors in which alternative measures of airport performance were analysed in the context of accessibility analysis (see Vega and Reynolds-Feighan, 2012 for details). The measures considered included graph theory measures of centrality, betweenness and closeness[16], and a variety of air traffic movement metrics indexed to take account of the 'importance' of linkages as described in Reynolds-Feighan and McLay, 2006. The weighted measures provide a more realistic measure of airport service levels; graph theory/social network analysis metrics were shown to overstate the degree of air access at regional airports.

With regard to the impedance function and cost variables, the cost t_{ij} in the first term is measured as the road travel times from each demand location or district *i* to each point of entry into the air travel system or airport *j*. The *Network Analyst* extension in ArcGIS is used to calculate an origin-destination matrix based on travel times[17] between each of the electoral/postal districts on the Island of Ireland and the twelve national and regional airports considered for the analysis.

In the second term, the impedance function is the inverse of the cost c_{jm} that contains information on the connectivity structure of the network under study and it is measured as follows:

$$c_{jm} = \sum_{m \in M} \left(M(p_j + p_m) + k_{jm}\right) \tag{3}$$

where *M* is the total number of airport nodes in the network; p_j and p_m are the proportion of airports that can be directly reached from origin airport *j* and destination airport *m* respectively and they measure the potential for connectivity in terms of available

[16] These measures have been extensively used recently in Social network Analysis.
[17] Travel time is generally used as an indicator of friction of the distance between origins and destinations in accessibility analysis.

alternatives for air travel; and k_{jm} is the frequency or the number of direct connections between airports. The hypothesis under the formulation for this cost measure is that the larger the potential for connectivity and the actual connectivity, the lower the cost of travelling for a particular passenger within the air transport system. The motivation for using directly connected routes in this paper is that in contrast to the US, where air operators sell indirect routes as individual products, European airlines tend to sell direct services to particular destinations and it is up to the traveller or an agent to combine different segments or direct routes to get to non-directly connected destinations.

Conceptually, the equations 2 and 3 assume that the level of accessibility for any location within a region is directly proportional to the level of service maintained between connected airports and inversely proportional to the cost of using that service to access alternatives available at an individual's origin or residential location.

Data for this study were obtained from Ordnance Survey Ireland, Northern Ireland Ordnance Survey and OpenStreetMap (for the most recent motorway network sections). The smallest administrative areal units, the Electoral Districts (EDs) are used to measure accessibility. The centroids of each of the 3,440 EDs were determined and form the basis for the accessibility measurements. Average speeds by road type were obtained from the Road Safety Authority, Ireland and relate to maximum allowable speeds on each road section[18]. In examining passenger air transport activity, *the Official Airline Guide Historical MaxPlus* datasets give comprehensive coverage of ex-post airline schedules for each year from 1996 to 2014 and cover scheduled and non-scheduled operations. Airline schedules are published one year ahead and the MaxPlus dataset presents the revised ex-post schedules. The OAG coverage of airlines is far more extensive than in either ICAO or IATA databases, and includes almost all passenger operators globally. The main problem with these datasets is that the activity measured is either seating or freight capacity available, rather than actual traffic performed. The categorisation of states and regions follows ICAO and IATA conventions rather than reflecting liberalised air transport markets such as the European Common Aviation Area (ECAA) or NAFTA. However, the comprehensive and consistent coverage of domestic and international air transport activity globally allows for comparative analysis of major continental air transport markets.

4. Results: Irish air transport accessibility analysis for the 2005-2010 period.

This section presents the results for the inter-modal analysis of air transport accessibility in Ireland. The levels of road network accessibility to Northern Ireland's three airports – City of Derry Airport (LDY), George Best Belfast City Airport (BHD) and Belfast International Airport (BFS) - and the levels of air transport accessibility within each of these airports' air passenger systems have also been computed. Therefore, the results presented in this paper take into account the potential benefits of road access to Northern Irish airports as well as their potential effect on air transport accessibility at the electoral district level. For residents in Northern Ireland, an additional cost of travel by air is the Air Passenger Duty (APD[19])

[18] Detailed traffic data by road section were not available for the regional road network, thus the travel time estimates do not reflect the impact of congestion.

[19] The Air Passenger Duty was introduced by the UK Government in 1994 as a tax on outgoing flights from UK airports. The level of tax varies depending on the flight distance and applies to children and adults over 12 years of age.

charge. The attractiveness of air travel via the Republic of Ireland's airports will be enhanced by the lower travel costs, though survey data is not available to measure the impact of this tax. The European airports network is taken into account when the *importance* of routes from airports is being considered[20].

4.1. Road network accessibility to Irish airports

Figure 7 show the road accessibility scores for 2010[21], which corresponds to the first term of the inter-modal air transport accessibility measure described in Equation 1. The most noticeable result is the relative high levels of road network accessibility around the Greater Dublin Area. High levels of road accessibility to airports are also found along the new motorways to the cities of Cork, Waterford, Galway and Limerick. Figure 8 shows the change in road network accessibility to Irish airports in the 2005-2010 period. Districts that experienced an increase in road network accessibility show scores >1. The relative improvement in road network accessibility has been higher in the east and southeast of the country, in particular around the city of Dublin and in the southern Greater Dublin Area.

[Figure 7]

[Figure 8]

There has been a relative decline in road accessibility to Irish airports in the southwest of the country, around Shannon and Kerry Airports and to a lesser extent, around Cork Airport. This reflects the relatively worse performance of these airports – in particular Kerry Airport - in terms of air passenger traffic within the European air transport system in the period under study.

Table 2 includes the percentage change in weighted movements[22] for each of the 12 airports under analysis. Waterford and Donegal are the only airports that show an increase in weighted movements in the 2005-2010 period, which partially explains the relative increase in road accessibility found around these airports and across western border districts. All other airports have experienced a drop in weighted air passenger traffic, with the largest decline found in Kerry Airport due to the loss of the Dublin route and an important reduction in the frequency of flights with Manchester Airport (MAN).

