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The impact of broadband and other infrastructure on the location of new business establishments

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Abstract

This paper analyses the impact of broadband infrastructure, along with a range of other local characteristics such as motorways and other infrastructure, availability of human capital and access to third level educational facilities, on the location of new business establishments. The sample period spans the introduction and recent history of broadband in Ireland, and during this period 86% of the current motorway network was constructed. Availability of broadband infrastructure is a significant determinant, but its effects may be mediated by the presence of sufficiently high human capital in the area. This indicates that ICT infrastructure is a necessary, but not sufficient factor in new firm formation.

Keywords: New business establishments; ICT; Infrastructure; Count panel regression model

JEL Classification: R3; R11; D22

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1 Introduction

A key determinant of the economic performance of regions is the rate of new enterprise formation. This is arguably a better indicator of a region's future development than current employment levels, since newly locating plants respond to current incentives, whereas current employment levels depend primarily on prior location decisions (Carlton, 1983).

Recent work has explored the diffusion of information and communications technology (ICT) infrastructure as a factor in explaining regional variation in a range of economic outcomes, including new firm formation and local growth (Mack and Grubesic, 2009; Kolko, 2012).

Other research has shown that the productivity effects of ICT can depend on complementary effects with other inputs, such as the availability of skilled labour, and how the ICT is actually used (David et al., 2003). ICT can displace less technically advanced workers while enabling higher skilled workers to be more productive. Thus ICT investment may be either a substitute or complement to labour, and correspondingly may have different productivity effects depending upon the skill mix prevalent in a given sector or area (Akerman et al., 2015; Hidalgo Perez et al., 2016), or whether firms can adapt their business practices appropriately (Colombo et al., 2013).

Given these relationships must also be observed internally by firms, one might expect entrepreneurs and firms to incorporate them in their location decisions. Areas with pre-existing high levels of human capital and knowledge intensive firms may be better equipped to reap the rewards of broadband roll-out than other areas less endowed with these attributes. Further, the uneven nature of broadband roll-out in time and space might result in sub-optimal deployment patterns. A number of studies have found this to be the case, and that the positive impact of broadband across a range of economic outcomes is more pronounced in urban areas and for knowledge-intensive firms (Gillet et al., 2006; Kandilov and Renkow, 2010). For urban areas the effect can depend on area size and industrial legacy (Mack and Rey, 2014). Firm size and industry type have also been found to affect the relationship between broadband and new business establishments (Mack and Grubesic, 2009).

We extend this work, by examining how the impact of broadband roll-out on the location of new firms depends on the existing skill-level in an area. The factors influencing the location of new business establishments are examined with a particular focus on the roll-out of basic broadband and it's interaction with human capital, measured as the level of educational attainment in each area. A unique panel-dataset of traditional digital subscriber line (DSL) and middle-mile fibre-broadband networks is created, allowing an examination of the relative impact of each on different types of firm.

Firm formation is affected by a range of other factors, such as clustering (Armington and Acs, 2002), agglomeration (Devereux et al., 2007; Alañón-Pardo and Arauzo-Carod, 2013) and specialisation (Feldman and

Audretsch, 1999). Transport infrastructure also matters (Button et al., 1995; Holl, 2004a,b; Percoco, 2015), and proximity to universities is particularly important for knowledge-intensive firms (Zucker et al., 1998; Audretsch et al., 2005). However, empirical research in this area has tended to focus on a subset of factors only, which increases the possibility of omitted variable bias. A recent exception is Audretsch et al. (2015) who examine the link between infrastructure and the startup activity of new firms at the county level across Germany over the period 2001-2005. Specifically the authors test for the relationship between new firm formation and the availability of broadband, motorway and rail infrastructure along with the presence of a university or research institution. Broadband was found to have a greater impact on startup activity than other forms of infrastructure, particularly in sectors such as software.

Our analysis builds on the analysis of Audretsch et al. (2015) and addresses the shortcomings of previous studies that focus on a limited range of factors that influence new firm formation by including a more comprehensive set of control variables. To this end the ICT data is supplemented with a broader set of infrastructure measures than has previously been examined in this literature. This includes proximity to motorways, universities and other third-level institutions, airports and rail stations. This information is combined with other important firm location determinants such as agglomeration economies, specialisation, human capital and data on the relative cost and quality of the labour force.

Another shortcoming in the existing literature is that the data available usually only covers a relatively short period, with a limited amount of space-time variation in the key variables. This makes identification of effects more difficult. The sample period for our dataset encompasses a period when Ireland's infrastructure was rapidly improved. For example the DSL roll-out data spans 0-100% penetration over our sample period, with substantial local variation. This is combined with GIS information on a national middle-mile fibre-optic network roll-out[1] including detailed information on the characteristics of these networks, and when they became operational. This allows an examination of the period in which broadband was introduced in Ireland, and compared with previous work is a significant improvement in broadband data quality.

Another feature of the sample period is that 86% of the current motorway network was constructed and average drive times to the nearest motorway junction almost halved. To capture a similar degree of space-time variation in the development of the motorway network in other developed countries would require data over a sample period of 40 years or more in many cases (see Figure 2). In addition, unlike much of the empirical literature, detailed spatial and temporal information on the drive-time to every motorway junction from the centroid of each location is used. Including the drive-time, rather than distance allows us to account for underlying road quality.

New firm formation in each area over time is modelled with negative-binomial (NB) panel estimators and a

[1] The Metropolitan Area Networks, or "MANs"

unit of analysis which helps to account for excess zeros and spatial dependence is used. These factors are also explicitly controlled for in robustness tests. It has been argued that focusing on new firm formation, rather than growth or other economic outcomes reduces problems of reverse causality between these measures and agglomeration economies or labour market factors (Artz et al., 2015; Jofre-Monseny et al., 2011). A range of specifications with lagged independent variables are estimated to further reduce reverse causality. An endogenous relationship may also exist between firm location choices and the placement of broadband infrastructure. To account for this, plausibly exogenous variation in MAN roll-out is exploited[2], and fixed effects for each MAN location are included to control for any time-invariant unobserved factors which might attract both firms and broadband. As the period in question was a turbulent one in Ireland's recent economic history, year fixed effects are also included to absorb any broader macroeconomic trends which might impact new firm formation.

Results show that both initial DSL and middle-mile fibre broadband have had a positive impact on firm formation, particularly in the high-tech sectors. Previous work has pointed to a skill complementarity between broadband adoption and skilled-labour. The results of this research indicate that pre-existing levels of human capital appear to be an important indicator of an area's ability to absorb new ICT technologies productively, in the form of new business establishments. The results also suggest a non-linear relationship in the effect of broadband along the distribution of educational attainment. The effect is greater for areas with greater education levels and may not be significantly different from zero below a threshold level of local educational attainment.

The rest of the paper is organised as follows; the following section describes the methodological approach and considerations undertaken; Section 2.3 the data; Section 3 outlines the empirical results; Section 4 outlines the robustness measures undertaken and Section 5 concludes.

2 Empirical approach and data

2.1 The model

The literature suggests that for both foreign and domestic new business establishments, the attractiveness of an area should be a function of agglomerative forces, factors relating to human capital, labour market pooling and relative labour costs. Infrastructure provision and market access should also play an important role. Demand based factors should matter more for domestic firms, as foreign firms locating in Ireland largely use it as an export platform.

Within the business establishment literature, two main methodologies are employed; choice models or count models[3]. We implement a count framework as we have a large proportion of zeros in our dependent variables and

[2]These networks were rolled-out to most towns and cities with a population of 1,500 or above. For details see http://www.dcenr.gov.ie/communications/en-ie/Broadband/Pages/Metroplian-Area-Networks.aspx

[3]Choice models are based on McFadden's random utility maximisation framework (McFadden et al., 1973). For recent examples

a relatively large choice set. New firm counts in a particular area in each time period are modelled as function of area characteristics, with year fixed-effects and sector-type effects included also, for sector-specific regressions.

