Broadband adoption and firm productivity: evidence from Irish manufacturing firms

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Abstract

We estimate the effects of adopting DSL broadband on firm productivity and productivity growth allowing for differing broadband speeds. We use a two-stage least squares estimator with geographical broadband availability as an instrument to address some potential endogeneity problems in a panel of Irish manufacturing firms. While more productive firms are on average more likely to be using DSL broadband, we find no statistically significant effect of broadband adoption on firms' productivity (growth).

Keywords: broadband adoption, productivity, IV regression, industry

JEL codes: D22, D24, L86

*This work makes use of data from the Central Statistics Office (CSO). The possibility for controlled access to the confidential micro data set on the premises of the CSO is provided for in the Statistics Act 1993. The use of CSO data in this work does not imply the endorsement of the CSO in relation to the interpretation or analysis of the data. This work uses a research dataset which may not exactly reproduce statistical aggregates published by the CSO. We thank Kevin Phelan and Gerard Doolan of the CSO for support with the data. We are grateful for financial support for this research from the Department of Energy, Transport and Communication and Comreg. We thank seminar participants at the Economic and Social Research Institute for helpful comments and suggestions. All remaining errors are our own.

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1 Introduction

Investment in information and communication technologies (ICT) has historically made a significant contribution to aggregate productivity growth. Policymakers understandably seek to obtain further societal benefits from this source by encouraging investment in the latest forms of ICT. Yet it is not obvious that the benefits of past generations of technology will necessarily be repeated in future ones. Firms and governments are now contemplating sizeable investments and other forms of support for high speed 'next generation' broadband. One factor behind this enthusiasm is an expectation that high speed broadband will increase the productivity of firms that use it. But the view that adoption of basic broadband, as opposed to ICT investment generally, increased firms' productivity has surprisingly limited empirical support. Even if one is willing to extrapolate the experience of basic broadband to its high speed successor, it is reasonable to ask whether adoption by firms of basic broadband had a direct effect on productivity or not. This paper adds to the literature on the effects of ICT by asking whether we can observe the sorts of productivity benefits seen in macro data when we focus on the micro level. More importantly, it adds to the limited base of evidence on the specific effects of broadband adoption on firms' productivity.

Empirical research in this area began with studies of the effects of ICT, particularly following identification by Solow (1987) of what came to be called the 'productivity paradox'. As the technology frontier has advanced, so has the technological focus for productivity research moved on. The current policy preoccupation is whether high-speed 'next generation' broadband services may increase productivity and increase societal welfare in various other ways, and how or whether governments should intervene to accelerate the deployment of such services (Kenny and Kenny, 2011). Nevertheless, the literature specifically trying to quantify the productivity contribution that broadband services offer to firms remains limited, perhaps due to a scarcity of firm level data linking broadband availability to adoption and total factor productivity.

There is a more substantial literature on how broadband affects GDP growth and employment (for example a survey by Holt and Jamison (2009) and Czernich et al. (2011)) or studies of ICT rather than broadband specifically (see Kretschmer (2012) for a recent survey). Studies using aggregate data to measure the productivity effects of ICT typically estimate production functions on national- or regional-level panel data. Establishing causality is a challenge in this setting. Reverse causality is a possibility, as telecoms network operators may be more likely to make broadband available in countries that have many highly productive firms and firms that have higher productivity might be better placed to adopt broadband. In addition, important omitted variables could drive both broadband adoption and productivity at national level. For example, a stronger endowment of human capital or a greater export orientation in a country's industries could have positive effects on both productivity and broadband adoption if increased human capital or exporting tend to raise demand for broadband services.

There are also many papers that aim to measure the effects of ICT using firm-level data (surveyed in Draca et al. (2007)). Fewer papers have attempted to quantify the the productivity effects of broadband *per se*. Why might broadband increase firms' productivity growth rates? In essence, broadband is thought to allow a higher speed of business transactions and a more efficient organisation of production activities. Some commentators consider that broadband is a "general purpose technology" akin to electrification, promising beneficial spillovers into many other domains. Howell and Grimes (2010) provide a useful discussion of how productivity effects might arise from broadband and offer a critical framework for policymakers considering the case for intervention to support broadband rollout or adoption.

We are aware of three studies using cross-sectional estimators and one using panel data methods. Taking the cross-sectional studies first, Bertschek et al. (2011) find no effect of broadband adoption on labour productivity using data for 1000 firms in German manufacturing and services sectors. They do find positive effects on product and process innovation. The study uses panel data for many explanatory variables, but the information on broadband use is cross-sectional for 2002 only.

Grimes et al. (2012) report that broadband adoption has a positive effect of 7-10% on productivity for firms in New Zealand. These results are consistent across geographical areas and between firms in sectors with higher and lower knowledge intensity. To address potential endogenity problems, they use propensity-score matching and carry out a robustness check using instrumental variables. Although the models are cross-sectional, they do include data on lagged productivity and firm size.

Hagén et al. (2008) estimate a series of equations on data covering Swedish firms from 2001-2005. All firms included in their dataset are observed for at least two consecutive years each, which seems to offer scope for panel analysis. However, their analysis appears to be carried out as a series of cross-sectional regressions (the paper is not entirely clear on the methods used). The authors employ a three-stage least squares estimator examining links between broadband adoption, ICT use and productivity. They find a significant relationship between broadband adoption for the 2001-2002 period, but not later. However, they suggest that this lack of significance may be due to a small sample size in subsequent years.

Turning to the one panel data study we have identified, van Leeuwen and Farooqui (2008) are interested in identifying how much of the productivity contribution of broadband use arises from capital deepening and how much from increases to TFP. They estimate a simultaneous-equation structural model using unbalanced panel data for a large sample of firms from the Netherlands (2002-2005) and the UK (2001-2005) in the manufacturing and services sectors. Equations are included for productivity, ICT capital inputs per employee and other capital inputs per employee, plus a wage equation, and each estimation allows for selection. They conclude that productivity improvements from adoption of broadband come through capital deepening rather than TFP. They also find that TFP is increased by electronic sales but not electronic buying.

The main contribution in this paper is to estimate productivity effects using firm-level panel data, allowing for differing broadband speeds. We use a two-stage least squares estimator with geographical broadband availability as an instrument to address some potential endogeneity problems (similar to Bertschek et al. (2011)), but our use of panel data also allows us to control for firm- and time-specific heterogeneity. Our panel includes over 8000 observations from about 2200 manufacturing firms in the Republic of Ireland from 2002-2009.