4.2. Air transport accessibility

The normalised levels of air transport accessibility for the 2005-2010 period are presented in Table 4 for each of the airports under analysis. Dublin Airport ranks first in both periods, followed by George Best Belfast City and Cork airports. There has been a large increase in air transport accessibility for Belfast International Airport. In spite of a reduction in air passenger traffic in the 2005-2010 period (see Table 4 for weighted movements), the level of air transport accessibility has increased due to the introduction of two new routes to London Heathrow Airport (LHR) and Munich International Airport (MUC), which were

[20] Vega and Reynolds-Feighan (2012) examine three different air transport networks when comparing metrics of air accessibility, namely Ireland and the UK, European network and global network.

[21] Accessibility scores normalised, range[0,1]

[22] Weighted by the proportion of traffic through the destination airport relative to the amount of traffic through the busiest airport in the European network (see Reynolds-Feighan and McLay, 2006 for details)

among the five-top European airports in weighted air passenger movements in 2010. In addition to the introduction of the new route, air traffic movements with London Heathrow represent over 40% of the overall air passenger traffic from Belfast International Airport in 2010, which is a major factor explaining the increased levels of air transport accessibility from this airport.

There has been a sharp decline in relative air transport accessibility for Kerry Airport as previously acknowledged in Table 4, followed by Derry and Knock Airports. Table 4 also shows a significant reduction in air accessibility for Shannon Airport due to a major decrease in air passenger traffic with Dublin (DUB) and London Heathrow (LHR) Airports in 2010.

[Table 4]

The overall levels of air transport accessibility in 2010 are shown in Figure 9. This map presents the results from the 2010 inter-modal composite measure of air transport accessibility taking into account the surface level of accessibility to each Irish airport and the level of air transport accessibility that can be potentially obtained from each airport, given the structure of linkages in the European air transport network. The results show the net effect of the relative increase/decrease in road network accessibility to Irish airports *and* the relative increase/decrease in air transport accessibility from each of these airports at the local or electoral district level.

[Figure 9]

Overall, the largest levels of inter-modal air transport accessibility are found in the Greater Dublin Area, the adjacent counties in the Midlands and the Southeast of Ireland and around Belfast City. The west-east division shown in Figure 9 suggests better inter-modal air transport accessibility in the Eastern half of the island, and the Greater Dublin Area in particular. This is mostly evident around Kerry and Shannon airports.

Figure 10 shows the change in inter-modal air transport accessibility scores in the 2005-2010 period. There has been a general decline in air transport accessibility in Ireland in the period under study (access scores < 1). With the exception of the south and southwest of Dublin City and the surrounding areas of Belfast City, all districts have experienced a net reduction in air transport accessibility, despite the relative increase in road network accessibility to Irish airports found across a large number of districts, as shown in Figure 8. In particular, predominantly rural western districts present relatively larger declines in air transport accessibility in the 2005-2010 period. These results are consistent with recent research on network accessibility of rural airports in the United States (Wei and Grubesic, 2015).

[Figure 10]

Figure 11 shows the change in inter-modal air transport accessibility presented in Figure 10 with the catchment areas of some of the western airports presented in Figure 4 (shaded on the map). In general, these western hinterlands experienced large declines in intermodal air accessibility between 2005 and 2010.

[Figure 11]

4.3. Inequality in Accessibility

While there has been an overall net decline in air transport accessibility in Ireland from 2005 to 2010, the question of whether this net effect has contributed to a more equal spatial distribution of air transport accessibility is of relevance from an Irish transport policy perspective. Taking the distribution of (i) road accessibility and (ii) road and air accessibility measures across all small area divisions, three indices of inequality were selected and computed – the coefficient of variation, the Gini Index and the Theil Index. These indices have been used in previous studies of accessibility and territorial cohesion (Condeço-Melhorado et al., 2011; Lopez et al., 2008; Martin et al., 2004).

Table 5 shows the extent to which the new improved motorway system has contributed to a more unequal spatial distribution of road network accessibility values to Irish airports. This table also demonstrates the extent to which intermodal air transport accessibility inequality has increased in the 2005-2010 period.

In 2010, road network accessibility differences among electoral districts have increased with respect to the accessibility scores obtained for 2005. As previously shown in Figures 2 and 3, the eastern half of the country shows relatively higher road accessibility levels in 2010, when compared to those in 2005. There has been a predominant decrease in absolute road travel times in Ireland (Figure 2) with the improvement of the road transport network. However, this improvement has been much greater in certain parts of the country, which has increased inequality in accessibility to airports across the electoral districts.

[Table 5]

There has been an increase in the differences in air transport accessibility among the 12 airports considered in the analysis. While most Irish airports have experienced a reduction in European air passenger traffic in the 2005-2010 period (Figure 6), this reduction has been more pronounced at certain airports, which has contributed to an increase in air transport accessibility inequalities at the national level.

5. Discussion and Conclusions

The provision of regional airports can provide regions and communities with fast access to national and international transport networks that are necessary for economic growth and development. Regional airports can be quickly constructed and air carrier services are flexible in terms of the potential connections or linkages that they may provide for communities. The air transport industry has been characterised by cyclical patterns of expansion and contraction in the last 40 years. In periods of expansion, many small and medium sized communities can experience increases in their traffic volumes and expansion in the number of service offerings by carriers (direct routes). However these communities are often first to be dropped by carriers when downturns in the economic cycle are experienced. The reduction in air access can have far ranging effects on businesses in smaller communities and the airport infrastructure investment is of little benefit to the community if there are no air services. An increasing number of studies have examined the traffic trends and difficulties faced by regional air transport service providers outside of the heavily populated hubs in Europe and the US (for example Suau-Sancheza, P. & G. Burghouwt (2011) in Spain; Papatheodorou, A. & P. Arvanitis (2009) in Greece; Bråthen, S. & N. Halpern (2012) in Norway; Wei, F. & T. Grubesic (2015) in the USA).