Formally:

$$Y_{it} = f(X_{it}; X_{ijt}; R_{kt}; Z_i; \alpha_i; \gamma_t) \tag{1}$$

Where:

$$Y_{ijt} = 0, 1, 2, ... \tag{2}$$

Y_{ijt} denotes the count of new firms of type j in area i at time t. X_{it} is a matrix of explanatory variables that vary by area i and time t. X_{ijt} is a matrix of explanatory variables that vary by by area i, time t and firm-type j. R_{kt} is a matrix of explanatory variables that vary at a more aggregated regional level k and time t. Z_i is a matrix of time-invariant explanatory variables, α_i are area fixed effects, which are included in some specifications. γ_t are time-dummies.

2.1.1 Econometric considerations

The econometrics literature encourages the use of fixed-effects models in panel-data estimations. This allows for a limited form of time-invariant endogeneity, α_i, which can be eliminated by differencing transformations, enabling consistent estimation of the coefficient of interest, β, for the time-varying regressors.

In this case, a number of the explanatory variables, particularly those relating to the accessibility of the locations are time-invariant. Further, high-proportions of areas never receive any firms. This makes the differencing transformation problematic as these areas and variables drop out of the estimations. To account for this, area fixed effects are included as dummy variables, along with year fixed effects in a range of random effects and population-averaged specifications. We also report results from a first-differenced fixed effects model as a robustness check in the supplementary material. This is not our primary specification as using this model significantly reduces our sample size due to reasons discussed. Results from a range of random effects models are also reported as a robustness check[4].

Related to the issue of over-dispersion is the excess zero problem. This arises when there are a large number of areas with zero counts for firms, or zero counts for firms of a specific type. Zero-inflated and hurdle-count models are widely used to accommodate this problem. Both of these models are finite mixture models with two components, the zero-truncated probability mass function and the untruncated probability mass-function (Cameron and Trivedi, 2013).

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see Pusterla and Resmini (2007); Siedschlag et al. (2013); Barrios (2006). For count models see Jofre-Monseny et al. (2011); Bhat et al. (2014). Research comparing the relative merits of each approach includes Guimaraes et al. (2003) and Schmidheiny and Brulhart (2011).

[4]The supplementary appendices provide results from a range of alternate model specifications.

Our choice of unit helps to ameliorate this issue (discussed in more detail in Section 2.4 and the supplementary material). We include only those locations which are at or above the 75th percentile of employment density in Ireland. A plausible argument can be made that all of these areas are legitimate potential locations for new businesses, negating the need to explicitly model the zeros as a separate process. As a robustness check we also report results from zero-inflated Poisson and zero-inflated Negative-binomial estimators and the results hold.

Another potential issue is spatial dependence. When modelling firm counts at a disaggregate spatial level, spatial dependence could exist in the dependent variable, independent variables, or through unobserved factors that affect the residuals. This has been widely observed in the literature on business location choices (Guimaraes et al., 2004; Alama-Sabater et al., 2010).

Practical difficulties exist in modelling spatial dependence in a non-linear panel setting. Much of the currently available toolboxes[5] deal with spatial dependence in an OLS panel setting, although recent work by Bhat et al. (2014) has developed a spatial multivariate count model in a panel setting, implemented in Gauss.

We mitigate this problem by choosing a specific unit of observation that significantly reduces the potential for spatial spill-overs (described in detail in Section 2.4 and the supplementary material). As a further robustness check models with spatially lagged explanatory variables are also used.

As robustness checks we also estimate a range of spatial models. As recommended by Halleck Vega and Elhorst (2015) we start with the spatial lag of X (SLX) model. Following this we also estimate a spatial autoregressive model (SAR) and a spatial Durbin model (SDM) model. Discussion of the lagged variables and weights matrix W is in Section 4.2

Formally the SLX model we estimate can be described by:

$$Y_{it} = \alpha_i + \rho W.Y_{it} + X_{it}\beta + \gamma_t + \epsilon_{it} \tag{3}$$

The SAR model by:

$$Y_{it} = \alpha_i + X_{it}\beta + W.X_{it}\lambda + \gamma_t + \epsilon_{it} \tag{4}$$

The SDM by:

$$Y_{it} = \alpha_i + \rho W.Y_{it} + X_{it}\beta + W.X_{it}\lambda + \gamma + \epsilon_{it} \tag{5}$$

[5]Such as those in Matlab provided by Elhorst (2012) and LeSage.

2.2 Identification

The potential endogenous relationship between the placement of broadband infrastructure and economic activity has been highlighted by a number of other authors (Van Gaasbeck, 2008; Mack et al., 2011; Kolko, 2012; Mack and Rey, 2014). This may arise from reverse causality between broadband availability and economic activity, such as new business counts, employment, payroll and house rents, or omitted variable bias due to unobserved heterogeneity in the locations.

The economics of DSL broadband roll-out, like most other networks is largely driven by population density. Reverse-causality is more likely to link DSL to employment levels in existing firms, not new firm formation. By restricting the analysis to new firms in each year, and by controlling for the pre-existing employment levels in each area at every time period, this problem is mitigated.

The locations of the MANs was decided based on applications made by the relevant local authorities. An area fixed-effect is used to control for unobserved area characteristics in these locations that might be related to new firm counts, and a time-varying dummy identifies the effect beginning with the period the network was enabled.

Local labour markets are represented by the proportion of people with a third level qualification, the unemployment rate and relative employment compensation. An influx of new firms may affect all of these measures. To account for this, we run a robustness check keeping these variables unchanged at their 2002 levels and the results hold.

To further ensure robustness, all explanatory variables are lagged by one period in all estimations, and further robustness checks are undertaken using variables lagged by two periods.

The period examined in the analysis is 2002-2011. This is selected as there were significant infrastructural investments in Ireland during this time and variation over time and across locations can be exploited to evaluate the impact of these changes.

2.3 Data overview

An overview of the assembled data-set and it's sources is provided in Table 1. Descriptive statistics on all variables used can be found in the appendices.

Table 1: Variables and their sources

Variable Type	**Variable**	**Spatial Level**	**Frequency**	**Source**
Firm	Firm location, sector, size, entry year	Urban Field	annual	Department of Jobs Enterprise and Innovation (DJEI)
Broadband	Local access: Eircom DSL enabled exchange	geocoordinates	annual	Eircom/Eir
	Middle mile: MAN data	geocoordinates	annual	enet
	Backhaul competition: BT backhaul	geocoordinates	annual	BT
Agglomeration	Localisation (sector share of tot employment)	Urban Field	annual	DJEI
	Specialisation(spatial HH index).	Urban Field	annual	DJEI
	Firms of own nationality	Urban Field	annual	DJEI
Accessibility (distance to:)	Motorway network	Urban Field	annual	Author's calculations using Microsoft MapPoint
	Rail Stations	Urban Field	2007	as above
	Airports	Urban Field	2007	as above
Human Capital	Distance to University/IT	Urban Field	2007	as above
	Proportion with third level qualification	Urban Field	2001, 2006, 2011	CSO Population Census
Demographic	Population in persons	Urban Field	2001, 2006, 2011	CSO Population Census
	Population density	Urban Field	2001, 2006, 2011	CSO Population Census
Labour market	Relative labour cost	County	annual	CSO Regional Accounts
	Unemployment rate	Urban Field	2001, 2006, 2011	CSO Population Census

