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Abstract

Extensive previous work on factors affecting regional development has considered the impact of aggregate measures of infrastructure like the public capital stock or individual infrastructures such as motorways. More recently the impact of ICT infrastructure, and in particular broadband, has received attention. This paper analyses the impact on new business establishments of broadband infrastructure, motorways, airports and railways and a range of other local characteristics such as availability of human capital and access to third level educational facilities. 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. Human capital, measured as the percentage of the population with a third level qualification and proximity to a third level institution prove to be important determinants of new firm establishments. Availability of broadband infrastructure is significant, but its effects may be mediated by availability of sufficient local human capital. Transport infrastructure access is significant for some sectors. For all sectoral groupings examined, firm establishments seem to favour a more diverse local sectoral mix rather than a concentrated one.

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 level of entrepreneurial activity, which can be measured by the rate of new enterprise formation. Firm entry and exit can also amplify economic cycles, increasing the persistence of aggregate fluctuations (Clementi and Palazzo, 2013). Importantly, the rate of new business establishments 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). Persistence is also an empirical feature of new firm formation rates (Fotopoulos, 2013).

We examine the factors influencing new business establishments. We significantly improve on the existing literature in a number of ways. Previous research has shown that firm formation is affected by human capital (Acs and Armington, 2004), proximity to universities (Zucker et al., 1998; Audretsch et al., 2005), transport infrastructure (Percoco, 2015; Button et al., 1995; Holl, 2004a,b; Rothenberg, 2012; Gibbons and Van Dender, 2012), ICT infrastructure (Gillet et al., 2006; Mack and Grubesic, 2009; Kandilov and Renkow, 2010; Kolko, 2012; Mack and Rey, 2014), clustering (Armington and Acs, 2002), agglomeration (Devereux et al., 2007) and specialisation (Feldman and Audretsch, 1999). However, these papers tend to focus on a subset of factors only, which raises the possibility of omitted variable bias.

We address this shortcoming by including a more comprehensive set of variables in our analysis. To this end we create a unique dataset for Ireland over the period 2002-2011, covering a broader set of infrastructure than has previously been examined in this literature, including ICT, motorways, and proximity to universities and other third-level institutions, airports and rail stations. This information is supplemented 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.

A second 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 Irelands infrastructure was rapidly improved. For example in relation to the development of the motorway network our data covers a period over which more than 86% of the 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 4). In addition, unlike much of the empirical literature, we have detailed spatial and temporal information on the drive-time to each motorway junction from the centroid of every location. Including the drive-time, rather than distance allows us to account for underlying road quality.

Our data also cover the entire history of broadband development in Ireland allowing us to create a unique panel-dataset on traditional digital subscriber line (DSL) and middle-mile fibre-broadband networks to disentangle the relative impacts of each. Our DSL roll-out data spans 0-100% penetration over our sample period, with substantial local variation. We also access GIS information on a national middle-mile fibre-optic network roll-out along with detailed information on the characteristics of these networks, and when they became operational.

Third, many papers are focused on either individual sectors, indigenous start-ups or foreign firms. We examine the factors influencing new business establishments for both foreign and domestic firms in Ireland. Our data allow us to split firms by sector, whether they are foreign or indigenously owned, and by the skill-level of their employees.

The location of indigenous start-ups is likely to contain more firm-specific heterogeneity than that of foreign direct investment. Choices by the latter group are likely to be more closely related to the factors which determine profitability. Different types of firm will require different types of infrastructure in their production processes. Very little exploration has been undertaken into the relative importance of different types of infrastructure. We contribute to this question in a number of ways.

We model new firm formation in each area over time with negative-binomial (NB) panel estimators and use a unit of analysis which helps to account for excess zeros and spatial dependence. Concerns of endogeneity between our outcome and explanatory variables are also addressed and we make a case for the direction of causality of our results.

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. Accessibility measures, such as driving times to motorway junctions and airports matter more for high-tech FDI than other firm types. New firms of all types value diversity of skills above specialisation. Human capital and access to third-level institutions are important for all types of firm, but particularly those in high-tech sectors.

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. Previous work such as Akerman et al. (2015) has pointed to a skill complementarity between broadband adoption and skilled-labour. Our results indicate a non-linearity in the effect of broadband along the distribution of educational attainment, in that the effect is greater for areas with greater education and may not be significantly different from zero below a certain threshold. This result perhaps indicates that broadband is a necessary but not sufficient condition for attracting firms to an area.

The rest of the paper is organised as follows; Section 2 describes the methodological approach employed and considerations undertaken; Section 3 the data; Section 4 outlines the empirical results; Section 5 outlines the robustness measures undertaken and Section 6 concludes.

2 Empirical approach and econometric considerations

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[1].