We find that higher productivity firms are more likely to use broadband (without controlling for firm characteristics), so the concern about possible reverse causality may be valid. We also find no statistically significant effect of broadband adoption on firms' productivity (growth).

The remainder of this paper is structured as follows: Section 2 discusses the methodology used in the analysis. Section 3 describes the different data sets and provides descriptive statistics. In

Section 4 we present our main results. Section 5 provides some robustness tests and Section 6 briefly concludes.

2 Methodology

In order to assess the importance of broadband (DSL) on firms' productivity (growth) we postulate that broadband is a potentially productivity-enhancing technology:

$$Y_{it} = \alpha_i + \beta_{DSL} DSL_{it} + \beta_{\mathbf{X}} \mathbf{X_{it}} + \varepsilon_{\mathbf{it}}. \tag{1}$$

Y_{it} denotes firm i 's productivity or productivity growth at time t , α_i is a constant term, DSL is a dummy variable equal to one if the firm uses broadband, $\mathbf{X_{it}}$ is a vector of control variables and ε_{it} is an i.i.d. error term. Our measure of total factor productivity is obtained using production function estimation. In particular, we calculate TFP_{it} as indicated in the following equation

$$\ln TFP_{it} = \ln Q_{it} - \hat{\alpha}_K \ln K_{it} - \hat{\alpha}_M \ln M_{it} - \hat{\alpha}_L \ln L_{it},$$

where Q_{it} is sales, K_{it} is capital stock, M_{it} is material purchases, and L_{it} is the number of employees in firm i in period t. $\hat{\alpha}_K$, $\hat{\alpha}_M$, $\hat{\alpha}_L$ are the estimated coefficients from an OLS regression where the log of turnover is regressed on the log of the three inputs, year and 3-digit industry dummies as well as 2-digit industry-year interactions. In this way, the TFP measure takes out any systematic differences in input use between sectors, across years, and also removes industry-specific trends. Our productivity growth measure ΔTFP_{it} is the one-period difference of TFP_{it}. For more details see Table 11 in the Appendix. For robustness checks we also employ labour productivity and a superlative TFP index as alternative measures of productivity.

We expect DSL adoption to have a positive impact on productivity (growth). It might, however, be the case that the choice to get a broadband connection is not independent of firm performance. More productive firms or firms with higher productivity growth may be more likely to install broadband. In this case the estimate of DSL in equation (1) will be biased. In order to account for endogeneity we use fixed effects instrumental variable regression to estimate equation (1). As instruments we employ the share of exchanges enabled for DSL and the average distance to an exchange at the level of the electoral division. While broadband providers are more likely to first install infrastructure in areas that do well economically, the individual firm's productivity is unlikely to matter for this. Controlling for fixed effects allows us to take account of unobserved heterogeneity that does not vary over time.

In the estimation of equation (1) we include the following control variables in $\mathbf{X_{it}}$ in both the first and second stage of the fixed effects instrumental variable regressions. We control for firm *size* and firm *age* to account for differences between firms at different stages of their life cycle. We also control for differences in firms' engagement in international markets by including a dummy for *foreign* ownership and dummies for whether a firm exports or imports (*exporter*, *importer*). To capture the ICT intensity of a firm we include the share of managerial and technical employees *manage* as well as the share of employees using the internet *shempuwww* as controls. Full variable definitions can be found in Table 10 in the Appendix. All regressions include time dummies.

3 Data and descriptive statistics

We combine data from three sources. The first source is the enterprise data from the annual Census of Industrial Production (CIP) for the Republic of Ireland which is conducted by the Central Statistics Office (CSO). The CIP covers all firms with 3 or more persons engaged in the mining, manufacturing and utilities sectors. In its current format the CIP goes back to 1991. This census collects information on typical firm census variables including industry classification, location, sales, employment, intermediate inputs, capital acquisitions and trade. The industry classification changed between 2007 and 2008 from NACE rev. 1.1 to NACE rev. 2, see the Appendix for more information on this. For the analysis we focus on the core manufacturing NACE rev 1.1 sectors 15-37. The CIP data is amended with information from the CSO's business register on the electoral division (ED) - a local administrative area - a firm is located in. From this source we also obtain information on the firm's year of establishment/first-time registration. While all firms have an entry for an ED code, in some instances only the two digits indicating the county a firm is located in are recorded. This is disproportionately the case for firms based in cities, i.e. in

Dublin (Dublin County Borough, Dublin Dun Laoghaire Rathdown, Dublin Fingal, Dublin South), Cork city, Limerick city, Galway city and Waterford city.

The second source of data is the 'Survey on E-Commerce and ICT'. This survey has been conducted as part of an EU-wide effort to gain information on ICT use since 2002 on an annual basis by the CSO. It targets a population of 8,000 enterprises in manufacturing, services and construction every year. The principal variables collected refer to the level of internet usage, types of connection, reasons for using the internet, sales and purchases via the internet, and barriers to e-commerce. The sampling frame for the survey is the central business register maintained by the CSO from which a random stratified sample is taken, the strata are industry and size class. From 2008 onwards this survey no longer targets firms with less than 10 employees.

The third dataset is panel data on availability of Digital Subscriber Line (DSL) broadband services in 1060 local fixed line telecoms exchange areas across Ireland. This dataset was provided by the main Irish fixed line telecoms operator Eircom, following a request from the regulator (the Commission for Communications Regulation). In order to identify when broadband is likely to have been available to a given firm, we assume that DSL was available in each area from the date the local exchange was enabled. Our firm-level data does not include precise geo-locations but does include the electoral division in which each firm is located. There are 3,440 electoral divisions in Ireland. The mapping between local exchange areas and electoral divisions is achieved by using GIS software to assign all business addresses in Ireland to the appropriate exchange and ED and assign the relevant DSL availability date to each business address. The map of business addresses is taken from the An Post Geodirectory, a database maintained by the Irish postal service that is intended to contain all Irish addresses. We can then calculate the share of business addresses in each ED that had DSL broadband available to them in a given year. These shares can be used as a proxy for the probability that fixed line broadband services were available to each firm in a given year, with the further assumption that firms in our data have the same spatial distribution within each ED as business addresses in general.

As an proxy for the quality of DSL available to each firm, we also calculate the average distance from business addresses in each ED to their local exchange. DSL technology imposes a negative relationship between distance and the speed with which data can be transmitted over a line.