Table 2: Firms: Most frequent NACE 4 digit categories by sector

Sector Type	Sector	Domestic firms	Foreign firms
High-tech	Computer consultancy activities	419	23
	Other information technology and computer service activities	105	39
	Other software publishing	59	0
	Computer programming activities	56	28
	Business and other management consultancy activities	55	0
	Artistic creation	44	0
	Engineering activities and related technical consultancy	44	0
	Data processing, hosting and related activities	42	4
	Manufacture of irradiation, electromedical and electrotherapeutic equipment	35	0
	Other education n.e.c.	32	0
	Computer facilities management activities	0	31
	Manufacture of pharmaceutical preparations	0	14
	Manufacture of electronic components	0	5
	Other Manufacture	0	5
	Manufacture of computers and peripheral equipment	0	4
Total high-tech		1563	171
Low-tech	Other personal service activities n.e.c.	87	0
	Manufacture of other food products n.e.c.	51	0
	Processing and preserving of meat	40	0
	Manufacture of other fabricated metal products n.e.c.	32	0
	Manufacture of metal structures and parts of structures	27	0
	Manufacture of medical and dental instruments and supplies	24	19
	Other specialised construction activities n.e.c.	24	0
	Manufacture of other furniture	21	0
	Recovery of sorted materials	21	0
	Manufacture of other plastic products	20	4
	Manufacture of metal structures, tools and metal treatment	0	6
	Other Manufacture	0	5
Total Low-tech		1141	42
Financial	Other financial service activities, except insurance and pension funding n.e.c.	7	0
	Insurance, pension funding and leasing companies	7	0
	Trusts, funds and similar financial entities	5	0
	Other credit granting	5	0
	Non-life insurance	4	0
	Other activities auxiliary to financial services, except insurance and pension funding	3	0
	Fund management activities	0	8
	Insurance and other financial services	0	7
Total Financial		33	19

Notes: Fields containing less than 3 firms merged to preserve anonymity

2.4 Unit of analysis: "Urban Fields"

New units of analysis which we refer to as "Urban Fields" are created for the analysis. These areas are either single Electoral Divisions (EDs) or are aggregations of contiguous EDs which are at or above the 75th percentile of employment density, based on the 2011 Census Place of Work School or College (POWSCAR) and merged using GIS software[6]. Any EDs which do not fall into this category are not considered for the analysis. This selection covers 97 percent of all new foreign firms and 75 percent of all new domestic firms in the sample period. Constructing this unit of observation helps to reduce spatial dependence and the excess-zero problem. The analysis does not include the Dublin City region, as this area is a uniquely attractive location for new firms in Ireland.

Table 3: Irish Census geographical areas

Geographical Areas	No of geographic units
Legal Towns and Cities	85
Towns/Cities (Settlements)	824

In total we create 192 Urban Fields. This contains the entire set of "Legal Towns and Cities", and 316 of the set of 824 "Towns/Cities (Settlements)". These are a heterogenous group and contain both urban and rural areas, indeed 42 percent of the geographical areas within our sample are considered rural by the Central Statistics Office in Ireland. This is defined as any area with a population of less than 1500 inhabitants. Of those rural areas included in our analysis, more than 50 percent have a total population of less than 800 people. The areas we omit could be described as countryside.

Comparing firm counts in the EDs located within Urban Fields to those outside in Table 4, average firm counts per ED and year differ by one order of magnitude between Urban Field and non Urban Field.

Table 4: Average firm counts per ED and year

	FDI	Domestic	High-tech	Low-tech
Urban Fields	0.050	0.344	0.276	0.097
Non-Urban Fields	0.001	0.038	0.017	0.021

2.5 Firm location variables

Dependent variables come from the Department of Jobs, Enterprise and Innovation (DJEI) Annual Employment Survey. This is an annual census of employment in all manufacturing and internationally-traded services companies in Ireland. This survey has been administered since 1972 by the agency formally known as Forfás,

[6] Detail on the relevant EDs and corresponding Urban Fields are available on request. There are approximately 3400 EDs in Ireland.

now subsumed within DJEI. This dataset contains firm-level annual data on employment, NACE 4 digit sector, location (geocoordinates), entry/exit, and whether a firm is majority foreign or domestic owned. Details of all new entrants by sector is displayed in Table 2. This survey under-represents the services sector (Lawless, 2012), but contains almost the full population of foreign firms and manufacturing firms (Barrios, 2006).

This dataset allows us to track the entry of all new firms over our sample period. Entry is recorded as the first time a firm records positive employment numbers in the dataset. The majority of new foreign entrants in our sample are high-tech knowledge intensive services providers. Domestic firms again are predominantly involved in services but there is a greater balance of firms across other sectors within the economy. For a detailed breakdown see the supplementary appendices.

2.6 Infrastructure

This subsection discusses the explanatory variables, which we divide into categories. Further detail is provided in the supplementary material.

2.6.1 Broadband

To deliver broadband services to businesses and homes, network operators need to put suitable infrastructure in place. Because we do not directly observe the set of network elements used by each firm to obtain broadband access, we have constructed three proxies for the availability of infrastructure that aim to capture the main local sources of variation in the quality and cost of broadband available across Ireland.

The consumer's premises is connected to an **"access network"**, sometimes referred to as the **"last mile"**. This connection may be provided using various different technologies, e.g. fibre optic cable, copper wire, or fixed wireless connection. DSL technology uses traditional telephone lines to deliver broadband services and during our sample period it was by far the main technology used to deliver local broadband access[7]. 75% of Irish enterprises with 10 or more employees reported having access to DSL services in 2012, 30% had access to other forms of fixed wired connections (some had both) (CSO, 2013). Larger firms in particular were more likely to have other types of fixed connections, probably reflecting a need for higher download speeds than those supported by DSL. Many firms also had some form of mobile broadband access, e.g. via smartphones. Cable broadband plays only a minor role in serving Irish businesses. According to a 2013 survey commissioned by the national regulatory authority, ComReg, 7 % of SMEs in urban areas and 3% in rural areas reported that their main fixed broadband provider was UPC, the only provider in the market offering cable broadband (RedC, 2013).

[7]The dataset is an updated version of the one employed by Haller and Lyons (2015) to look at broadband adoption and firm productivity in Ireland.

Data traffic from local access connections is concentrated at nodes which in some areas are situated on a **"middle mile"** network such as a local fibre optic ring around a town. Larger firms, or those wishing to have higher access speeds, may connect directly to these middle mile networks and obtain higher speed service at lower cost than was formerly available using leased line services. Finally, longer distance **"backhaul"** connections are required to bring regional traffic flows together, linking all areas to the internet. Backhaul services are available across Ireland, but some places have more competition in the supply of backhaul than others. Competitive supply should reduce the cost of internet access to firms, ceteris paribus.

Ultimately it is an empirical question which, if any, of these levels of network infrastructure affect different sorts of firms choices about where to locate. Below we describe how each proxy is constructed

2.6.1.1 Local access. Developing a meaningful and accurate representation of broadband availability at a local level can be difficult. Much of the prior research into how broadband affects economic activity has been based in the US, and as outlined by Flamm in Chapter 10 of Taylor and Schejter (2013), many errors and inconsistencies arise when using Federal Communications Commission (FCC) zip-code level data to measure broadband. The proxies available to us have some advantages over the US metrics.

In this paper, the proxy for the availability of local broadband access services in an area is based on data provided by Ireland's former incumbent telecoms operator, Eircom. This panel dataset captures the availability over time of DSL services in 1,060 local telecoms exchange areas. We have data on the proportion of enabled exchanges in each area for each time period and we use this to create dummy variables which identify the period from which DSL was enabled in an area[8].

Between 2001 and 2010, Eircom rolled out basic broadband services to local exchanges across the country. Enabling went from 0-100% for most parts of the country over our sample period with significant geographic variation[9]. This proxy is probably more appropriate for SMEs than for larger enterprises; the largest firms would likely have used leased line infrastructure which could have been provided anywhere - at a price. However, roll-out of DSL access is still a reasonable proxy for the availability of cost-effective broadband service for most of the firms in our sample.