We implement a count framework as we have a large proportion of zeros in our dependent variables and 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.

$$y_{ijt} = \alpha_i + \beta_{X_1} X_{it} + \beta_{X_2} X_{ijt} + \beta_{X_3} X_{kt} + \beta_Z Z_i + \gamma_t + \epsilon_{it} \quad (1)$$

Where:

$$y_{ijt} = 0, 1, 2, ... \quad (2)$$

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

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

The econometrics literature encourages the use of fixed-effects (FE) 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 our case, many of our explanatory variables, particularly those relating to the accessibility of our locations are time-invariant. Furthermore, we have high-proportions of areas which never receive any firms. This makes a fixed-effects specification problematic, but a number of other options remain.

A random-effects (RE) assumes the individual effects α_i to be independent of the regressors. As per Cameron et al. (2013), suppose $f(y_{it}|x_{it}, \alpha_i)$ denotes the density for the it^{th} observation, conditional on α_i and the regressors. If $(y_{it}|x_{it}, \alpha_i)$ is Poisson distributed with mean $\alpha_i \lambda_{it}$ and α_i is gamma distributed with mean 1, a normalisation, and variance $1/\gamma$. The conditional mean can be expressed as:

$$E[y_{it}|x_{it}] = \lambda_{it} = \alpha_i.exp(x'_{it})\beta \tag{3}$$

with variance:

$$V[y_{it}|x_{it}] = \lambda_{it} + \lambda_{it}^2/\gamma \tag{4}$$

In the case of over-dispersion, this can be extended to a Negative-binomial (NB2) model as per Hausman et al. (1984). In this case y_{it} is iid NB2 with parameters $\alpha_i \lambda_{it}$ and ϕ_i, where $\lambda_{it} = exp(x'_{it})\beta$. y_{it} has mean $\alpha_i \lambda_{it}/\phi_i$ and variance $(\alpha_i \lambda_{it}/\phi_i) * (1 + \alpha_i/\phi_i)$. To obtain a closed-form solution it is assumed that $(1 + \alpha_i/\phi_i)^{-1}$ is a beta-distributed random variable with parameters (a, b). Estimation is generally conducted with maximum likelihood methods.

The random-effects model can be transformed to a pooled or population-averaged estimator, by averaging out the individual effects (Cameron and Trivedi, 2013). In this case:

$$E[y_{it}|x_{it}] = \alpha.exp(x'_{it})\beta \tag{5}$$

Whether random-effects or population-averaged estimators should be used depends on the inference one would like to make. Each is estimating a different population parameter, but the results tend to be close in practice. Taking the introduction of broadband as an example; the random (or individual) effects estimator will estimate the change in new business establishments for the same area following the introduction of broadband, while the population-averaged will estimate this effect for the average area.

From a policy perspective, we are more interested in the average effect, and employ population-averaged estimators as a result. Some would argue that to adequately control for unobserved variables and gain insight into the individual-level dynamics, a properly specified random-effects model is required (Neuhaus et al., 1991). Given this concern, we also report results from this specification as a robustness check[2]. All models are run with year dummies and cluster-robust/bootstrapped standard errors.

A number of other econometric issues arise when modelling firm counts over time and across space. These include excess zeros in the dependent variable, spatial dependence and other sources of potential endogeneity.

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

2.1 Excess zeros

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).

Our choice of unit helps to ameliorate this issue (discussed in more detail in Section 3.1). 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.

2.2 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).

Central to the identification of such effects is identifying the appropriate weights matrix W. This contains an explicit quantification of the magnitude of the spatial effects being transmitted through all locations, but is impossible to observe. As outlined by Corrado and Fingleton (2011), this is a crucial unresolved issue within spatial econometrics, akin to Manski's reflection problem in the identification of endogenous social effects (Manski, 1993).

Even if we can we can correctly characterise the weights matrix, practical difficulties exist in modelling spatial dependence in a non-linear panel setting. Much of the currently available toolboxes[3] deal with spatial dependency 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. Other work by Bertanha and Moser (2015) has demonstrated that the Poisson conditional fixed-effects maximum likelihood estimator (PCFE) is consistent even if the data are not poisson distributed, and are correlated over time - provided the spatial dependence is time-invariant.

Adapting either of the above approaches would be a possibility for us, however, as discussed previously we have important time-invariant explanatory variables which we would like to include, the coefficients of which cannot be estimated in a fixed-effects setting.

We mitigate this spatial dependance problem by choosing a specific unit of observation that significantly reduces it (described in detail in Section 3.1). As a further robustness check models with spatially lagged explanatory variables are also used.

2.3 Endogenous explanatory variables

There is the potential for an endogenous relationship to exist between new business establishments and a number of our explanatory variables relating to infrastructure and human capital. Improved infrastructure may encourage economic activity, but equally, areas with large or fast-growing economies are more likely to attract better infrastructure. This is primarily a concern for time-varying measures of ICT infrastructure, motorways, human capital and unemployment, as they may be responding to changes in firm formation. As

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

the other time-invariant measures of accessibility do not change, we can be clear enough about the direction of causality for these measures.

The potential endogenous effect of broadband on economic activity has been highlighted by a number of other authors (Van Gaasbeck, 2008; Mack et al., 2011; Kolko, 2012; Mack and Rey, 2014). Largely this is described as reverse causality between economic activity - such as new business counts, employment, payroll, house rents etc. - and broadband availability.