[hp]

Table 1: Type of connection - options on the questionnaire over time

	Type of external connection to the internet	2002	2003	2004	2005	2006	2007	2008	2009
wireless	wireless connection (satellite, mobile phone)	a	a						
	wireless connection (e.g. satellite, mobile phone)			e	f	f			
	other fixed wireless connection (e.g. satellite, wireless broadband - excluding use of wireless router with DSL or cable modem)						f	f	
modem	modem (analogue)	b	b						
	modem (dial-up access over normal telephone line)			a	a	a	a	a	a
ISDN	ISDN	c	c						
	ISDN connection			b	b	b	b	b	b
DSL	xDSL(ADSL, SDSL, etc)^s	d	d	c					
	- of which $\geq$ 2MB/sec^f			-c					
	DSL (xDSL, ADSL, SDSL etc) $<$ 2MB/sec^s				c				
	DSL (xDSL, ADSL, SDSL etc) $\geq$ 2MB/sec^f				d				
	DSL $<$ 2MB/sec^s					c	c		
	DSL $\geq$ 2mb/sec^f					d	d		
	DSL broadband $<$ 2MB/sec^s							c	c
	DSL broadband $\geq$ 2mb/sec^f							d	d
other	other fixed connection $<$ 2MBps^s	e	e						
	other fixed connection $\geq$ 2MBps (e.g. frame relay/other broadband network service)^f	f	f						
	other broadband connection (e.g. cable etc.)^o			d	e	e			
	other fixed wire based connection (e.g. cable, leased line, fibre optic cable, frame relay etc.)^o						e	e	
	other fixed internet connection (e.g. cable,leased line, frame relay, fixed wireless connection)^o								e
mobile	mobile connection (e.g. analogue mobile phone, GSM, 3G or datacards)						g		
	mobile broadband connection (e.g. 3G datacard or modem)							g	f

Note: Possible answers to the question 'Type of external connection to the internet in January (year)' in Survey on e-Commerce and ICT. a-f indicate the options given on the questionnaire. For the purpose of the analysis in this paper the options marked s are grouped together as DSL$<$ 2MBs, those marked f are grouped together as DSL$\geq$ 2MBs, and those marked o as DSL other.

The data from the CIP and the e-Commerce survey can be merged using the business identifier on the CSO's business register.[1] From this merge we obtain an unbalanced panel of manufacturing firms for the period 2002-2009. Since the 'Survey of e-Commerce and ICT' does not target firms with less than 10 employees from 2008, we use only firms with 10 or more employees in the following.[2] For this group the matched sample covers on average 38% of CIP firms ranging from 31% in 2009 to 42% in 2004. The sample is representative of the eight NUTS3 regions; larger and foreign-owned firms have somewhat higher sampling probabilities. The information on broadband availability is matched onto this sample on the basis of firms' ED codes. As indicated above we do not have full-length ED codes for all firms; we are able to match DSL availability at the ED level for 70% of firms. Where we only have information on the firm's county, we match the information on broadband availability aggregated to the county level. Our results on the effects of broadband adoption on productivity are robust to estimating separate regressions using only the ED-level information. Our final working sample contains 8,029 observations from 2,290 firms.

Table 2: Share of firms by type of connection over time

year	Modem	ISDN	DSL any type	Wireless	Mobile	Firms with internet	Firms without access
2002	47.5	57.6	14.4	4.2		946	71
2003	42.0	55.3	19.9	3.9		1131	85
2004	36.6	48.8	33.8	5.2		1085	35
2005	22.7	37.4	54.1	9.0		898	29
2006	18.8	27.8	66.7	12.0		947	16
2007	16.0	26.3	67.5	23.7	19.8	1097	19
2008	11.4	19.4	81.9	19.3	27.2	970	16
2009	9.1	19.8	93.4		32.0	678	6
Avg/Total	25.5	36.6	54.0	11.0	26.3	7752	277

Note: Shares in per cent of firms with internet access. Connection types are not mutually exclusive. The column on the number of firms without an internet connection also includes firms that say they do not know whether they have an internet connection.

[1] Both of these data sets are checked for digit issues and outliers and cleaned where appropriate. More detailed information on this is provided in the Appendix.

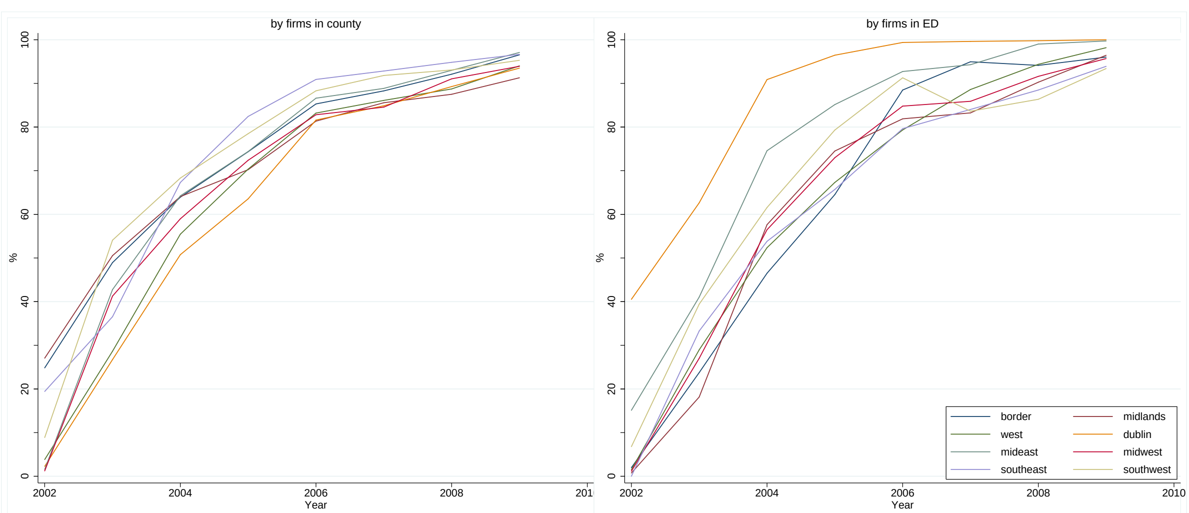
[2] When we estimate for subsamples, we produce a separate set of results for firms with up to 10 employees for the period until 2007.