2.6.1.2 Middle mile infrastructure. In 2004 the Irish Government funded an initiative to roll-out wholesale, open-access fibre optic infrastructure, known as the Metropolitan Area Networks (MANs) scheme. The MANs are town-level fibre rings, which provide a high bandwidth network to authorised operators, in turn allowing them to sell high capacity broadband services to end-users. The network was rolled out in two phases: phase 1 covered 28 locations and began in 2004, phase 2 covered an additional 66 locations and began in 2009

[8]Proportions were used in initial estimations but dummy variables proved to have greater explanatory power in this case.
[9]This is illustrated graphically in the supplementary material

(some of these are illustrated in Fig. 1). The scheme focused on areas outside the Dublin city region, which has greater access to broadband infrastructure due to its high population density and concentration of business activity. As the MANs are a middle-mile infrastructure, users require local access to the nearest MAN and also local backhaul infrastructure to connect to the global network. Our proxy variable "MAN effect dummy" is set equal to 1 if a MAN was in operation in the Urban Field during a given year, and 0 otherwise. We also include a "MAN area fixed-effect" variable to capture any omitted characteristics of these areas that might also be correlated with new firm formation

2.6.1.3 Backhaul proxy. There is no comprehensive public source of mapping data on the development of Ireland's backhaul networks over time. Eircom offers backhaul services across much of the country, but as a proxy for the availability of backhaul competition in an area we use data provided by BT Ireland. BT leases a national duct network from CIE (Irish National Rail Network) in which fibre is laid along the railway lines with transmission access points at towns located along the routes. In addition to this, CIE have metropolitan access fibre networks laid along the roads of the major cities and some of the smaller towns. We have the geo-coordinates of each node in this network, and the installation date of each wholesale On-Net circuit, allowing us to map it spatially and temporally. Here too, we use a dummy variable - "MAN increased backhaul" for the availability of BT's backhaul network in a given Urban Field.

2.6.2 Motorways and other infrastructure

The drive times to motorway junctions, airports, railway stations, universities and institutes of technology (IT) were calculated using Microsoft MapPoint in conjunction with the MP MileCharter utility, which can compute travel times and distance between multiple points. Specifically, the shortest travel times are calculated between the centroid of each electoral district (ED) in Ireland and the respective infrastructure. These are then averaged to calculate the drive time from the centroid of each Urban Field. The travel times relate to drive time by car and the route optimisation takes into account the quality of the underlying road infrastructure by allowing the average speeds for different types of roads to differ. For example the average speed in urban streets is assumed to be 32 km/h while that on motorways is assumed to be 104 km/h. The inverse drive-times are then calculated to characterise proximity.

Transport infrastructure, and in particular the motorway network underwent significant extensions in Ireland over our sample period, with 86.1% of the current Irish network constructed during this timeframe. In order to capture these changes we include panel data on the driving time from the centroid of each Urban Field to the nearest motorway junction. Fig. 2 highlights the expansion over our sample period, and contrasts this with some international examples.

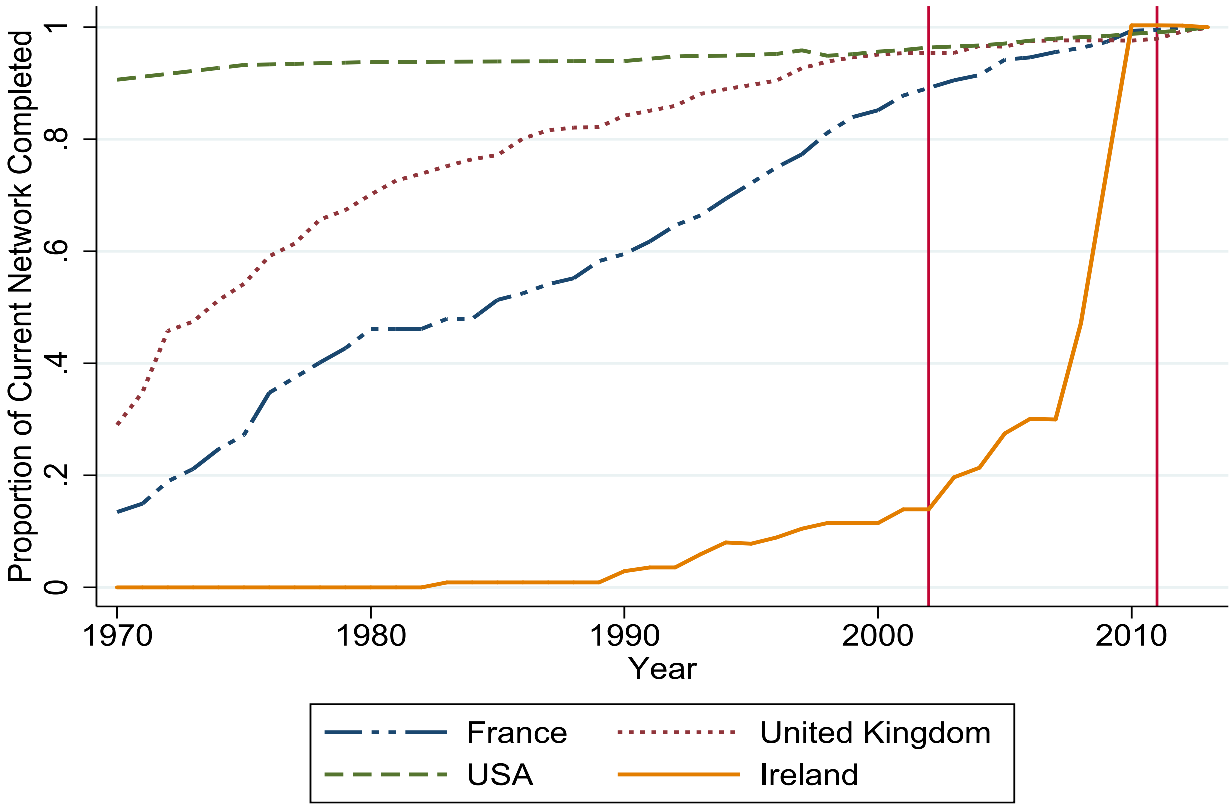

Figure 1: International comparison of motorway extension, 1970-2013. Sources: The data for the USA is from the Bureau of Transportation, for the UK from the Office of National Statistics, for France from EUROSTAT and for Ireland from the National Roads Authority (now Transport Infrastructure Ireland). Note: Vertical lines indicate sample period.

Equally important for our analysis is where the expansion occurred. Fig. 3 geographically illustrates the change in driving times between 2002 and 2011 in Ireland. During this period the network was extended to link most major urban centres, with the exception of the south-west and north-west, to the capital city, Dublin.

Other accessibility measures include the driving time in minutes from the centroid of each Urban Field to the nearest airport, train station, port, university and IT. This data is only available for 2007. However relatively little change occurred in these measures over time.

2.7 Agglomeration and human capital

Using the DJEI Annual Employment Survey we calculate a number of alternate agglomeration measures. These include economies of specialisation and diversification, along with a range of measures that reflect employment size and density by sector, skill-level and location of owner.

The sector share of total employment in each Urban Field in each year is defined as:

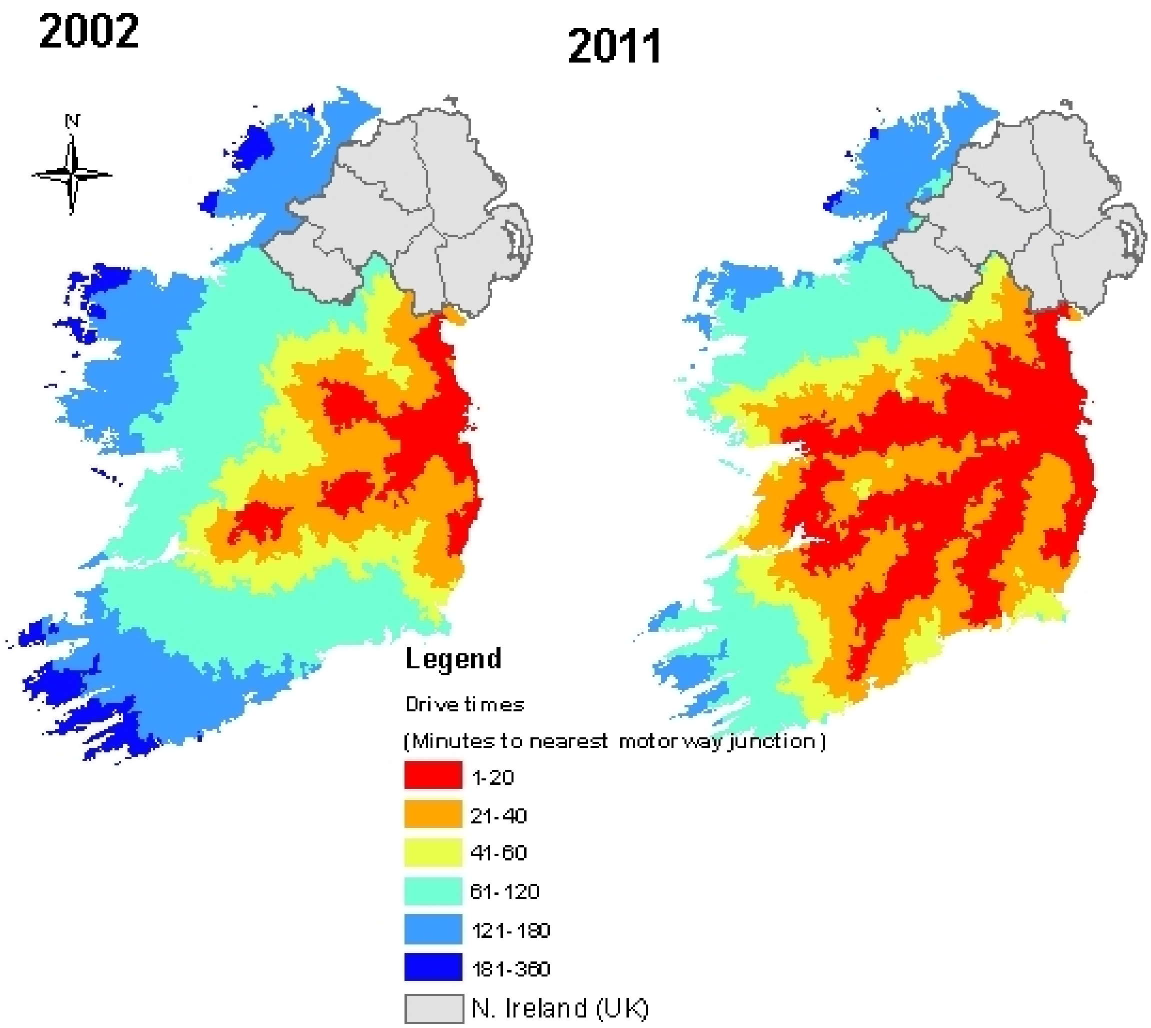

Figure 2: Location of motorway extensions, Ireland 2002-2011

$$s_{ij}(t) = \frac{E_{ij}(t)}{\sum_{i=1}^{I} E_{ij}(t)} \tag{6}$$

Where $E_{ij}(t)$ is employment in sector i in Urban Field j at time t, where $i = 1, 2, ..., I$, $j = 1, 2, ..., J$ and $t = 1, 2, ..., T$. and $\sum_{i=1}^{I} E_{ij}(t)$ is total employment across all sectors in Urban Field j at time t.

The measure of specialisation is calculated as the sum of square of each sectoral employment share in each Urban Field (the spatial Herfindahl-Hirschman index)[10].

$$u_{ij}(t) = \sum_{i=1}^{I} (l_{ij}(t))^2 \tag{7}$$

The proportion of the population with a third-level degree and the unemployment rate come from the CSO

[10]Sectors are based on a Eurostat aggregation of NACE 2 digit codes. For details see http://epp.eurostat.ec.europa.eu.

Population Census. Data from the 2002, 2006 and 2011 Censuses are used in creating these variables.

To proxy for the relative wage costs employers face, Compensation of Employees data from the CSO County Incomes and Regional Accounts is included. These are available on an annual basis at county level.

2.8 Demand-side variables

Many of the previously mentioned measures represent supply-side factors. Although, relative labour costs, unemployment, human capital and total employment in each Urban Field will also capture local demand. To further characterise access to local markets a variable called "centrality" is calculated which captures the proximity of each Urban Field to population centres in Ireland.

$$c_i(t) = \sum_{j=1}^{J} \frac{P_j(t)}{D_{ij}} \tag{8}$$

$c_i(t)$ is the centrality of Urban Field i at time t, , where $i = 1, 2, ..., I$, and $t = 1, 2, ..., T$. $P_j(t)$ is the population of each Electoral Division (ED) i at time t, $j = 1, 2, ..., J$. D_{ij} is the drive time in minutes from each Urban Field i to each ED j.

3 Econometric results

In this section we report our empirical results. Time trends are captured using year dummies in all models. The coefficients on these terms are significant and negative from 2006 onwards, consistent with the economic downturn experienced in Ireland during this time. In total we examine 190 Urban Fields in a balanced panel of 10 time periods.

For all estimations, significant average marginal effects (AME) are reported. The AME is the average of the marginal effects taken at each $x = x_i$[11]. In all cases, the unit change in y for an associated change in x is presented: as broadband variables are binary, the effect on y of a discrete change in the base level of x is examined; as all other variables are continuous, the effect on y of a percentage change in x is examined. Given this, the magnitude of the effect size for all variables are comparable to each other and reveal which factors have most influence on new business establishments. Results are reported for all variables, but particular emphasis is placed on the broadband results, given the focus of this research and greater confidence regarding the robustness of these effects.

[11] The value of marginal effect will depend on the point at which they are evaluated. For non-linear models the AME is generally larger than the marginal effect at the average (MEM) and in practice can be similar to the coefficients estimated with OLS models. For policy analysis the AME or marginal effect at representative values (MER) are recommended over the MEM. See Cameron and Trivedi (2013) for further details.

3.1 New business establishments by location of owner

The first section focuses on a split between foreign and domestic-owned firms. Considering the broadband variables first, it appears that the availability of first-generation, last-mile DSL infrastructure in an area was a statistically significant determinant of new domestic firms, but not foreign (columns (1) and (2) respectively of Table 5), resulting in 0.588 more firms in an area. The MAN area dummy is not significant in any estimation. The MAN effect dummy is positive and significant for foreign firms but not domestic. On average having a MAN operational in an area is associated with 0.103 more new foreign firms.

Accessibility is represented in the model by the inverse drive-time to the nearest motorway junction, airport and train station. For foreign firms, all of these measures have a positive sign, indicating that firms value proximity. The relative magnitudes suggest an implicit ranking. Access to airports is valued above access to motorway junctions which in turn is valued above access to train stations. Accessibility results were not statistically significant for domestic firms.

In terms of magnitude, halving the driving time from an area to the nearest motorway junction is associated with 0.037 new foreign firms, compared to 0.103 new foreign firms associated with having a fibre broadband network made operational in an area.

Considering the agglomeration variables next, it appears firms value diversity of skills in a location above specialisation. This result applies to both foreign and domestic firms and holds throughout various sample splits employed in subsequent sections. This is consistent with previous research examining firm location choices in Ireland (Barrios, 2006). Areas with pre-existing high proportions of foreign(domestic) employment are associated with increased foreign(domestic) firm birth rates. Employment density is positive and significant for domestic firms but not foreign. The pre-existing total employment in each area is included as a scale variable and is an important determinant of new foreign and domestic firms.

Both inverse drive-time to the nearest third-level institute and the proportion of the population with third-level qualifications are significant factors in new foreign and domestic firm formation. This holds throughout our analysis and is one of the key messages of this research. Also, the magnitude of the effect on third level distance is considerably larger than any of the other accessibility measures reported. A doubling (or 100% increase) in educational attainment is associated with 0.479 more foreign and 0.621 more domestic firms. Human capital is key for both entrepreneurship and the spatial distribution of FDI. Section 3.6 will further explore the interaction of this effect with ICT provision.

Relative labour costs do not have significant effects on either foreign or domestic firms. Interestingly, for new foreign establishments there is a positive and significant coefficient on the variable representing the proportion of the labour force who are unemployed. Further estimation reveals that this effect only exists when human capital is controlled for, indicating that firms may be locating where there is an excess supply of skilled labour. Higher unemployment rates may also put downward pressure on wages. This result is consistent with Coughlin et al. (1991). However, significance is weak and any inference must be tempered with caution.

Finally, centrality or access to domestic markets in not significant in any of our estimations.