As more expensive and long term surface transport infrastructure investments are put in place, this has the effect of 'shrinking' the time-space geography of a region or national territory. The reduction in travel times achieved through increasing average speeds on higher class roads enhances the level of absolute accessibility within the territory. However in relative terms, the larger centres tend to enjoy greater improvements in accessibility when compared with smaller regional centres. This tends to draw more services and activities into the larger centres and away from the smaller centres. This trend has been documented in other settings (Gjerdåker et al., 2008, US General Accounting Office (2003)).

The long term sustainability of the regional airports in Ireland is questionable because not only has service been cut by air carriers, but Dublin Airport has become a more attractive alternative for air travel because it is more accessible by road and it has the largest range of service offerings of any Irish airport. This 'leakage' of traffic from regional airports to larger airports has been documented in the literature (Lian & Rønnevik (2011); Fuellhart (2007) and Suzuki, Crum & Audino (2003)). The continued funding of an essential air service programme is difficult to justify when surface transport links have been improved significantly. The regional airports had provided their local communities with fast access to the international air transport network and thus served a useful purpose during the 1990s and early 2000s; but with closer surface transport integration and greatly improved surface transport travel times, these communities are not as remote as they were in the 1980s.

This paper shows the impact of the substantial roads investment programme by the Irish government particularly during the 2000s. The impact of declining air transport access (because of reduction in/withdrawal of air transport service offerings by carriers) is combined with the enhanced surface transport access to demonstrate aggregate intermodal changes in accessibility at local level. The decline in air transport services at the regional airports has reduced direct links to many European centres and also indirect linkages, thereby decreasing the extent of connectivity in the European and global airports system. The improved surface access to the larger Irish airports (Dublin and Belfast) has enhanced the range of European and global locations directly accessible by air for many communities in Ireland. The net effect of these changes has been to concentrate air traffic at the largest Irish airports.

The methodology used in the analysis has the potential to be further extended to take account of other surface transport options, and to monitor incremental changes to the surface or air transport networks. The analysis presented helps to justify the PSO policy decisions taken by the Irish government in the 2011 to 2014 recovery period.

The road network improvements have increased the extent of airport hinterland overlaps outside of the Dublin region. All of the airports will not be viable in the long run. In the west of Ireland, the closure of Galway and Sligo airports has facilitated expansion of services at Knock which now acts as a focal point for air transport access in the west of Ireland. This will have also benefited Shannon Airport by enlarging its exclusive hinterland northwards into Galway County.

The continued funding of the Carrickfinn (CFN) PSO in Donegal and the Kerry (KIR) PSO in the southwest are justified given the low levels of air accessibility in the surrounding districts in 2010. These regions registered the greatest declines in intermodal air accessibility between 2005 and 2010. Because of the dispersed and low levels of population in these regions, substantial investment in the upgrading of the road network may be difficult to justify in the short to medium term. The provision of the PSO air services facilitates the continued development of tourism products and enables connectivity to European air transport networks via Dublin. Competition between Cork, Kerry and Shannon airports has increased in intensity with the road network improvements.

Many studies have examined the impacts of air transport network development and shown the increasing spatial concentration of air traffic at the larger urban centres. Liberalisation has enabled secondary centres to develop air transport services but urban size, urban economic structures and population density emerge as key determinants of air transport supply in Europe (Dobruszkes et al (2011); O'Connor (2003), Dennis (2005)). Small- and medium-sized communities face difficulties in attracting and maintaining air services, and this has implications for regional economic development (see for example Papatheodorou & Arvanitis (2009), Lian & Rønnevik (2010)). The concentration of air transport activity in an Irish context mirrors a more general trend towards concentration of air transport activity at the largest global hubs. This should be a matter of concern for European policy makers as it raises questions about the long term viability of smaller communities.

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Table 1: Data description of Irish road network

2010 Road Network – Republic of Ireland		
Road Type	***Length (km)***	***Average speed levels (Km/h)****
Motorway	900.3	107
Dual Carriageway	324.3	96
National Primary	2697.2	91
National Secondary	2716.3	81
Others – Regional/County/Urban roads	14,013.9	76 (Regional and County roads); 60 (Urban)

* Road Safety Authority of Ireland (2008). Free Speed Survey (Urban and Rural), Ballina, County Mayo, Ireland.

2010 Road Network – Northern Ireland		
Road Type	***Length (km)***	***Average speed levels (Km/h)****
Motorway	114.2	93
Dual Carriageway	171.9	93
Single Carriageway A Roads	2101	79
B Roads:	2884.3	76

* Department of Health, Social Services and Public Safety (NI) Project Support Analysis Branch Average Travel Speeds in Northern Ireland

Table 2: Summary data on air transport activity at airports on the island of Ireland, 2010 and 2014

Airport	Airport Code	Total Departure Movements, 2010	Total Departure Movements, 2014	*Change in Weighted Movements between 2005 and 2010 (%)*	*Number of Routes, 2010*	*Number of Routes, 2014*	Average stage length 2014 (km)	Number of countries Served (2014)
Belfast International Airport	BFS	4056	15110	-30.6	43	47	1918	20
George Best Belfast City Airport	BHD	18892	17993	-16.31	21	21	583	3
Donegal Airport	CFN	884	964	23.32	2	2	243	2
Dublin Airport	DUB	76616	83328	-14.34	168	168	1820	38
Galway Airport	GWY	3575	0	-12.78	10	0	0	0
Kerry Airport	KIR	2320	1614	-91.52	8	6	1174	4
City of Derry Airport	LDY	1292	1274	-52.4	8	8	945	3
Knock Airport	NOC	3012	3053	-46.73	13	21	1328	7
Cork Airport	ORK	11465	6583	-34.78	43	34	1457	11
Shannon Airport	SNN	6117	7359	-39.03	30	30	2110	10
Sligo Airport	SXL	728	0	0.02	1	0	0	0
Waterford Airport	WAT	1625	294	70.51	5	2	356	2

Table 3: Correlations among airports in Ireland/NI, UK and Europe between 2005 and 2010 by measure of departure air traffic services (i.e. seats, movements or routes).