Table 3: Share of firms by type of DSL connection over time

year	any type	<2MBs	≥2MBs	other	Obs
2002	13.4	10.6	2.8		1017
2003	18.6	14.3	4.6		1216
2004	32.8	14.6	6.3	12.9	1120
2005	52.4	16.8	15.5	22.8	927
2006	65.6	17.0	26.4	25.9	963
2007	66.7	18.5	30.6	24.7	1116
2008	80.5	22.6	42.3	23.5	986
2009	92.5	21.6	50.0	33.3	684
Avg/Total	52.8	17.0	22.3	23.8	8029

Note: Column ‘any type’ combines columns <2MBs, ≥2MBs and other. Categories <2MBs, ≥2MBs and other are nearly but not fully mutually exclusive. Shares in the ‘any type’ column in this table are relative to all firms, hence the difference to Table 2.

Figure 1: Share of exchanges enabled for DSL over time by NUTS3 region (8 regions)



Note: The apparent drop in DSL availability in the southwest region is due to differences between the firms included in the sample in each year rather than exchanges being disabled.

We obtain information on whether a firm uses DSL broadband from the question on the type of external connection in the Survey on e-Commerce and ICT. While firms have been asked to answer this question every year since the survey was first conducted the options given changed nearly every year. Table 1 gives an overview. Firms may tick multiple options when answering this question. The detail in the survey allows us to examine the effects of different types of broadband connections. We define three types, DSL$<$2MBs, DSL$\geq$2MBs and DSL other. The first two refer to the advertised maximum download speed on the line. The 'DSL other' category includes other types of fixed connections such as cable, leased line, fibre optic cable, frame relay or a fixed wireless connection. For the purpose of the analysis we start by grouping all firms that fall into one of these three categories together into a 'DSL any type' group. For our main results the DSL indicator in equation (1) is a dummy variable based on DSL any type. We also estimate separate regressions where we check whether the effects differ for firms adopting a fast internet connection, i.e. DSL$\geq$ 2MBs or those using a type of broadband that falls into the 'DSL other' category.

Table 2 gives the share of firms using a particular connection in each year. Already back in 2002 the vast majority of manufacturing firms had a connection to the internet. At the time most firms used either a modem or an ISDN connection, only about 14 per cent of firms used a DSL connection. By 2009 an overwhelming majority of firms (93.4%) use a DSL connection. Modems and ISDN are still in use, but not very widespread anymore. Instead, nearly a third of firms is using mobile internet connections.

Table 3 displays a breakdown of the different types of DSL connections. In 2002 most firms with a DSL connection had a transmission speed of less than 2MBs. From 2005 firms increasingly started to opt for the 'other' types of broadband connections such as cable, leased line, fibre optic cable or frame relay as well as for DSL connections with a transmission speed above 2MB per second. At the end of the sample period about half of the firms in the sample use a fast DSL ($\geq$ 2MBs) connection and a third of firms use an other type of connection. It seems likely that the 'other' category is dominated by relatively high speed forms of access, but we cannot directly observe this.

Figure 1 shows how DSL availability developed over the sample period across the eight NUTS 3-digit regions in Ireland. As is evident the period of analysis captures nearly the entire period of the roll-out of DSL across the country. In 2002 in all NUTS3 regions there were less than 30% of exchanges enabled, in some NUTS3 regions there were none at all. By 2009 there is nearly full coverage in all eight regions. The panel on the left based on the county-level information suggests that the trajectories of enabling exchanges for DSL in different counties were rather similar. The figure which aggregates over electoral divisions on the right indicates that there is more variation in availability and trajectories of roll-out within regions. Comparing, for example, DSL availability between the left- and the right-hand figure for the greater Dublin area, we can see that those firms for which we know the ED code in this area (this is the case for only 17% of firms in this particular NUTS3 region) are based in EDs with much higher than average DSL availability compared to firms in the rest of the country over the full sample period.

4 Results

Table 4: Productivity and covariates by type of connection - Means and standard deviations

	all firms	no DSL	DSL any type	DSL$\geq$ 2MBs	DSL other	DSL$<$ 2MBs
TFP	2.507 (0.495)	2.423 (0.369)	2.592 (0.583)	2.558 (0.543)	2.697 (0.654)	2.559 (0.565)
ΔTFP	-0.001 (0.235)	-0.002 (0.245)	-0.001 (0.224)	-0.003 (0.225)	0.008 (0.231)	-0.007 (0.221)
$TFPindex$	-0.036 (0.617)	-0.030 (0.598)	-0.042 (0.636)	-0.075 (0.609)	-0.048 (0.659)	-0.006 (0.644)
$\Delta TFPindex$	-0.005 (0.250)	-0.001 (0.260)	-0.009 (0.240)	-0.014 (0.240)	-0.004 (0.241)	-0.010 (0.233)
LP	4.946 (0.847)	4.740 (0.708)	5.151 (0.922)	5.120 (0.895)	5.348 (1.003)	5.080 (0.884)
ΔLP	0.011 (0.268)	0.014 (0.281)	0.007 (0.254)	-0.004 (0.254)	0.020 (0.242)	0.005 (0.263)
size	3.751 (1.099)	3.394 (0.859)	4.108 (1.193)	4.105 (1.151)	4.433 (1.282)	3.948 (1.175)
$\ln age$	2.903 (0.691)	2.823 (0.706)	2.984 (0.666)	3.012 (0.659)	2.980 (0.664)	2.968 (0.682)
manage	0.157 (0.131)	0.137 (0.101)	0.177 (0.153)	0.177 (0.155)	0.194 (0.182)	0.168 (0.137)
shempuwww	0.296 (0.257)	0.205 (0.205)	0.386 (0.272)	0.401 (0.267)	0.426 (0.298)	0.354 (0.261)
multi	0.047 (0.211)	0.028 (0.164)	0.065 (0.247)	0.070 (0.255)	0.084 (0.277)	0.063 (0.244)
foreign	0.249 (0.432)	0.144 (0.351)	0.353 (0.478)	0.319 (0.466)	0.478 (0.500)	0.296 (0.457)
exporter	0.684 (0.465)	0.593 (0.491)	0.775 (0.418)	0.778 (0.416)	0.813 (0.390)	0.747 (0.435)
importer	0.799 (0.401)	0.744 (0.436)	0.854 (0.353)	0.866 (0.341)	0.865 (0.342)	0.829 (0.377)
Obs	8029	4011	4018	1654	1340	1343

Note: Categories DSL$<$2MBs, DSL$\geq$2MBs and DSL other are nearly but not fully mutually exclusive.