Previous research emphasises that the economics of DSL broadband roll-out are largely driven by population density. Any endogenous relationship between DSL and firms is more likely to link DSL to existing employment levels, not new firm formation. By restricting our analysis to new firms in each year, and by controlling for the pre-existing employment levels in each area at every time period, we mitigate this problem. Essentially we argue that any endogeneity relates to the stock of existing employment in an area rather than the flow of new firms to an area.

Our data on fibre networks come from a large public investment project, the Metropolitan Area Networks (MANs) scheme. The location of these middle mile networks was initially driven by local authorities that applied for funding [4]. We use an area fixed-effect to control for unobserved area characteristics in these locations that might be related to new firm counts, and a time-varying dummy to identify the effect from when the areas had fibre enabled.

Similar problems might exist with the time-varying motorway network data. Again, we argue that any endogenous relationship will be related to the stock rather than the flow of new business establishments.

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.

2.4 Identification strategy

The identification comes from exploiting space and variation in the location of infrastructure and firms. This is illustrated in fig. 1. We know what type of firms located in each location and when they first recorded employment. We also know what type of infrastructure was constructed in each location and when it was made operational. We represent infrastructure using the MANs in fig. 1, however the following section describes our wide range of data on different infrastructure for each location.

[4] This scheme was later extended to most towns in Ireland with a population of over 1500. See Department of Communications, Energy and Natural Resources (2008) for details.

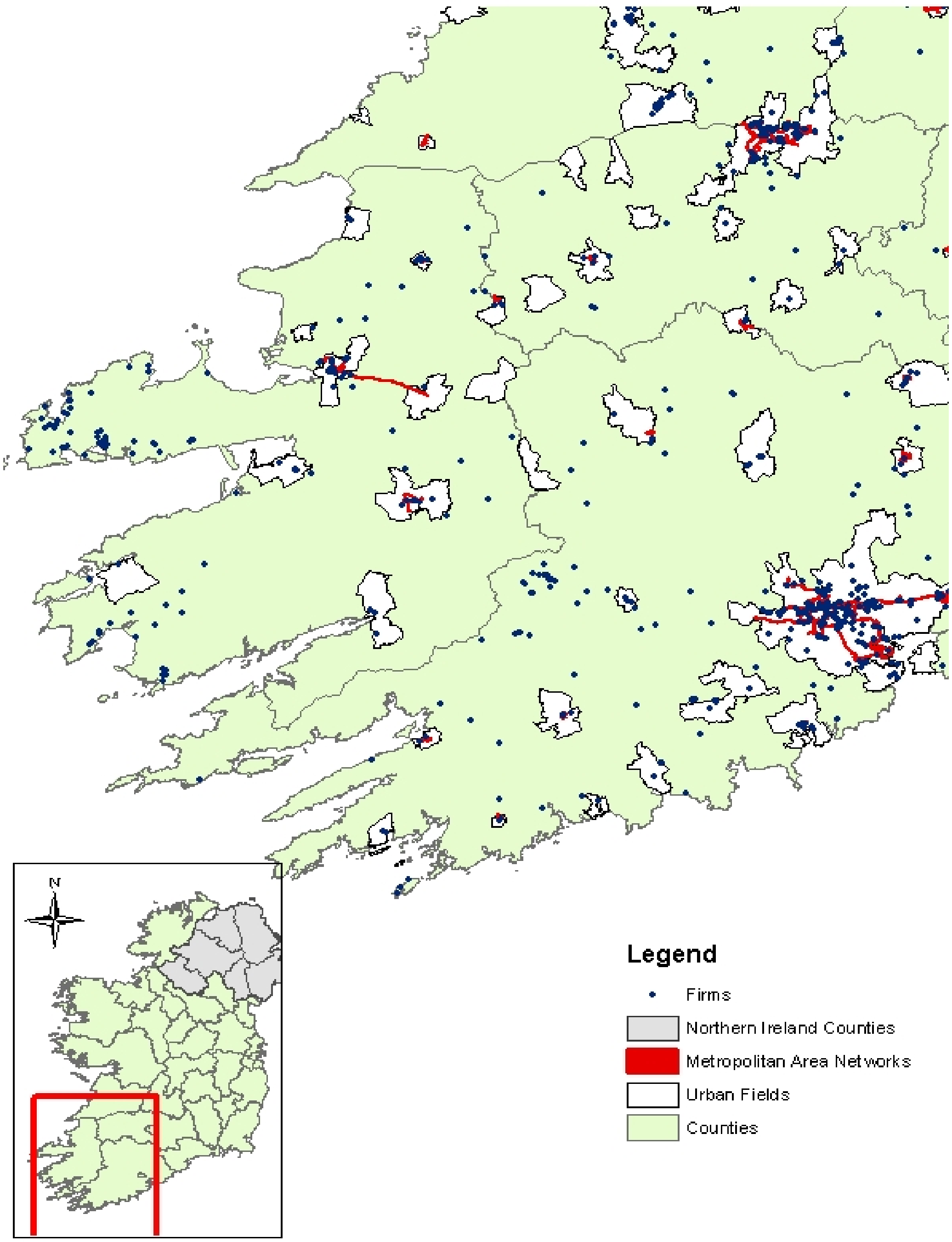

Figure 1: Map of Urban Fields and Metropolitan Area Networks for South-East of Ireland