Movements		
	Ireland/NI	**UK**
UK	0.996	
Europe	0.410	0.326
Seats		
	Ireland/NI	**UK**
UK	0.772	
Europe	0.098	-0.557
Routes		
	Ireland/NI	**UK**
UK	0.663	
Europe	-0.053	-0.782

Table 4: Change in Air Transport Accessibility, 2005-2010 period.

Airport	*Change (%)* *(Absolute)*	*2005 Air Accessibility (normalised)*	*2010 Air Accessibility (normalised)*	*Change (%) (normalised)*
Kerry Airport	-90.298	1.960	0.231	-88.199
City of Derry Airport	-59.923	2.165	1.055	-51.252
Knock Airport	-55.987	1.887	1.010	-46.464
Galway Airport	-42.328	3.490	2.448	-29.849
George Best Belfast City Airport	-33.992	22.702	18.228	-19.709
Shannon Airport	-31.443	7.483	6.240	-16.608
Cork Airport	-31.007	21.392	17.953	-16.079
Dublin Airport	-17.789	100.000	100.000	0.000
Sligo Airport	-13.730	0.840	0.882	4.938
Waterford Airport	5.262	0.489	0.626	28.038
Donegal Airport	6.402	0.747	0.967	29.425
Belfast International Airport	57.878	4.258	8.178	92.041

Table 5: Accessibility inequalities

	Road Network Accessibility		*Air Network Accessibility*		*Change (%)*	*Change (%)*
	2005	***2010***	***2005***	***2010***	***Road Network Accessibility***	***Air Network Accessibility***
Coefficient of variation	1.1386	1.3027	2.0201	2.1378	14.41	5.82
Gini coefficient	0.3604	0.432	0.7329	0.7543	19.86	2.93
Theil index (GE(a), a = 1)	0.3187	0.4351	1.1036	1.196	36.54	8.36