Table 4 shows a comparison of means and standard deviations of productivity (growth) as well as of our explanatory variables by type of DSL connection. For our preferred measure of TFP and for labour productivity the table shows that firms using any type of DSL connection are more productive than firms that do not have a DSL connection. For the TFP index measure which will

Table 5: Correlations between productivity and type of DSL connection

	TFP	TFPindex	LP	ΔTFP	$\Delta TFPindex$	ΔLP
DSL any type$_{it}$	0.1708^a	-0.0092	0.2428^a			
DSL≥2MBs$_{it}$	0.0523^a	-0.0326^a	0.1047^a			
DSL other$_{it}$	0.1933^a	-0.0151	0.2207^a			
DSL<2MBs$_{it}$	0.0470^a	0.0217^c	0.0713^a			
DSL any type$_{it-1}$				-0.0106	-0.0560^a	-0.0304^b
DSL≥2MBs$_{it-1}$				-0.0158	-0.0486^a	-0.0524^b
DSL other$_{it-1}$				0.0092	0.0003	0.0433^b
DSL<2MBs$_{it-1}$				-0.0030	-0.0152	-0.0154

Note: ^{a}, ^{b}, ^{c} indicate significance at 1, 5, 10%, respectively.

be discussed in detail in the section on robustness, firms with a DSL connection are less productive than firms without a DSL connection, except for those using a slower connection (< 2MBs). In terms of average growth rates of productivity, firms with a DSL connection have lower average growth rates than firms without a DSL connection. Based on our main TFP measure and the LP measure those firms using an 'other' type of DSL connection form an exception to this observation. Firms with a DSL connection are also larger and somewhat older than firms without DSL. They have higher shares of employees using the internet and there are more multi-unit, foreign-owned, exporting as well as importing firms among them.[3]

Table 5 shows the pairwise correlations between productivity and the different measures of DSL adoption. In levels TFP is positively correlated with the different measures of DSL adoption. This is also the case for labour productivity. The opposite is true for the TFP index measure except for DSL< 2MBs. The negative correlation is significant only for DSL≥ 2MBs. For growth rates the correlations are negative except for other types of broadband connections. In the case of our main TFP measure none of the correlations are significant. In the following we test whether the descriptive evidence which suggests a positive relationship between broadband adoption and productivity and a negative or nonexistent relationship between broadband and productivity growth from Tables 4 and 5 is confirmed in the instrumental variable estimation specified in equation (1) above.

[3] A table which includes only the observations of firms of which we know the ED code provides a similar picture, see Table 12 in the Appendix.

Table 6 shows the results of these regressions. In the first we use the full sample, that is for those firms where we know the ED code we use the instruments - share of exchanges enabled and average distance to exchange - at ED level and supplement this with the county-level information for the firms where we only know the county they are located in. Based on this definition only one instrument - the share of exchanges enabled - is significant in the estimation displayed in the first column. The Sargan-Hansen test of overidentification restrictions for all instruments does not reject instrument validity. Firms with a higher share of employees using the internet are more likely to be using DSL, the opposite is true for foreign-owned firms. The second stage of the regression indicates a negative effect of DSL adoption on productivity, however, this effect is close to zero and not statistically significant. The results also indicate that larger firms are less productive, while firms with a high share of managerial and technical employees are more productive as are firms with a high share of employees using computers and multi-unit firms.

In the second column of Table 6 we present results only for those firms where we have full-length ED codes. As indicated in the data description ED codes are disproportionately missing for counties in the five main Irish cities, thus this regression can be read as being more focussed on the rural regions. Here in the first stage regressions both instruments are significant. The share of exchanges enabled in an electoral division is positively related to firms' having a DSL connection and the average distance to an exchange within an electoral division is negatively related to firms' having a DSL connection. The Sargan-Hansen test does not reject instrument validity. As in the first column firms with a higher share of employees using the internet are more likely and foreign-owned firms are less likely to have a DSL connection. In the second stage the coefficient on DSL adoption is again negative, close to zero and insignificant. Size, the share of managerial and technical employees and the share of employees using the internet are significant determinants of productivity also in this regression, multi-unit status is not.

In columns 3 and 4 Table 6 we show the results for TFP growth. As in the levels equations in the full sample only the share of exchanges enabled is positive and significant. When restricting the sample to those firms where we have full-length ED codes both instruments are significant and their signs go in the expected direction. In both cases the test statistics do not reject instrument validity. The coefficients on the effect of DSL adoption on productivity growth are positive, but

Table 6: Fixed effects IV regressions, TFP levels and growth rates, DSL any type

	TFP levels		TFP growth	
	all	obs w ED code	all	obs w ED code
DSL any type$_{it}$	-0.004 (0.132)	-0.038 (0.116)	0.018 (0.178)	0.079 (0.177)
size$_{it}$	-0.152 (0.025)^{a}	-0.126 (0.028)^{a}	0.099 (0.024)^{a}	0.096 (0.027)^{a}
age$_{it}$	0.060 (0.045)	0.068 (0.055)	0.002 (0.047)	0.036 (0.060)
manage$_{it}$	0.125 (0.057)^{b}	0.225 (0.072)^{a}	0.001 (0.083)	-0.109 (0.117)
shempuwww$_{it}$	0.059 (0.030)^{b}	0.082 (0.032)^{b}	-0.027 (0.038)	-0.022 (0.044)
multi$_{it}$	0.137 (0.068)^{b}	0.105 (0.110)	-0.077 (0.068)	0.026 (0.048)
foreign$_{it}$	0.010 (0.036)	0.019 (0.041)	0.014 (0.026)	0.013 (0.046)
exporter$_{it}$	-0.005 (0.027)	-0.018 (0.029)	0.036 (0.030)	0.052 (0.045)
importer$_{it}$	-0.041 (0.028)	-0.030 (0.028)	-0.004 (0.032)	-0.012 (0.035)
Obs/Firms	7493 1756	5209 1216	4307 1157	3020 803
LogL	1651.4	1259.9	797.8	563.7
Hansen(p)	2.893 (0.09)	1.281 (0.26)	1.529 (0.22)	1.086 (0.30)
sigma_e	0.22	0.22	0.24	0.23
First stage				
% exch enabled$_{t}$	0.128 (0.026)^{a}	0.148 (0.027)^{a}	0.119 (0.033)^{a}	0.133 (0.035)^{a}
dist to exch$_{t}$	-0.016 (0.103)	-0.311 (0.037)^{a}	-0.070 (0.118)	-0.242 (0.016)^{a}
size$_{it}$	0.015 (0.025)	0.023 (0.030)	-0.026 (0.038)	-0.009 (0.043)
age$_{it}$	0.018 (0.056)	0.046 (0.067)	0.009 (0.084)	0.046 (0.100)
manage$_{it}$	-0.072 (0.066)	0.009 (0.084)	-0.073 (0.095)	0.021 (0.122)
shempuwww$_{it}$	0.112 (0.034)^{a}	0.133 (0.042)^{a}	0.034 (0.047)	0.028 (0.058)
multi$_{it}$	-0.011 (0.066)	-0.062 (0.087)	0.038 (0.093)	0.072 (0.118)
foreign$_{it}$	-0.095 (0.054)^{c}	-0.168 (0.063)^{a}	-0.070 (0.074)	-0.180 (0.096)^{c}
exporter$_{it}$	0.047 (0.030)	0.013 (0.039)	0.062 (0.054)	0.026 (0.069)
importer$_{it}$	0.005 (0.032)	-0.020 (0.034)	0.003 (0.046)	-0.020 (0.052)
R^2	0.42	0.44	0.37	0.38