3 Data

The data used in this analysis comes from a wide range of sources covering the period 2002-2011. We select this period because there were significant infrastructural investments in Ireland during this time and we can exploit this variation in our data in order to evaluate the impact of these changes. We first discuss the unit of analysis used, followed by a description of our dependent variables and the range of independent variables included. Descriptive statistics on all variables used can be found in the appendices.

3.1 Unit of analysis: "Urban Fields"

We create new units of analysis which we will refer to as "Urban Fields". 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[5]. We do not consider any EDs which do not fall into this category in our analysis. This selection covers 97 percent of all new foreign firms and 75 percent of all new domestic firms in our sample period.

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

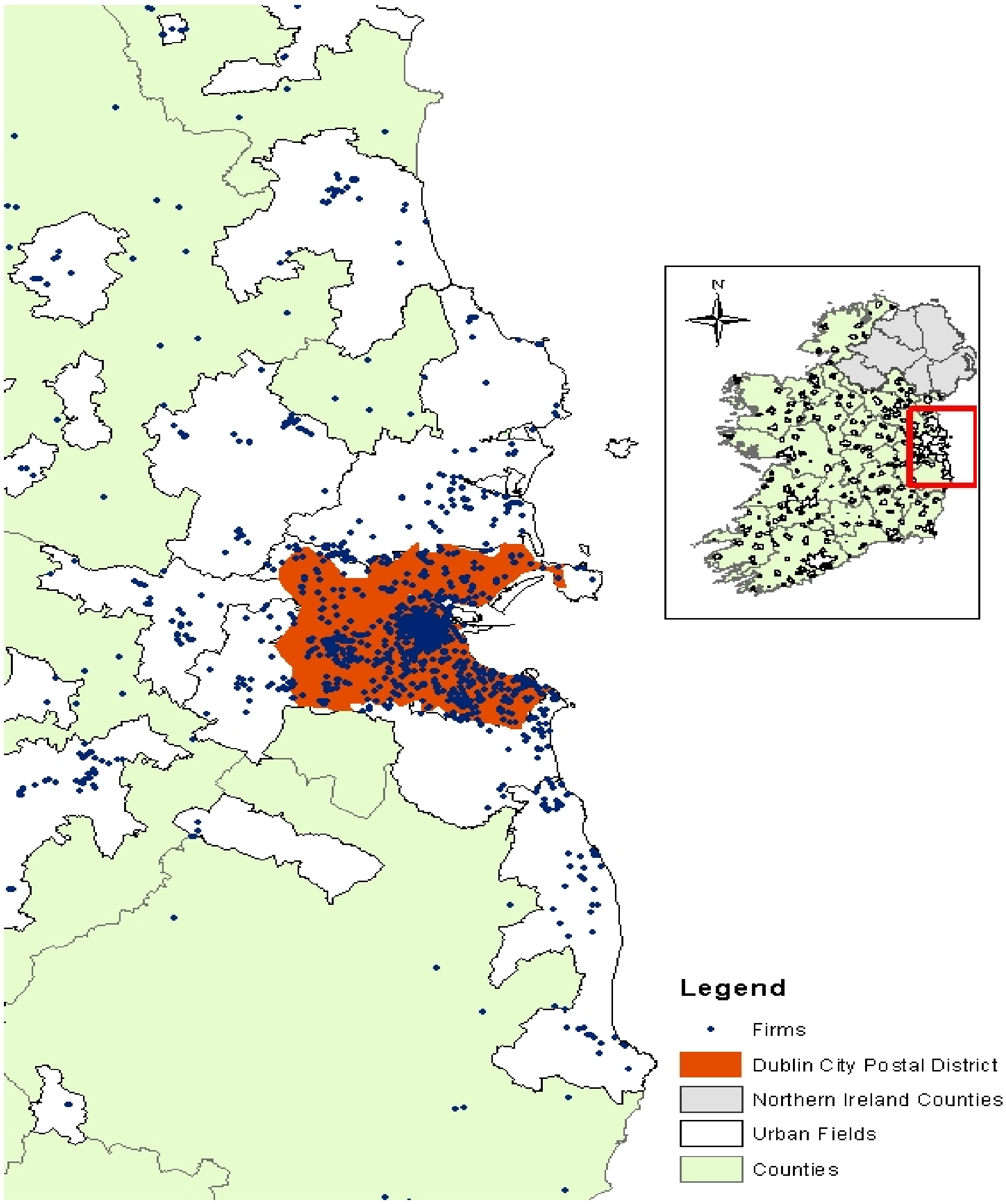

Figure 2: Map of East Coast Urban Fields

As discussed in the previous section, our Urban Field unit of aggregation yields a number of benefits in terms of reducing the potential for spatial dependence[6] and excess zeros when modelling firm formation over time.