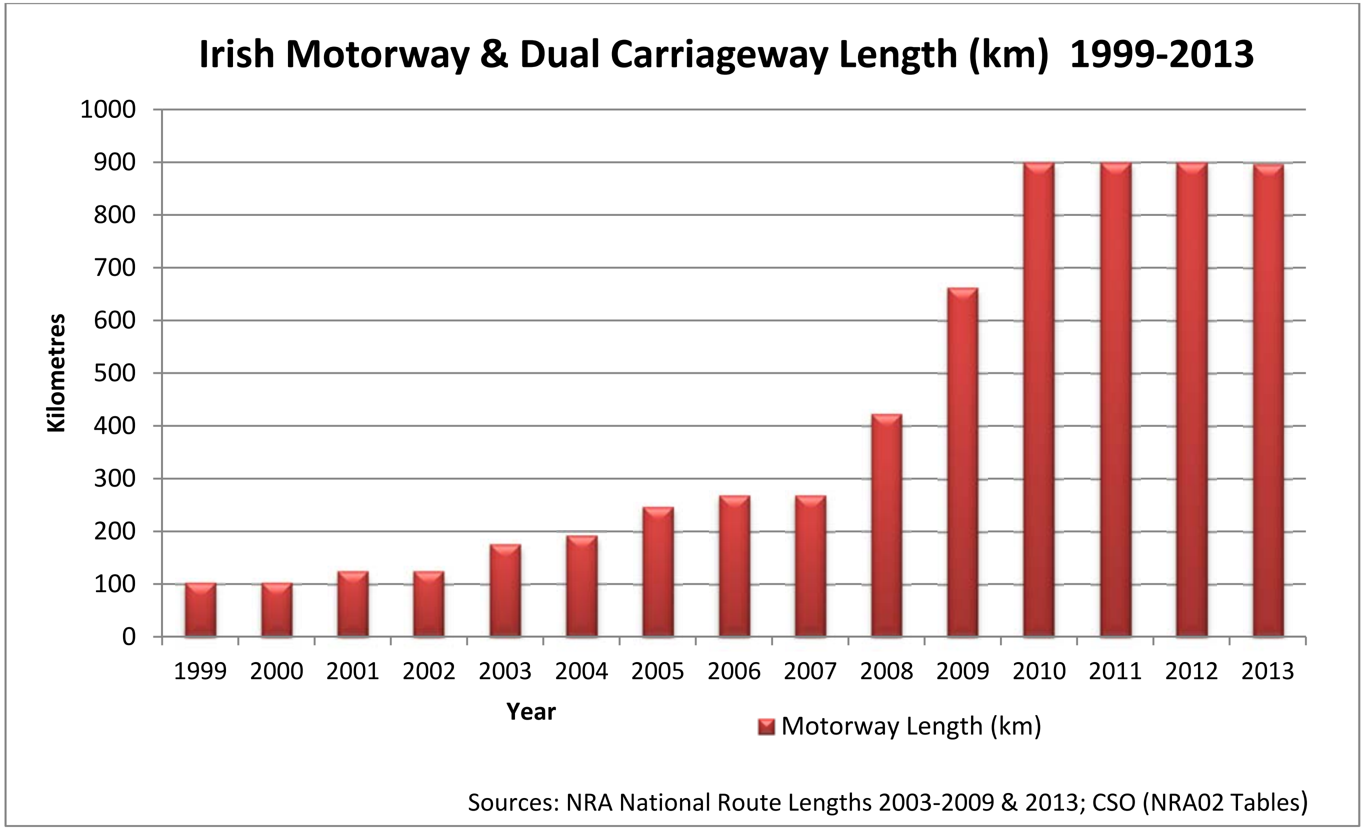


Figure 1: Irish Motorway Total Length, 1999-2013

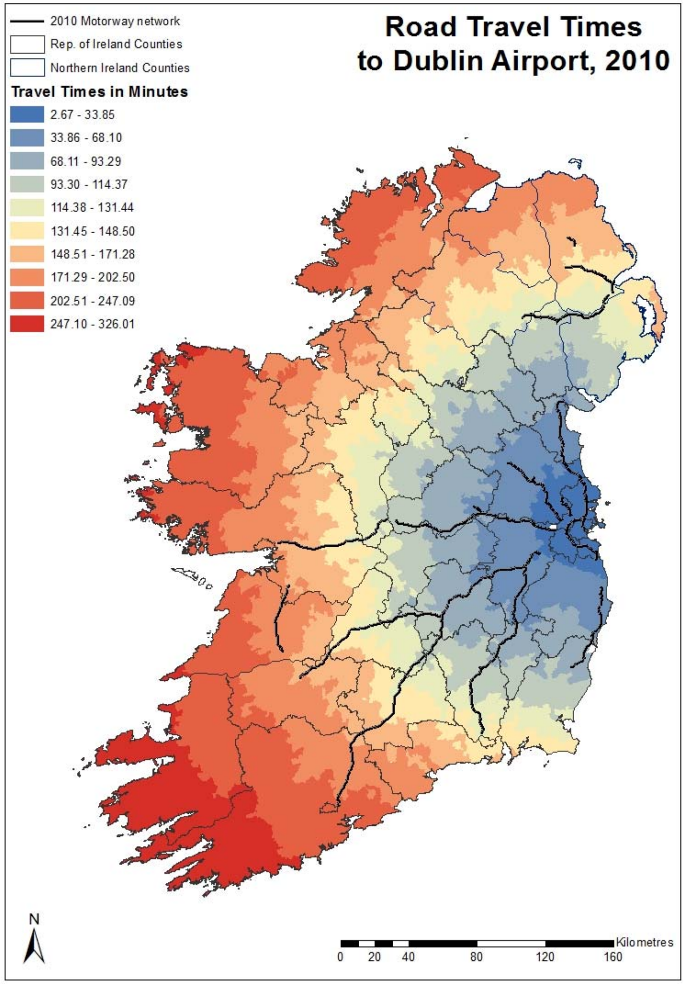


Figure 2: Travel times by road between each Electoral Division (ED) and Dublin Airport in 2010

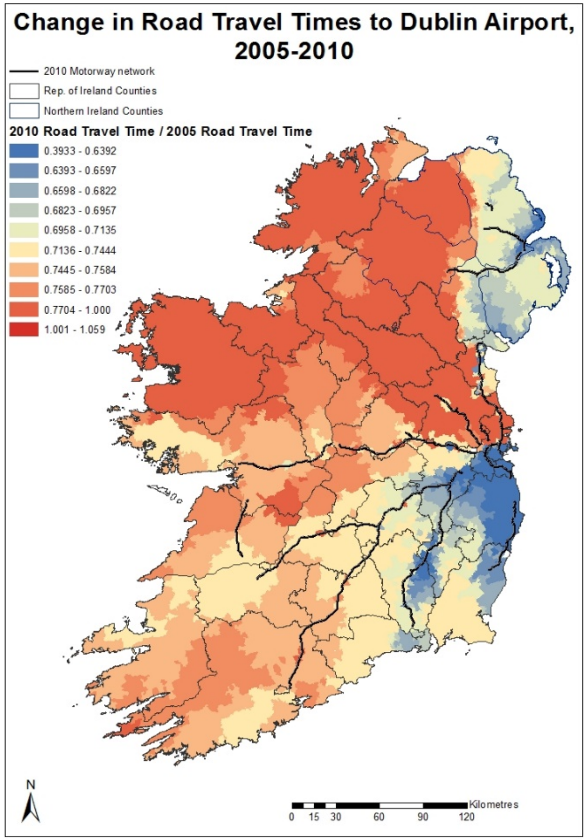


Figure 3: Change in Travel time (minutes) by road[23] between each Electoral Division and Dublin Airport, 2005-2010

[23] Measured as the ratio between the 2010 road travel time and the 2005 road travel time between each district and each of the airports under analysis. For example, if the 2010 road travel time from a given district to Dublin Airport (DUB) is 100 minutes and the 2005 road travel time is 80 minutes, the values represented in the map show a 25% increase in road travel time in the 2005-2010 period. Therefore, districts with values >1 experience an increase in road travel times and districts with values <1 experience a decrease in road travel times.