Note: In columns (1) and (3) the instruments (% exch enabled$_t$ and dist to exch$_t$) are calculated at ED level where available, for the firms without ED they are at the county level. In columns (2) and (4) only firms with ED code are included in the regressions. Coefficients and standard errors in parenthesis. Explanatory variables in the levels regressions are contemporaneous, in the growth regressions they are lagged by one period. All regressions include year dummies. Standard errors adjusted for clustering at the firm level in parenthesis; ^{a}, ^{b}, ^{c} indicate significance at 1, 5, 10%.

estimated with large standard errors in both cases and hence insignificant. The only other variable with a significant relationship to TFP growth is firm size; this relationship is positive.

Table 7: Fixed effects IV regressions, TFP levels and growth, DSL≥ 2MBs and other DSL

	TFP levels		TFP growth	
DSL definition	DSL≥ 2MBs	DSL other	DSL≥ 2MBs	DSL other
DSL	-0.453 (0.477)	-0.160 (0.235)	1.305 (1.741)	-0.490 (0.613)
$size_{it}$	-0.151 (0.028)^a	-0.183 (0.030)^a	0.128 (0.066)^c	0.177 (0.050)^a
age_{it}	0.037 (0.062)	0.100 (0.072)	0.010 (0.121)	0.083 (0.240)
$manage_{it}$	0.130 (0.067)^c	0.062 (0.064)	-0.156 (0.275)	0.117 (0.102)
$shempuwww_{it}$	0.079 (0.039)^b	0.031 (0.036)	-0.110 (0.130)	0.026 (0.066)
$multi_{it}$	0.171 (0.075)^b	0.044 (0.073)	-0.294 (0.341)	-0.046 (0.052)
$foreign_{it}$	-0.029 (0.062)	0.026 (0.040)	0.126 (0.185)	0.053 (0.095)
$exporter_{it}$	0.009 (0.032)	-0.027 (0.030)	-0.022 (0.098)	0.061 (0.057)
$importer_{it}$	-0.055 (0.034)	-0.037 (0.034)	-0.014 (0.064)	-0.015 (0.095)
Obs/Firms	7493 1756	5275 1446	4307 1157	2804 863
LogL	368.3	1454.2	-1829.8	192.2
Hansen(p)	1.524 (0.22)	4.649 (0.03)	0.306 (0.58)	1.475 (0.22)
sigma_e	0.26	0.22	0.43	0.27
First stage				
% exch $enabled_t$	0.026 (0.022)	0.091 (0.031)^a	0.011 (0.028)	0.058 (0.042)
dist to $exch_t$	-0.101 (0.098)	-0.075 (0.128)	-0.110 (0.118)	0.024 (0.061)
$size_{it}$	0.003 (0.026)	0.037 (0.030)	-0.021 (0.037)	0.042 (0.046)
age_{it}	-0.053 (0.061)	0.085 (0.095)	-0.008 (0.084)	0.311 (0.166)^c
$manage_{it}$	0.011 (0.076)	-0.036 (0.080)	0.122 (0.109)	0.051 (0.103)
$shempuwww_{it}$	0.044 (0.035)	0.090 (0.043)^b	0.063 (0.045)	0.066 (0.054)
$multi_{it}$	0.079 (0.064)	-0.035 (0.064)	0.170 (0.089)^c	-0.053 (0.036)
$foreign_{it}$	-0.087 (0.060)	0.038 (0.080)	-0.087 (0.081)	0.101 (0.130)
$exporter_{it}$	0.032 (0.029)	-0.028 (0.032)	0.045 (0.044)	-0.043 (0.059)
$importer_{it}$	-0.033 (0.031)	-0.054 (0.052)	0.007 (0.042)	-0.110 (0.083)
R^2	0.21	0.06	0.17	0.07

Note: The instruments (% exch $enabled_t$ and dist to $exch_t$) are calculated at ED level where available, for the firms without ED they are at the county level. Coefficients and standard errors in parenthesis. Explanatory variables in the levels regressions are contemporaneous, in the growth regressions they are lagged by one period. All regressions include year dummies. Standard errors adjusted for clustering at the firm level in parenthesis; ^{a}, ^{b}, ^{c} indicate significance at 1, 5, 10%.

As there is currently a debate whether broadband infrastructure needs to be upgraded to high-speed lines for its full benefits to be reaped (Kenny and Kenny 2011), we investigate the effects of faster connections on productivity and productivity growth. Specifically, we look at firms using DSL connections that are faster than 2MBs and firms using 'other' types of broadband connections. As discussed in Section 3 other types of broadband connections include among others cable, leased line, fibre optic cable and frame relay. While these types of connections do not necessarily all provide faster service than a standard DSL connection, in the regressions using other DSL we are likely to capture firms which require a broadband connection in areas where DSL service is poor or firms which require a connection that is faster than that available through existing infrastructure. The DSL other variable is only available from 2004, hence sample size in these regressions is reduced. The results from these regressions are presented in Table 7.

The first column shows the results for the effect of a firm having a DSL connection with a speed of 2MBs or more on productivity. In the first stage, the instruments are not significant. The Sargan-Hansen test does not reject instrument validity. In the second stage the coefficient on DSL is negative and insignificant. As in the regression considering any type of DSL in Table 6 size, the share of managerial and technical employees, the share of employees using the internet and the multi-unit dummy are significant determinants of TFP. In the second column of Table 7 we estimate the effect of using an 'other' type of broadband connection on TFP. Here the share of exchanges enabled is positive and significant in the first stage regression. The Sargen-Hansen test does not reject instrument validity. The sign on the other DSL measure is negative but not significant.