3.2 New business establishments by skill-level

Foreign and domestic firms are now pooled and then split by the skill-level of their employees (columns (3) and (4) respectively of Table 5). This is to examine if patterns emerge at this level that are common to both.

The initial roll-out of DSL has impacted both high-tech and low-tech firms, although the magnitude of this effect is much greater for high-tech firms. Another MAN category is now created, which allows examination of the impact of increased competition in the backhaul market using data provided by BT. The positive impact of the MANs appears confined to the high-tech sector. There is a slight premium in areas where MANs have access to greater competition in the local backhaul market above those without.

Motorway access is important for low-tech firms. The agglomeration results again underline the importance of skills diversity as opposed to specialisation in attracting new firms of all types.

Both human capital measures emerge again as significant determinants of both new high-tech and low-tech business establishments. The effect is much larger for high-tech firms.

3.3 New business establishments by skill-level and location of owner

Further sample splits are undertaken to compare firms by skill-level and location of their owner (columns (4-8) of Table 5).

Initial DSL roll-out is again important for all firm types with the exception of low-tech foreign firms, but much more so for those in the high-tech sector. The impact of middle-mile fibre is again concentrated in the high-tech sectors, and there is a premium where increased competition in backhaul exists.

Motorway access emerges as significant for high-tech foreign and low-tech domestic firms. High-tech foreign firms also value proximity to airports, the effect size is more than double that of motorways. Low-tech foreign firms appear to value proximity to train stations. This variable may also be picking up the fact that most large towns have train stations and foreign firms almost exclusively locate in large urban areas.

Human capital once again emerges as an extremely powerful determinant of location for all firms. This effect is particularly strong for high-tech firms.

High-tech foreign firms appear to be drawn to areas with higher relative wages. The unemployment rate is again significant. The simple correlation of unemployment and new firm births is negligible,[12] and only present

[12] If anything this effect is negative. Correlation with high-tech FDI is -0.02 and high-tech domestic -0.06.

once labour cost and quality are controlled for, indicating if anything an excess labour supply effect.

Table 5: Count of new establishments at Urban Field level 2002-2011, by location of ownership and skill-level

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		All Firms		All Firms		High-tech Firms		Low-tech Firms	
Variable Type	Variable	Foreign	Domestic	High-tech	Low-tech	Foreign	Domestic	Foreign	Domestic
Broadband	1.DSL	0.043	0.588***	0.531***	0.142***	0.063***	0.455***	0.009	0.143***
		(0.035)	(0.181)	(0.103)	(0.054)	(0.020)	(0.078)	(0.007)	(0.051)
	1.MAN effect dummy	0.103**	0.297	0.422**	-0.092	0.177**	0.309*	0.003	-0.095
		(0.043)	(0.200)	(0.192)	(0.067)	(0.088)	(0.164)	(0.013)	(0.061)
	1.MAN increased backhaul	-	-	0.683***	0.041	0.144**	0.537***	0.017	0.014
		-	-	(0.237)	(0.095)	(0.072)	(0.204)	(0.017)	(0.090)
Accessibility	Motorway	0.037*	0.017	0.055	0.070**	0.043**	0.021	0.001	0.069**
		(0.020)	(0.013)	(0.054)	(0.029)	(0.018)	(0.046)	(0.005)	(0.028)
(inverse drive time to nearest...)	Airport	0.067*	0.015	0.118	0.012	0.095**	0.062	-0.002	0.019
		(0.038)	(0.031)	(0.168)	(0.065)	(0.038)	(0.132)	(0.008)	(0.061)
	Train Station	0.044**	0.019	0.051	0.011	0.027	0.036	0.018***	-0.001
		(0.020)	(0.017)	(0.060)	(0.025)	(0.019)	(0.051)	(0.006)	(0.023)
Domestic Market Access	Centrality	-0.179	-0.547	-1.811	-0.161	-0.505	-1.317	-0.135	-0.115
		(0.578)	(1.048)	(2.977)	(1.572)	(0.649)	(2.482)	(0.122)	(1.533)
Agglomeration	Specialisation	-0.132***	-0.244***	-0.448***	-0.203***	-0.076**	-0.402***	-0.023***	-0.190***
		(0.034)	(0.061)	(0.096)	(0.056)	(0.030)	(0.080)	(0.008)	(0.055)
	Foreign/domestic share of employment	0.127**	0.104**	-	-	-	-	-	-
		(0.056)	(0.046)	-	-	-	-	-	-
	Foreign/domestic density of employment	-0.011	0.024*	-	-	-	-	-	-
		(0.026)	(0.013)	-	-	-	-	-	-
	High-tech/Low-tech share of employment	-	-	0.116	0.088	0.001	0.123	-0.012	0.097*
		-	-	(0.152)	(0.056)	(0.031)	(0.126)	(0.007)	(0.055)
	High-tech/Low-tech density of employment	-	-	0.082	0.034	0.011	0.071	0.004	0.032
		-	-	(0.174)	(0.028)	(0.022)	(0.144)	(0.003)	(0.028)
	Total employment	0.096**	0.046***	1.186**	0.465*	0.084**	0.867**	0.007*	0.431*
		(0.041)	(0.009)	(0.604)	(0.280)	(0.040)	(0.409)	(0.004)	(0.258)
Human Capital	Inv dist to nearest third level	0.062**	0.058***	0.314***	0.122***	0.055***	0.224**	0.007	0.110***
		(0.025)	(0.012)	(0.116)	(0.041)	(0.018)	(0.088)	(0.007)	(0.036)
	Pop prop with third level qual	0.479***	0.621***	3.096***	0.539***	0.496***	2.515***	0.077***	0.477***
		(0.094)	(0.101)	(0.643)	(0.161)	(0.100)	(0.490)	(0.019)	(0.153)
Labour Market	Relative employment comp (county)	0.304*	0.136	0.509	-0.210	0.375**	0.364	-0.018	-0.170
		(0.164)	(0.220)	(0.743)	(0.313)	(0.187)	(0.613)	(0.045)	(0.297)
	Unemployment	0.105*	0.138*	0.530***	0.077	0.120***	0.461***	0.010	0.072
		(0.054)	(0.073)	(0.200)	(0.091)	(0.045)	(0.162)	(0.015)	(0.086)
	Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
	MAN area fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
	N	1910	1910	1910	1910	1910	1910	1910	1910
	Number of new entrants	232	2737	1734	1183	171	1563	42	1141
	Wald chi2(24)	484.240	680.552	849.634	871.072	448.354	610.618	386.781	411.366
	Prob > chi2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: NB population-averaged panel estimation with cluster robust standard errors. Dublin City omitted. Explanatory variables lagged by one period
Results vary slightly with alternate specifications. See the supplementary appendices for details
Marginal effects: dy/dx for factor levels is the discrete change from the base level. Semi-elasticity: dy/ex reported for all other variables
*** p<0.01, ** p<0.05, * p<0.1.

3.4 The effect of ICT over time

The rationale for deploying in some places rather than others is driven by economies of density (i.e. existing customers) rather than the expectation that firms are more likely to enter in such places. However, it might take time for deployment to reach its full effects. This section seeks to disentangle the baseline deployment effect of broadband from the length of time since initial deployment.

The coefficients of interest here take the form:

$$a_B Broadband_{jt} + a_B Broadband_{jt} * (t - t_{dj}) \tag{9}$$

Where $(t - t_{dj})$ is the time since deployment.

The baseline coefficients for the impact of broadband reduce across all specifications, and the interaction terms indicate that the is an additional effect for each year since initial deployment. Table. 6 illustrates that this effect is greater for traditional DSL than for the MANs, and there is an additional effect of DSL on FDI firms that was not picked up in previous specifications.