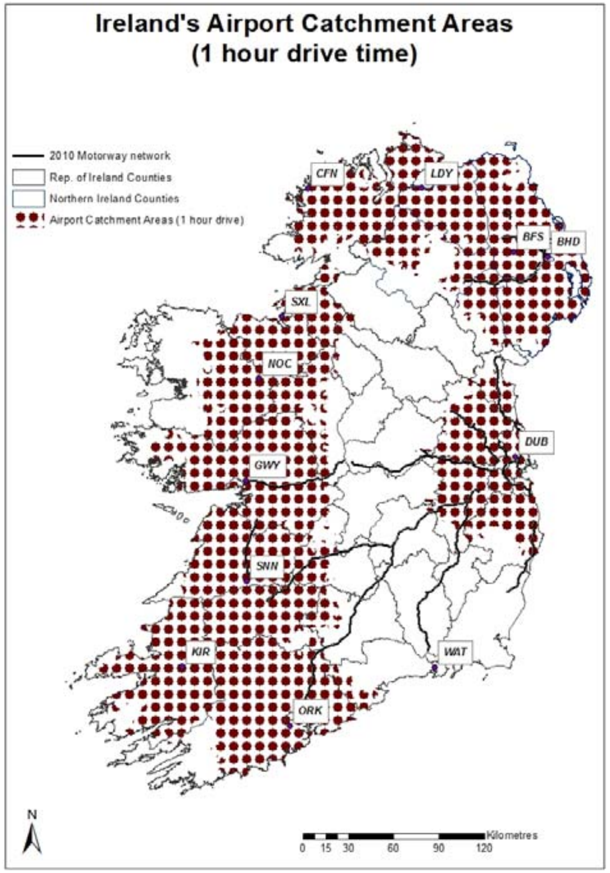


Figure 4: Irish airport catchment areas based on one-hour distance by road from each airport, 2010