The effects of having a DSL connection faster than 2MBs or an other type of DSL connection on firm's productivity growth are displayed in columns 3 and 4 of Table 7. In both instances the instruments are not significant. The Sargan-Hansen tests do not reject instrument validity. The coefficient estimate on a DSL connection faster than 2MBs is positive whereas the coefficient estimate on an other type of DSL connection is negative, but both coefficients are not statistically significant. Thus, to summarise the results presented so far, we find that broadband adoption does not affect firm productivity or productivity growth. This is the case for any type of DSL connection as well as for fast and non-standard broadband connections.

It might be the case that there are specific groups of firms which derive a benefit in terms of productivity from using a DSL connection. To investigate this possibility we split the sample along a number of different dimensions. The results from this exercise are presented in Table 8. We split the sample by firm size into four size classes: firms with 10-20, firms with 20-100, firms

Table 8: Fixed effects IV regressions, TFP levels and growth, by type of DSL and type of firm

		TFP levels			TFP growth	
	DSL all	DSL$\geq$ 2MBs	DSL other	DSL all	DSL$\geq$ 2MBs	DSL other
< 10emp	2.427 (4.305)	-2.726 (3.330)	-0.909 (1.257)	0.238 (1.779)^{u}	6.821 (8.096)^{u}	-30.904 (52.781)^{u}
	1873 701	1873 701	602 269	483 205	483 205	94 43
10$\leq$emp<20	0.178 (0.247)	0.263 (0.532)	0.389 (0.443)^{u}	0.130 (0.376)^{u}	-0.028 (0.926)^{u}	0.168 (0.792)^{u}
	1863 561	1863 561	1180 404	921 316	921 316	457 174
10$\leq$emp<100	-0.046 (0.155)	-0.230 (0.618)	-0.186 (0.273)	0.003 (0.196)	1.110 (1.923)	-0.758 (0.946)
	3762 903	3762 903	2667 738	2282 599	2282 599	1526 463
$\geq$100emp	-0.533 (0.709)	-0.982 (1.953)	-0.082 (0.289)	-0.009 (0.363)	-0.123 (0.140)	1.162 (11.129)
	1587 381	1587 381	1227 342	959 269	959 269	721 231
domestic	0.000 (0.145)	-0.545 (0.470)	-0.108 (0.187)	-0.194 (0.200)	0.799 (3.170)	-0.617 (0.448)
	5568 1349	5568 1349	3848 1090	3099 857	3099 857	1941 618
foreign	-0.149 (0.550)	0.914 (8.693)	0.064 (0.477)	-0.201 (1.689)	-7.125 (25.170)	1.056 (1.747)^{u}
	1892 425	1892 425	1398 361	1191 309	1191 309	852 246
no-multi	0.032 (0.133)	-0.590 (0.837)	-0.251 (0.234)	0.057 (0.184)	0.987 (1.476)	-0.390 (0.714)
	7039 1652	7039 1652	4940 1359	4064 1090	4064 1090	2623 806
empuwww$\leq$.2	-0.117 (0.180)	-0.307 (0.494)	-0.312 (0.247)	-0.111 (0.211)	-0.604 (1.448)	-0.647 (0.622)^{u}
	2632 780	2632 780	1613 542	1393 451	1393 451	784 283
empuwww>.2	0.348 (0.276)	-0.817 (0.693)	0.765 (0.689)	0.007 (0.305)	0.592 (0.940)	0.145 (0.671)^{u}
	4277 1132	4277 1132	3212 959	2574 755	2574 755	1779 583
BMW region	-0.102 (0.139)	-0.332 (0.610)	-0.146 (0.246)	-0.074 (0.155)	-0.369 (0.716)	-0.461 (0.819)
	2168 509	2168 509	1531 415	1264 336	1264 336	850 262
SE region	0.204 (0.268)	-0.538 (0.637)	0.327 (0.409)	0.234 (0.538)	1.479 (2.097)	-0.586 (0.929)
	5313 1248	5313 1248	3734 1030	3040 822	3040 822	1951 601
ICT prod	1.673 (1.625)	-0.175 (0.340)	-2.043 (2.473)	0.506 (0.982)^{u}	0.075 (0.093)^{u}	0.357 (0.332)^{u}
	469 111	469 111	353 94	279 73	279 73	206 63
ICT using	-0.645 (0.516)	-1.023 (1.194)	-1.205 (1.491)	0.625 (0.648)	-0.296 (0.814)	1.895 (4.106)^{u}
	2327 571	2327 571	1590 451	1315 373	1315 373	802 252
non-ICT	0.129 (0.146)	1.136 (2.658)	0.049 (0.181)	-0.012 (0.182)	-0.305 (0.735)	-0.030 (0.319)
	4667 1094	4667 1094	3313 911	2698 719	2698 719	1782 549

Note: Coefficients and standard errors in parenthesis, number of observations and firms in the row below. Regressions are as specified in equation (1) and with the same control variables as in Tables 6 and 7 above. Regressions for firms with less than 10 employees do not include the importer dummy as a control variable. The instruments (% exch enabled$_t$ and dist to exch$_t$) are calculated at ED level where available, for the firms without ED they are at the county level. Explanatory variables in the levels regressions are contemporaneous, in the growth regressions they are lagged by one period. Standard errors adjusted for clustering at the firm level in parenthesis; ^{a}, ^{b}, ^{c} indicate significance at 1, 5, 10%. ^{u} indicates that the standard errors are deemed unreliable by STATA, the reason given is typically "estimated covariance matrix of moment conditions not of full rank".

with more than 100 and firms with less than 10 employees. The latter group are not part of our estimating sample above since these firms were not part of the survey population anymore after 2007. We further split the sample into firms that are domestically (Irish-)owned and those that are foreign-owned. Since the multi-unit firms may be using different types of connections across their plants, we estimate our models separately only for those firms that are single-unit firms. As the level of ICT use within a firm may be important we also split the sample by the median of the share of employees using the internet which is 20%. We split the sample by NUTS2 region, namely into the border, midlands and Western (BMW) region and the more affluent South-Eastern (SE) region which includes Dublin. Further, we split the sample by type of industry using two different definitions. We split firms into ICT producing, ICT using and non-ICT firms based on the taxonomy developed by Robinson et al. (2003).[4]