We define the Dublin City Urban Field as those EDs that broadly map onto Dublin postcode regions, as highlighted in fig. 2. This area is omitted from all estimations as this is a uniquely attractive area for new firms and very different from the rest of the country in terms of population and employment density, infrastructure and general accessibility. In total, we create $N = 192$ Urban Fields. Omitting this area also reduces the potential for spatial spill-overs.

[6]Generally speaking, contiguous EDs with a sufficiently high employment density are considered part of the same Urban Field. The exception to this is on the east coast, highlighted in fig. 2. As a robustness check spatial lag models are also estimated and the results do not change substantively

3.2 Firm location variables

Our 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, 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. 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.

3.3 Explanatory variables

This subsection discusses the explanatory variables, which we divide into categories. The supplementary appendices list the sources for these variables.

3.3.1 Broadband

To deliver broadband services to businesses and homes, network operators need to put suitable infrastructure in place. These network facilities can be segmented into levels reflecting their cost, technical and competition characteristics. 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 radio. Tying together many local access connections, there may be a "middle mile" network such as a local fibre optic ring around a town with local exchanges or nodes in each small area. Finally, longer distance "backhaul" connections are required to bring local traffic together, linking all areas to the internet.

3.3.1.1 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 impacts economic activity has been based in the US, and as outlined in 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[7]. 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[8]. Between 2001 and 2010, Eircom rolled out basic broadband services to local exchanges across the country. Fig. 3 illustrates that enabling went from 0-100% for most regions over our sample period. This proxy is probably

[7]Proportions were used in initial estimations but dummy variables proved to have greater explanatory power in this case.

[8]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.

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.

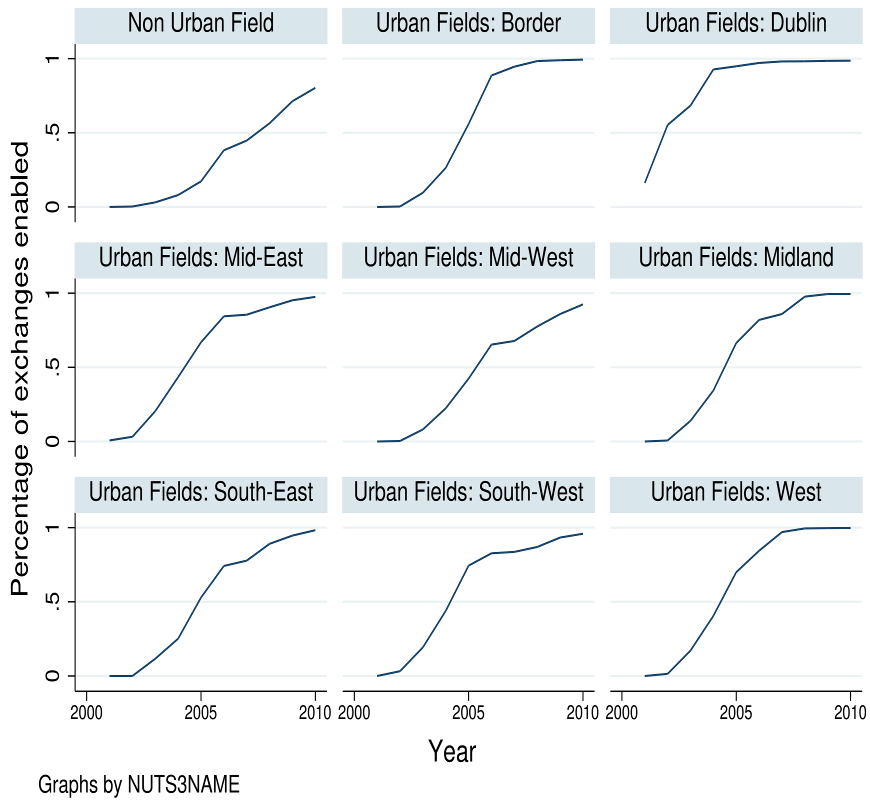

Figure 3: Share of enabled exchanges for DSL over time in Urban Fields by NUTS3 regions

3.3.1.2 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 (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

3.3.1.3 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.

3.3.2 Accessibility variables

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.

3.3.2.1 The motorway network. 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. 4 highlights the expansion over our sample period, and contrasts this with some international examples.