Table 6: Effect of time since deployment of ICT on firm formation

	All Firms		All Firms	
Variable	Foreign	Domestic	High-tech	Low-tech
1.DSL	0.031	0.560***	0.515***	0.121**
	-0.045	-0.178	-0.105	-0.06
1.MAN effect dummy	0.097*	-0.204	0.295*	-0.267
	-0.055	-0.222	-0.169	-0.210
1.MAN increased backhaul	-	-	0.549*	-
	-	-	-0.28	-
MAN*time since deployment	-0.005	0.108*	-0.008	0.059***
	-0.011	-0.061	-0.052	-0.021
DSL*time since deployment	0.094*	0.374***	0.265***	0.097***
	-0.049	-0.122	-0.084	-0.032
Year fixed effects	Y	Y	Y	Y
MAN area fixed effects	Y	Y	Y	Y

3.5 The effect of ICT during boom and bust

Ireland experienced an extreme economic expansion and contraction during our period of analysis. We control for annual trends using year fixed effects, however the effect of deployment may differ depending on which period is examined. To test this we split the sample into two periods: up to and including 2008 (Table. 7); 2009 and after (Table. 8).

The effect of DSL remains broadly consistent across both periods. The effect of the MANs is largely concentrated in the earlier period. This is not surprising as this coincides with phase 1 deployment of the MANS in which they went to larger towns and cities.

Table 7: Effect of ICT on firm formation 2008 and before

1.Eircom DSL	0.059**	0.817***	0.679***	0.174***
	-0.028	-0.243	-0.122	-0.067
1.MAN effect dummy	0.102**	0.578*	0.737***	-0.027
	-0.043	-0.304	-0.277	-0.088
1.MAN increased backhaul	-	-	0.756**	-
	-	-	-0.383	-
Year fixed effects	Y	Y	Y	Y
MAN area fixed effects	Y	Y	Y	Y

Table 8: Effect of ICT on firm formation post 2008

		All Firms		All Firms	
Variable Type	Variable	Foreign	Domestic	High-tech	Low-tech
Broadband	1.DSL	0.138***	0.833***	0.539***	0.206***
		-0.017	-0.315	-0.11	-0.044
	1.MAN effect dummy	0.170***	-0.002	-0.26	-0.041
		-0.057	-0.241	-0.171	-0.082
	1.MAN increased backhaul	-	-	0.283**	-
		-	-	-0.128	-

3.6 Interaction of ICT and human capital

Much literature would suggest that certain areas are better equipped to absorb the effects of new technology productively. Given this, we are interested in how the impact of ICT varies across different levels of educational attainment. To explore this question we examine the interaction between traditional DSL, fibre broadband and human capital for new firm formation. We do not distinguish between MANs with and without backhaul in this specification, otherwise the model is identical to that used in previous estimations.

Fig. 4 illustrates this effect, by comparing the difference in the expected firm counts between the presence and absence of ICT at different levels of educational attainment. This is examined for DSL and MANs separately, and for foreign, domestic and high-tech firms.

The impact of ICT on all types of new firm counts in an area increases as human capital increases. For many firm types the effect is not significantly different from zero (based on 95% CI) when the proportion of the population with a third-level degree is below a certain threshold. This suggests that broadband alone is not sufficient for firm formation. The exception to this is the effect of DSL on domestic and high-tech firms.

There also appears to be a certain degree of non-linearity in the relationship. Expected firm counts in the presence of a MAN are higher in areas with greater average educational attainment, and the magnitude of the marginal effect increases as the level of educational attainment increases.

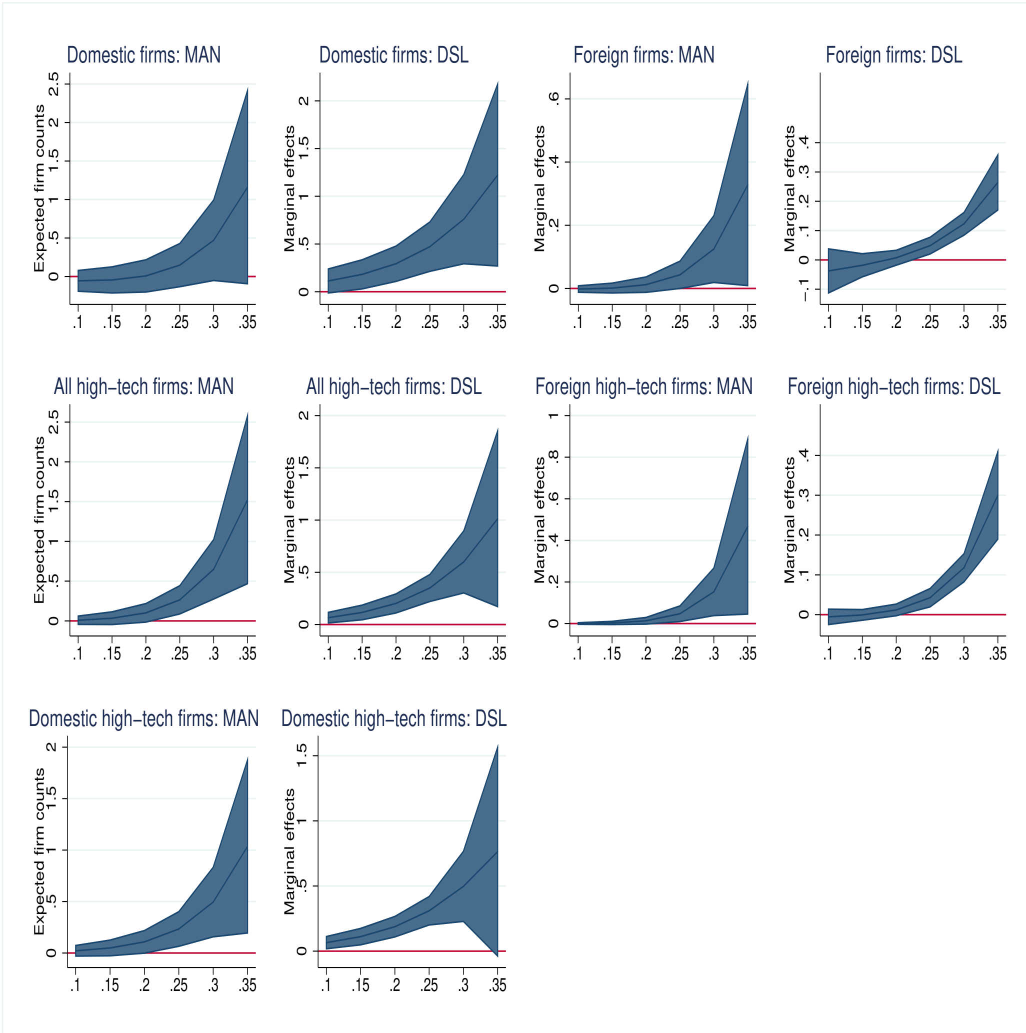

Figure 3: Expected firm counts in the presence of ICT at different levels of educational attainment

One particular feature of the relative levels of educational attainment by area is persistence over time. Table 9 illustrates this using Spearman's rank correlation. It is clear that there is very little change in the relative rankings of areas over our sample period. If ICT interacts with third level attainment in the manner discussed above, it might be the case that broadband roll-out exacerbates differences between areas, in their ability to attract new business establishments.

Table 9: Spearman rank correlations of educational attainment over time

	2002	2006	2011
2002	1		
2006	0.942***	1	
2011	0.923***	0.953***	1

Urban Fields with higher educational attainment tend to be those more densely populated regions along the east coast - close to Dublin, and large regional cities and their surrounding Urban Fields. This is perhaps another channel through which the "urban bias" of broadband persists.

4 Robustness

As discussed in Section 2 several potential sources of error exist. To account for this we estimate multiple alternate specifications, comparing the results to our reported estimates for high-tech firms. The magnitude of the results change in some cases, but overall remain relatively consistent across all specifications.

4.1 Excess zeroes

By modelling at the Urban Field level we reduce the excess zero problem. To further account for these issues we also include other model specifications which explicitly model the zero observations as a separate process. The results of these zero-inflated negative binomial and poisson models are reported in the supplementary material. The magnitude of most coefficients reduce slightly in these specifications, but the significance remains throughout.

4.2 Spatial dependence

To account for potential labour market spill-overs we generate spatially lagged variables for the dependent variable; the unemployment rate; the proportion of the population with a third-level qualification; and specialisation. The spatial weights matrix is distance-based with the threshold at 50km. This allows estimation of a SLX, SAR and SDM models. The coefficients on the spatially lagged variables displayed in Table 10 are not significant, and their inclusion does not substantively alter our results.