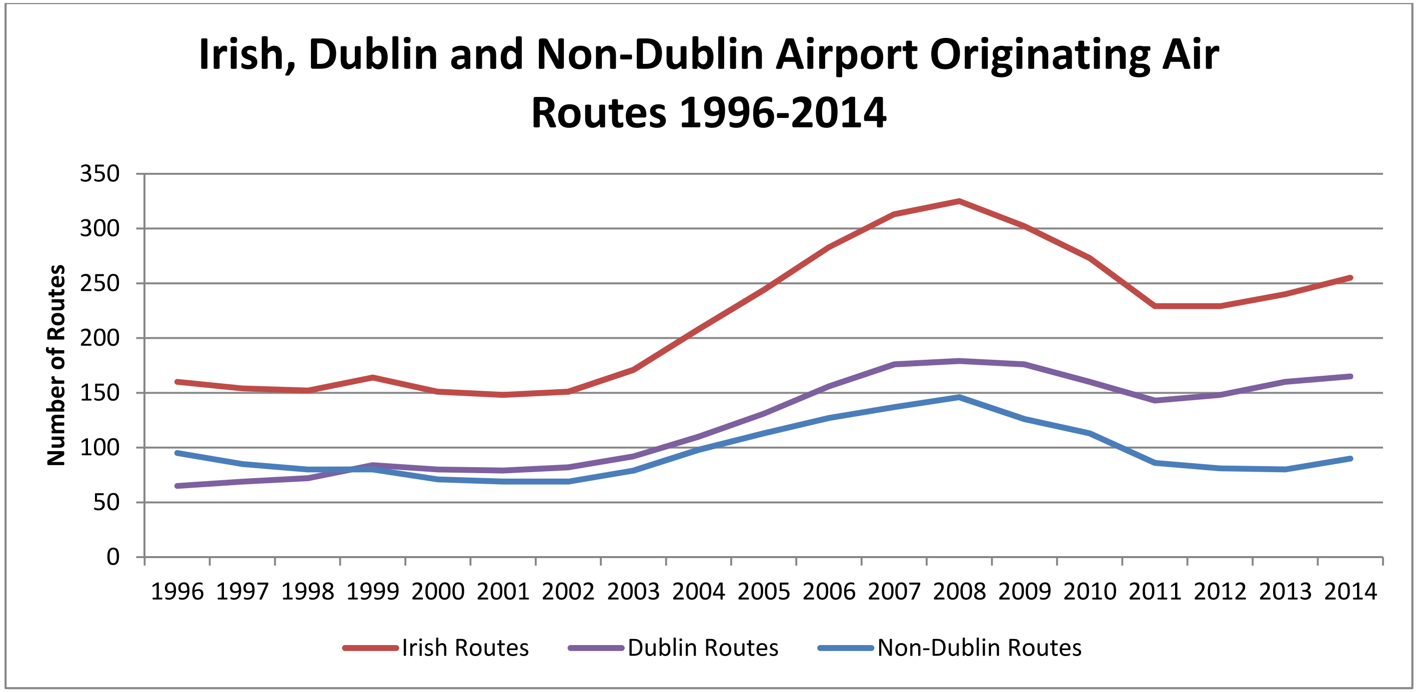


Figure 5: Irish air routes, Dublin and non-Dublin air routes, 1996-2014

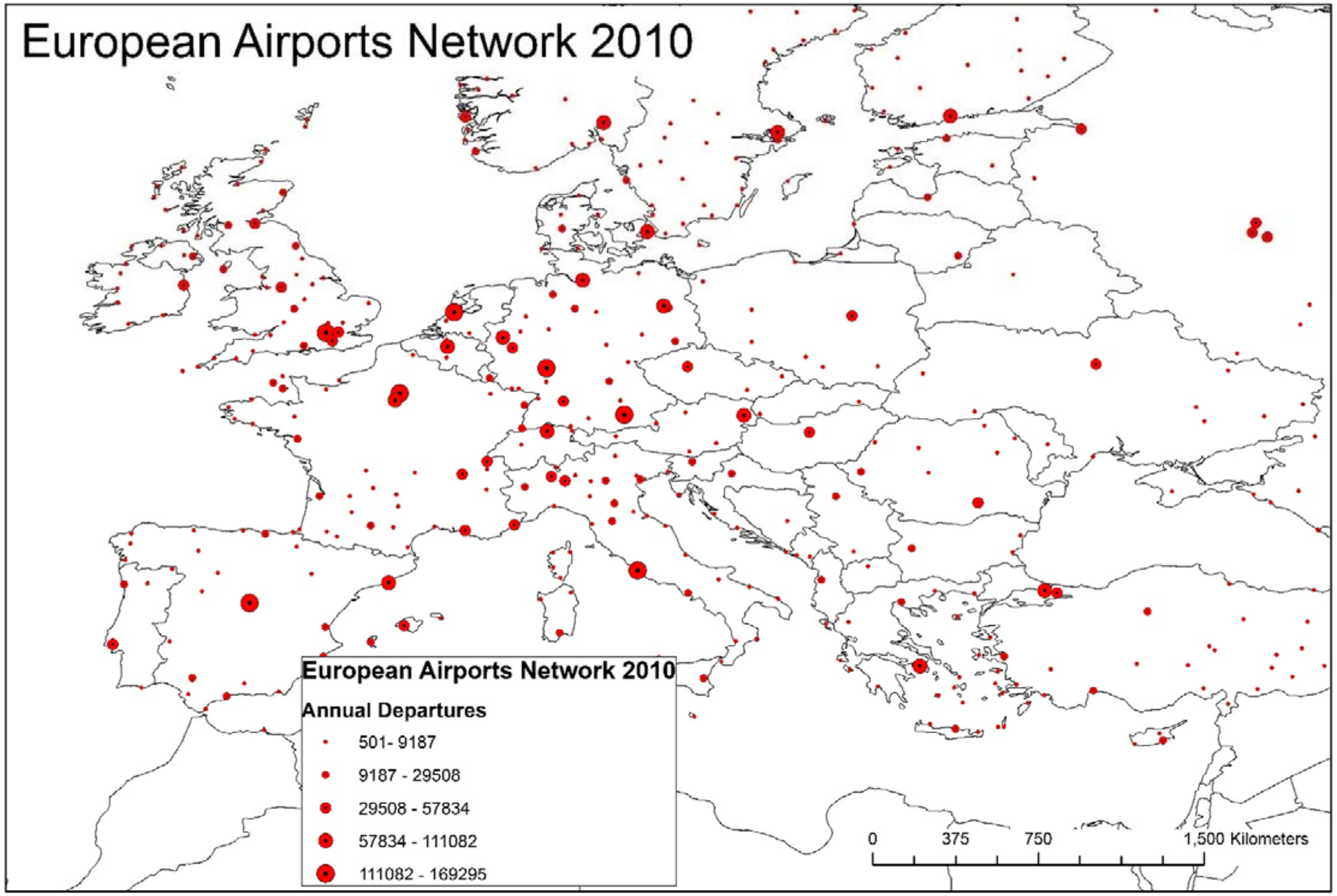
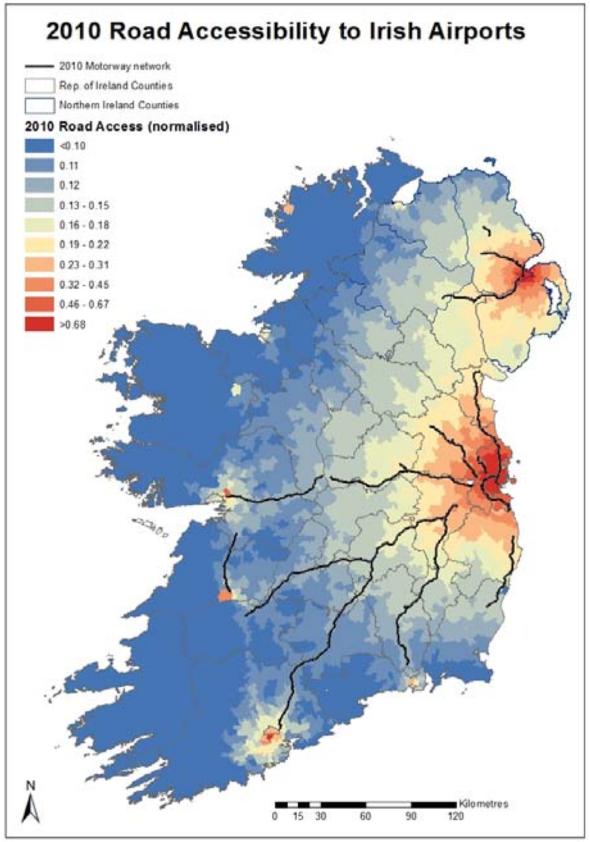

European Airports Network 2010
European Airports Network 2010
Annual Departures
501- 9187
9187 - 29508
29508 - 57834
57834 - 111082
111082 - 169295
0
375
750
1,500 Kilometers

Figure 6: European Airports Network 2010



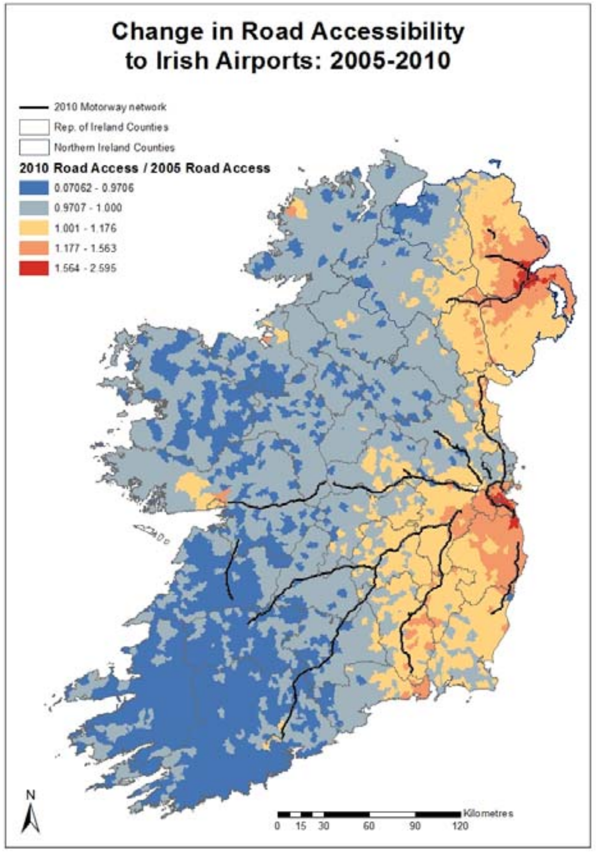


Figure 7: Road Network Accessibility to Irish Airports. Period: 2010

Figure 8: Change in Road Accessibility to Irish Airports[24]. Period: 2005-2010

[24] Measured as the ratio between the 2010 road access score (normalised) and the 2005 road access score (normalised) for each district. Districts with values >1 experience an increase in road accessibility to Irish airports and districts with values <1 experience a decrease in road accessibility to Irish airports.