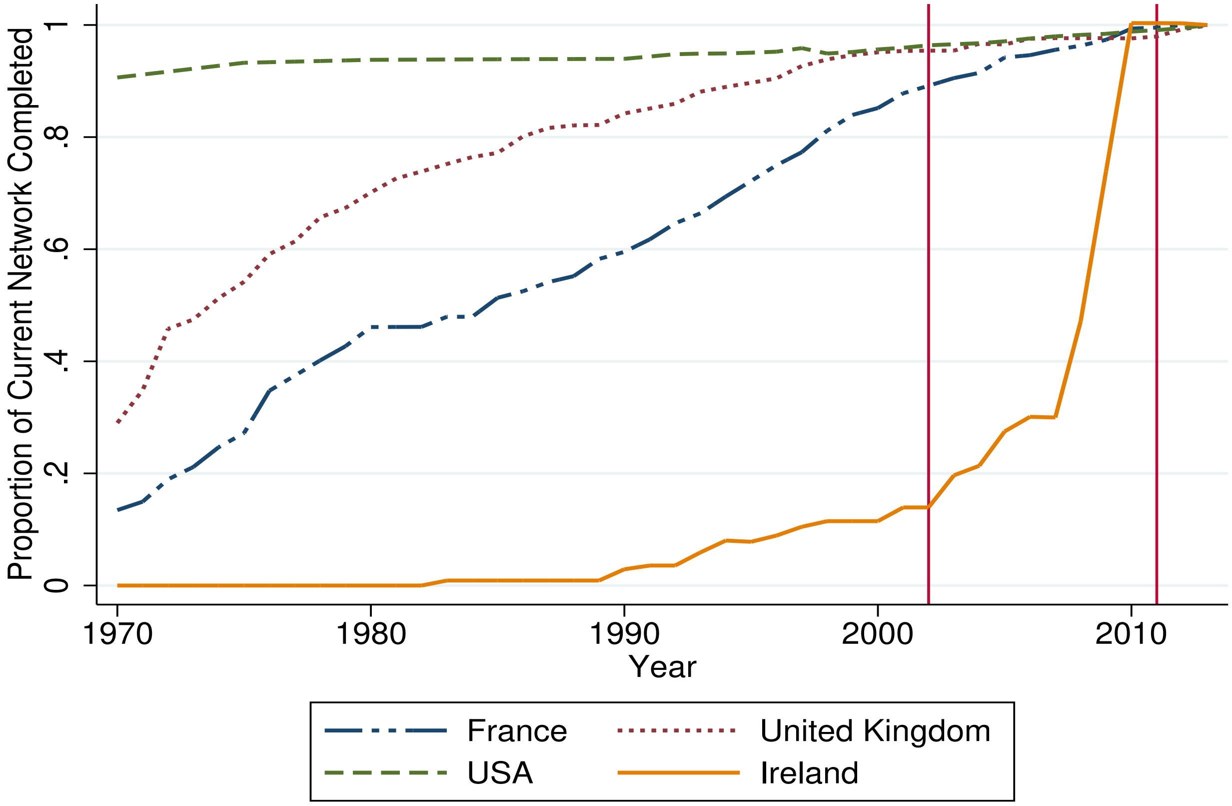

Figure 4: International comparison of motorway extension, 1970-2013

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. 5 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.