Table 10: Spatially lagged specifications

	Reported results	Spatially lagged models		
Variable	High-tech firms	SLX	SAR	SDM
1.Eircom DSL enabled exchange	0.531***	0.514***	0.533***	0.515***
	-0.103	-0.097	-0.106	-0.098
1.MAN effect	0.422**	0.394**	0.434**	0.400**
	-0.192	-0.191	-0.197	-0.195
1. MAN with increased backhaul	0.683***	0.666***	0.695***	0.675***
	-0.237	-0.228	-0.243	-0.234
Motorway	0.055	0.054	0.056	0.056
	-0.054	-0.054	-0.054	-0.054
Airport	0.118	0.13	0.11	0.11
	-0.168	-0.161	-0.17	-0.17
Train Station	0.051	0.049	0.054	0.054
	-0.06	-0.059	-0.059	-0.059
Urbanisation (diversity of employment)	-0.448***	-0.438***	-0.437***	-0.437***
	-0.096	-0.094	-0.094	-0.094
Sector share of employment	0.116	0.127	0.114	0.114
	-0.152	-0.148	-0.146	-0.146
Sector density of employment	0.082	0.077	0.08	0.08
	-0.174	-0.172	-0.17	-0.17
Total employment in island	1.186**	1.170**	1.227**	1.227**
	-0.604	-0.552	-0.591	-0.591
Inv distance to nearest TL institute	0.314***	0.320***	0.339***	0.339***
	-0.116	-0.118	-0.124	-0.124
Pop prop with third level qual	3.096***	3.201***	3.140***	3.140***
	-0.643	-0.661	-0.678	-0.678
Relative employment comp (county)	0.509	0.383	0.255	0.255
	-0.743	-0.742	-0.754	-0.754
Unemployment	0.530***	0.557***	0.543***	0.543***
	-0.2	-0.197	-0.201	-0.201
Spatial Lag - unemployment		-0.243		-0.229
		-0.166		-0.17
Spatial Lag - third level prop		-0.457		-0.496
		-0.304		-0.309
Spatial Lag - specialisation		0.003		0.013
		-0.239		-0.24
Spatial Lag - dependent variable			0.035	0.035
			-0.041	-0.041
Year fixed effects	Y	Y	Y	Y
MAN area fixed effects	Y	Y	Y	Y
N	1910	1910	1910	1910

We also check the residuals from each of our main reported models for spatial autocorrelation. The Moran's I results and their associated p-values are reported in the supplementary material and indicate no significant spatial autocorrelation in almost all cases. Where we observe significant spatial autocorrelation the magnitude of it is extremely small.

4.3 Endogeneity of explanatory variables

All explanatory variables are lagged by one period in all estimations, we also report the results of estimations with two-period lags. Further, we address potential endogeneity between new business establishments and the proportion of educational attainment and the unemployment rate, by re-running estimations keeping the 2002 level of these variables fixed. As these quantities do not change over time, they cannot possibly be responding to changes in the dependent variable. Again, the results hold.

4.4 Alternate panel specifications

Finally the results of several alternative panel specifications are reported. As we have a considerable degree of over-dispersion in the data we employ a NB model with cluster-robust standard errors at the Urban Field level. A range of alternative NB/Poisson fixed effects, random effects and population-averaged models with cluster-robust and bootstrapped standard errors were estimated. Results remain reasonably consistent across all specifications, and our reported results are somewhere towards the middle of the range for most variables.

5 Discussion and concluding remarks

This research examines the factors influencing new business establishments for both indigenous and foreign firms in Ireland over a period of significant infrastructural investment. The data spans a wide range of infrastructure, covers the introduction and recent history of broadband in Ireland, and captures a period in which 86% of the current motorway network was constructed. Complementing this is a rich dataset of other factors such as human capital and agglomeration measures.

The analysis does not include the Dublin City region, as this area is a uniquely attractive location for new firms in Ireland. We also do not consider areas below the 75th percentile of employment density. Given this, the analysis is an evaluation of how infrastructure roll-out affects regional towns and cities.

On average, the introduction of broadband in an area is associated with increased new firm counts. Other work such as Lehr et al. (2006) has also found this to be the case. Unusually for this literature, we are able to create detailed proxies for the availability of broadband provision. It is found that the availability of basic DSL has resulted in increased counts of both high and low-tech firms, while the benefits of middle-mile fibre appear to be concentrated in the high-tech sector. There is an additional effect in areas with greater competition in backhaul availability. The elasticity of new firm counts with respect to broadband is greater for foreign firms than for indigenous, but the marginal effect, in terms of increased new business establishments is smaller, as the rate of new foreign owned establishments is much lower than that of indigenous firms. Colombo et al. (2013) found that the adoption of basic broadband resulted in negligible productivity gains for Italian SMEs, while the benefits of advanced broadband are only realised if relevant to the firm's industry of operations. Given that many of the high-tech firms in our sample are involved in IT services, consultancy and component manufacture, it is likely that a complementarity exists between the adoption of high-speed broadband and their production processes.

Kandilov and Renkow (2010) find evidence of an urban bias when evaluating the impact of broadband on economic activity. Within different urban centres, Mack et al. (2011) finds quite a degree of heterogeneity in the elasticity of new firm counts with respect to broadband provision. It seems certain areas, perhaps related to industrial legacy or geography, have a greater capacity to absorb new technology in a productive manner. We add to this literature by examining how broadband provision interacts with educational attainment in an area for high-tech firms. It appears the benefits of broadband, in terms of increased new businesses, is greater in areas with higher educational attainment, and may not be effective at encouraging new business at all below a certain threshold of educational attainment. This finding echoes previous work, such as Mack (2014), who cautions that while broadband is a key factor in dispersing knowledge intensive firms, it should not be viewed as the only factor.

Accessibility, measured by drive times, appears important to high-tech FDI, but less so for indigenous and low-tech firms, with the relative importance of proximity to airports almost twice that of proximity to motorway junctions. Similarly, Button et al. (1995) found that road and air links have a greater importance for inward investment than for domestic firms, and Mack et al. (2011) found proximity to airports to be important for knowledge-intensive firms.

Previous work, such as Holl (2004a) and Holl (2004b) found that large scale motorway investments in Portugal and Spain, respectively, resulted in a dispersal of manufacturing firms, with the benefits concentrated mostly near the new infrastructure. Given the level of motorway investment during our sample period, it is perhaps surprising that we do not observe a larger effect.

We find that diversity of skills in an area is more important for new business establishments than specialisation. This work is consistent with other research, such as Holl (2004b); Viladecans-Marsal (2004), Li et al. (2016) for high-growth firms and Barrios (2006) in an Irish context. This supports the "Nursery City" argument proposed by Duranton and Puga (2001), which suggests that diversity of skills is more important for start-ups, whereas specialisation is more important for subsequent employment growth. Diversified areas may act as a "nursery" for new firms in search of their ideal production processes, offsetting the comparatively lower production costs they might find in more specialised areas. In Ireland, more specialised areas tend to be lower skilled and rural in which agriculture dominates, consistent with our results.

The local unemployment rate has a positive and significant effect on new business establishments for FDI and the high-tech sector, consistent with Coughlin et al. (1991), perhaps suggesting an effect of greater labour availability.

Proximity to third level institutions is highly significant for all firm-types, with the exception of low-tech FDI. The level of educational attainment is important for firms of all types, but particularly those in high-tech sectors. Previous work such as Akerman et al. (2015) has pointed to a skill complementarity between broadband adoption and skilled-labour. Broadband can increase the productivity of skilled graduates, particularly in scientific and technical disciplines, but can act as a substitute for less educated workers, lowering their marginal productivity.

Our results point to another interaction between broadband and human capital. While broadband infrastructure can have a positive influence on firm formation, it seems not to be sufficient on its own; the pre-existing level of human capital may be an important indicator of an area's ability to absorb new ICT technologies productively.

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