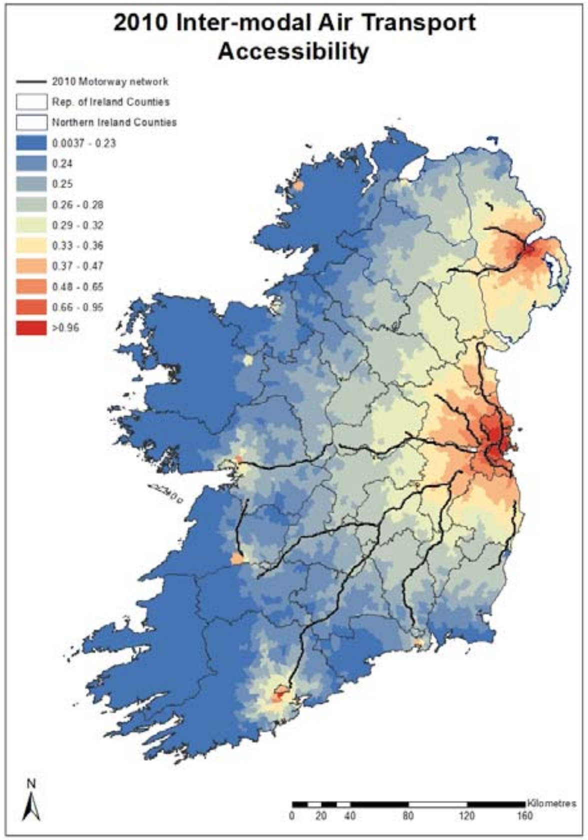


Figure 9: Inter-modal Air Transport Accessibility. Period: 2010

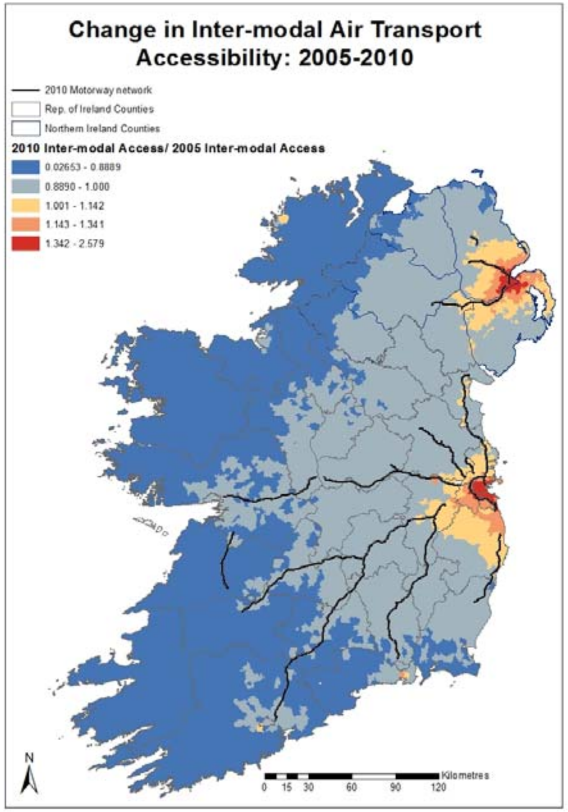


Figure 10: Change in Inter-modal Air Transport Accessibility[25]. Period: 2005-2010

[25] Measured as the ratio between the 2010 inter-modal air transport accessibility score (normalised) and the 2005 inter-modal air transport accessibility score (normalised) for each district. Districts with values >1 experience an increase in air transport accessibility and districts with values <1 experience a decrease in air transport accessibility.

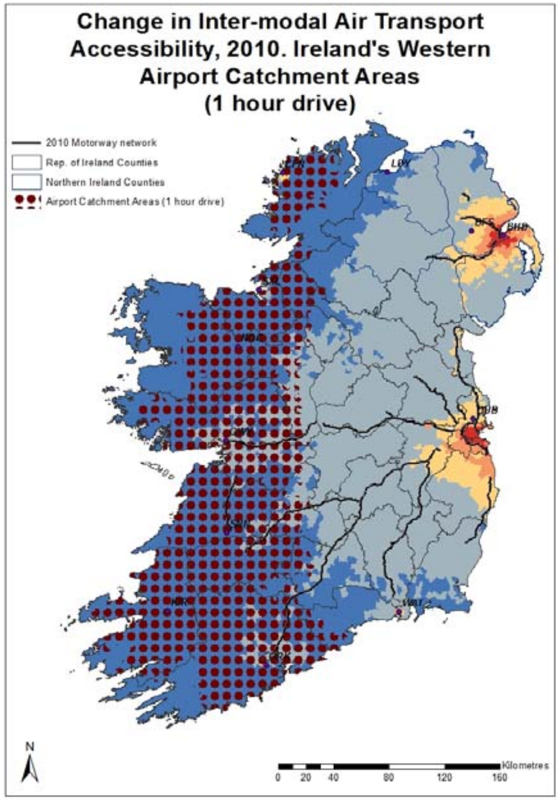


Figure 11: Change in Inter-modal Air Transport Accessibility. Period: 2005-2010. Irish airport catchment areas based on one-hour distance by road from each airport in 2010 (Western airports only)