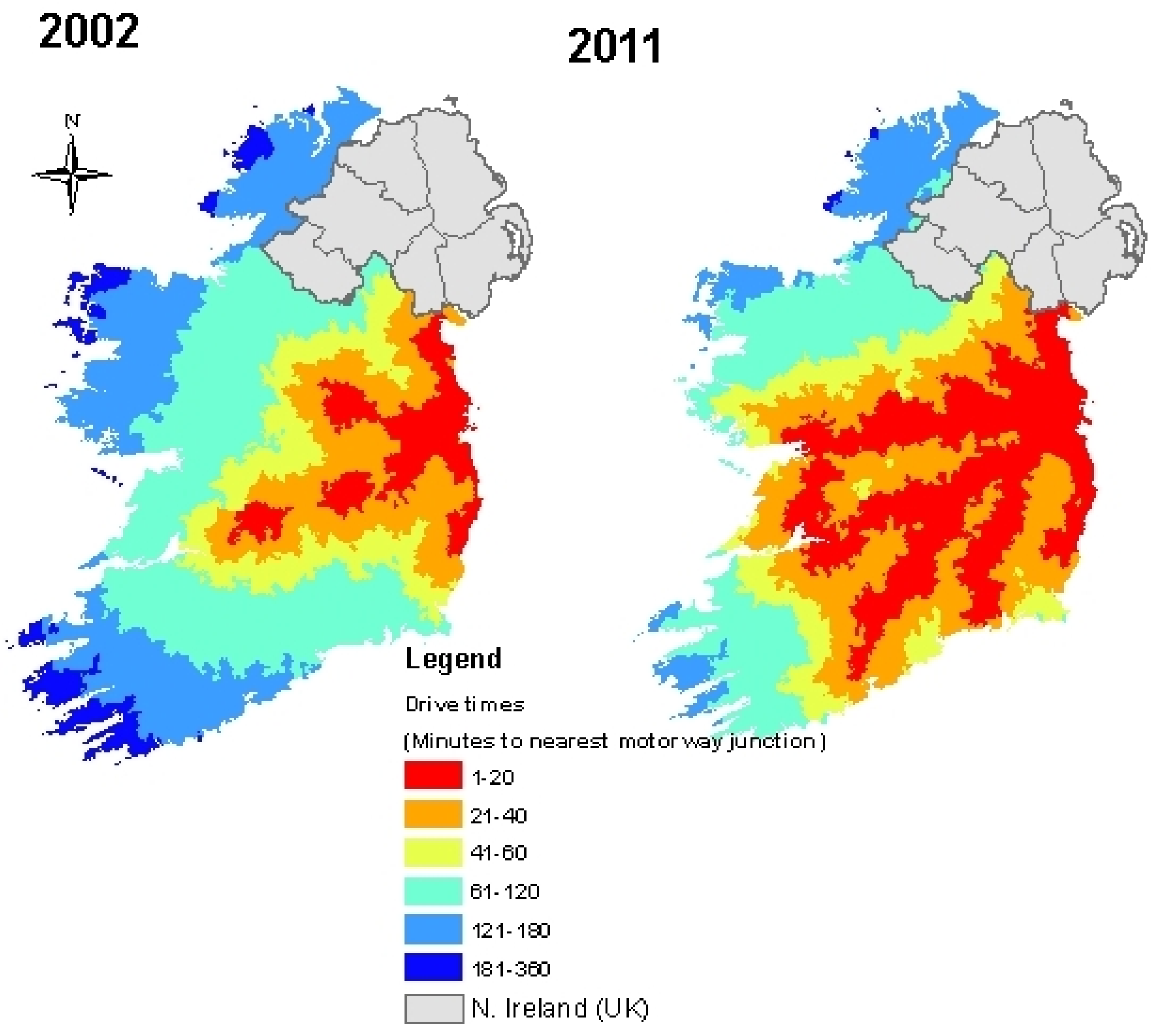

Figure 5: Location of motorway extensions, Ireland 2002-2011

3.3.2.2 Other accessibility measures. These 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.

3.4 Agglomeration variables

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:

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

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)[9].

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

3.5 Human capital and demographic variables

The proportion of the population with a third-level degree and the unemployment rate come from the CSO Population Census. We use data from the 2002, 2006 and 2011 Censuses in creating these variables.

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

3.6 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 we include a variable called "centrality" 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.

4 Econometric results

In this section we report our empirical results. We control for time effects 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. For all estimations we report significant average marginal effects (AME). The AME is the average of the marginal effects taken at each $x = x_i$[10]. In all cases, we examine the unit change in y for an associated change in x. All broadband variables are binary in which we look at the unit change in y for a discrete change in the base level. For all other variables we report semi-elasticities in which we examine the unit change in y for a proportionate change in x. 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.

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

[10] 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.

4.1 New business establishments by location of owner

The first section of our results focuses on 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 1), resulting in 0.588 more firms in an area. The MAN area dummy is not significant in any estimation. Inclusion of this variable is a robustness check as these locations may have unobserved characteristics that are correlated with new firm counts. By controlling for this we reduce the risk of spurious correlation. 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. However, weak significance suggests that caution is advisable when drawing inference from these results. Accessibility results were not statistically significant for domestic firms.

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. Density of either foreign or domestic employment is not significant. 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 4.4 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.

4.2 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 1). 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. We now create another MAN category, in which we examine the impact of increased competition in the backhaul market using data provided by BT. We find 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.

4.3 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 1).

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,[11] and only present once labour cost and quality are controlled for, indicating if anything an excess labour supply effect.

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

Table 1: 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.Eircom DSL	-	0.588***	0.531***	0.142***	0.063***	0.455***	-	0.143***
		-	(0.181)	(0.103)	(0.054)	(0.020)	(0.078)	-	(0.051)
	1.MAN area fixed-effect	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	1.MAN effect dummy	0.103**	-	0.422**	-	0.177**	0.309*	-	-
		(0.043)	-	(0.192)	-	(0.088)	(0.164)	-	-
	1.MAN increased backhaul			0.683***	-	0.144**	0.537***	-	-
				(0.237)	-	(0.072)	(0.204)	-	-
Accessibility	Motorway	0.037*	-	-	0.070**	0.043**	-	-	0.069**
		(0.020)	-	-	(0.029)	(0.018)	-	-	(0.028)
(inverse drive time to nearest...)	Airport	0.067*	-	-	-	0.095**	-	-	-
		(0.038)	-	-	-	(0.038)	-	-	-
	Train Station	0.044**	-	-	-	-	-	0.018***	-
		(0.020)	-	-	-	-	-	(0.006)	-
Domestic Market Access	Centrality	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
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	-	0.024*						
		-	(0.013)						
	High-tech/Low-tech share of employment			-	-	-	-	-	0.097*
				-	-	-	-	-	(0.055)
	High-tech/Low-tech density of employment			-	-	-	-	-	-
				-	-	-	-	-	-
	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**	-	0.110***
		(0.025)	(0.012)	(0.116)	(0.041)	(0.018)	(0.088)	-	(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*	-	-	-	0.375**	-	-	-
		(0.164)	-	-	-	(0.187)	-	-	-
	Unemployment	0.105*	0.138*	0.530***	-	0.120***	0.461***	-	-
		(0.054)	(0.073)	(0.200)	-	(0.045)	(0.162)	-	-
	Year dummies	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.

4.4 Exploring some interactions

This section explores the interaction between fibre broadband and human capital for new high-tech knowledge-intensive 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. 6 illustrates this effect, by comparing the difference in the marginal effects in the presence and absence of a MAN at different levels of educational attainment. For all firms this effect is not significantly different from zero (based on 95% CI) when the proportion of the population with a third-level degree is below approximately 20%. This suggests that broadband alone is not sufficient for firm formation. 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. For foreign firms, the difference while significantly greater than zero is small in magnitude.

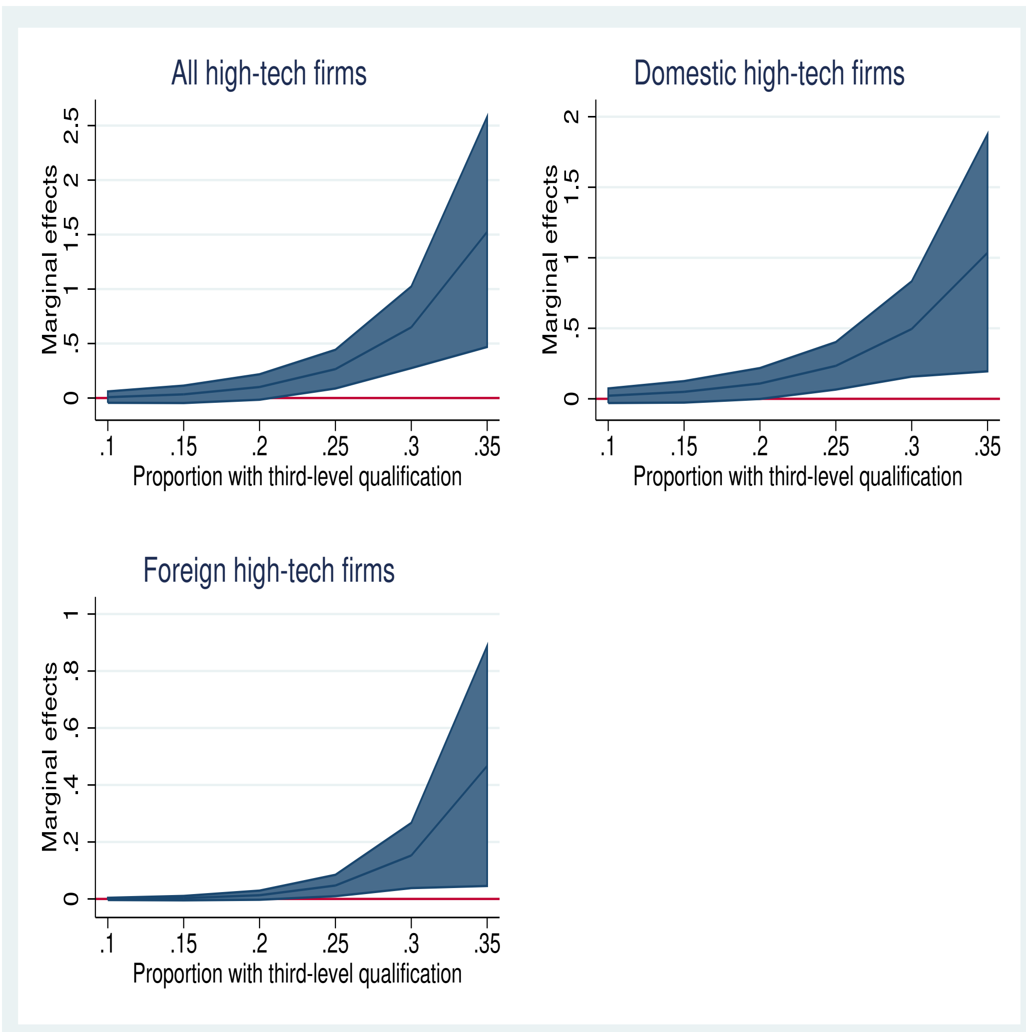

Figure 6: Expected firm counts in the presence of MAN at different levels of educational attainment

One particular feature of the relative levels of educational attainment by area is persistence over time.

Table 2 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 2: 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.

5 Robustness

As discussed in Section 2 several potential sources of error exist. By modelling at the Urban Field level we reduce the potential for spatial spill-overs and this also helps 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. All further results are reported in the supplementary appendices. Some coefficients change a little in magnitude but in general the sign and significance remain consistent across all models. To account for potential labour market spill-overs we generate spatially lagged variables for 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. The inclusion of these variables does not substantively alter our results.

Endogeneity is a concern for a number of our explanatory factors. We have already addressed this with a particular focus on the broadband variables in section 2.3. To further account for this, 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.

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 population-averaged and random-effects 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.

6 Discussion and concluding remarks

We have examined the factors influencing new business establishments for both indigenous and foreign firms in Ireland over a period of significant infrastructural investment. Our 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, we have 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, our 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. (2005) 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. We find 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), 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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