Table 8 reports the estimates for the DSL coefficient, standard errors, number of observations and firms of the regressions specified in equation (1). First stage results and coefficients for other explanatory variables are not reported to preserve space. We present results for TFP and TFP growth using the comprehensive DSL variable as in Table 6 as well as DSL faster than 2MBs and 'other' DSL as in Table 7. Breaking the sample into more homogenous groups of firms does not change the earlier results: in no instance in Tables 8 is the coefficient on the particular DSL measure significantly different from zero. We further grouped firms into industries according to the NACE letter classification; these results are not reported for brevity but are available on request. The estimated standard errors are unreliable for many of the NACE letter industries. Similarly to the reported breakdowns, the coefficient estimates take on a wide range of values but with the exception of one case (DSL other on TFP levels in NACE sectors 36 and 37 which is unreliably estimated) they are never significant. This implies that the absence of a significant relationship

[4] *ICT Producing Manufacturing:* Office machinery (30); Insulated wire (313); Electronic valves and tubes (321); Telecommunication equipment (322); Radio and television receivers (323); Scientific instruments (331). *ICT Using Manufacturing:* Clothing (18); Printing & publishing (22); Mechanical engineering (29); Other electrical machinery & apparatus (31-313); Other instruments (33-331); Building and repairing of ships and boats (351); Aircraft and spacecraft (353); Railroad equipment and transport equipment nec (352+359);Furniture, miscellaneous manufacturing; recycling (36-37). *Non-ICT Manufacturing:* Food, drink & tobacco (15-16); Textiles (17); Leather and footwear (19); Wood & products of wood and cork (20); Pulp, paper & paper products (21); Mineral oil refining, coke & nuclear fuel (23); Chemicals (24); Rubber & plastics (25); Non-metallic mineral products (26); Basic metals (27); Fabricated metal products (28); Motor vehicles (34).

between DSL and TFP (growth) in the sample with all firms is not due to averaging over smaller groups of firms with positive and negative effects.

5 Robustness

In this section we examine the robustness of our results. A key concern is the measurement of productivity. In Table 9 we present results for our main specification in the first and third column of Table 6 using a TFP index measure and labour productivity as alternative productivity measures. The TFP index measure is based on the superlative index number approach as proposed in Caves et al. (1982a,b). In the present context the TFP index and the TFP growth index are implemented as described in Griffith et al. (2009), see also Table 11 in the Appendix. In contrast to the TFP measure based on the production function approach used above, this measure imposes constant returns to scale on the production technology. The second measure of productivity considered is a basic labour productivity measure defined as $LP_{it} = \ln(Y_{it}/L_{it})$.

Despite the fact that based on the TFP index firms with broadband seem to have lower productivity than those without when looking at sample means (cf. Table 4) - which is in contrast to our main TFP measure and the labour productivity measure - the results presented in Table 9 confirm the absence of a significant relationship between DSL adoption and productivity (growth). For both the TFP index and the labour productivity measure the results are similar to our main set of results. In all four instances distance to exchange is positive and significant. The Sargan-Hansen test does not reject instrument validity. The coefficient on DSL is insignificant in all cases. Using the TFP index and labour productivity to re-estimate the additional results presented in Section 4 yields similar conclusions. Note also, that using only the sample of firms for which we full-length ED codes throughout yields similar results to those described above.

There is also an argument that the effects of DSL adoption may take time to materialise. To examine this possibility we have estimated a specification of the results reported in Section 4 where the explanatory variables are lagged by one period. Specifically, in the levels regressions the explanatory variables are at $t-1$ and in the growth regressions the explanatory variables are at $t-2$. While associated with a considerable loss in the number of observations these regressions

Table 9: Fixed effects IV regressions, TFP index, labour productivity, all types of DSL

	prod levels		prod growth	
	TFP index	LP	TFP index	LP
DSL all_{it}	-0.112 (0.181)	0.016 (0.137)	-0.002 (0.176)	-0.075 (0.193)
$size_{it}$	-0.019 (0.028)	-0.310 $(0.026)^a$	-0.051 $(0.029)^c$	0.336 $(0.034)^a$
age_{it}	-0.082 (0.066)	0.094 (0.058)	0.051 (0.046)	-0.073 (0.056)
$manage_{it}$	-0.114 (0.083)	0.080 (0.064)	0.126 (0.092)	0.077 (0.088)
$shempuwww_{it}$	0.077 $(0.038)^b$	0.066 $(0.029)^b$	0.029 (0.041)	-0.019 (0.037)
$multi_{it}$	0.267 $(0.086)^a$	0.133 $(0.069)^c$	-0.208 $(0.112)^c$	-0.150 (0.099)
$foreign_{it}$	-0.062 (0.044)	0.071 (0.049)	0.015 (0.038)	-0.018 (0.049)
$exporter_{it}$	-0.006 (0.035)	-0.000 (0.024)	0.042 (0.039)	-0.009 (0.035)
$importer_{it}$	-0.037 (0.037)	0.059 $(0.029)^b$	-0.017 (0.033)	0.006 (0.032)
Obs/Firms	7458 1749	7497 1758	4251 1147	4324 1162
LogL	171.1	1780.5	694.6	594.8
Hansen(p)	0.944 (0.33)	0.996 (0.32)	0.050 (0.82)	4.503 (0.03)
sigma_e	0.27	0.22	0.24	0.25
% exch $enabled_t$	0.124 $(0.026)^a$	0.128 $(0.026)^a$	0.120 $(0.033)^a$	0.118 $(0.033)^a$
dist to $exch_t$	-0.018 (0.103)	-0.016 (0.103)	-0.064 (0.118)	-0.071 (0.118)
$size_{it}$	0.012 (0.025)	0.015 (0.025)	-0.021 (0.038)	-0.028 (0.038)
age_{it}	0.020 (0.056)	0.018 (0.056)	0.010 (0.084)	0.005 (0.083)
$manage_{it}$	-0.068 (0.066)	-0.072 (0.066)	-0.083 (0.095)	-0.073 (0.094)
$shempuwww_{it}$	0.109 $(0.035)^a$	0.111 $(0.034)^a$	0.035 (0.047)	0.035 (0.047)
$multi_{it}$	-0.011 (0.066)	-0.011 (0.066)	0.037 (0.089)	0.038 (0.090)
$foreign_{it}$	-0.092 $(0.054)^c$	-0.095 $(0.054)^c$	-0.071 (0.074)	-0.071 (0.074)
$exporter_{it}$	0.047 (0.030)	0.046 (0.030)	0.062 (0.054)	0.064 (0.054)
$importer_{it}$	0.003 (0.032)	0.005 (0.032)	0.016 (0.045)	0.002 (0.046)
R^2	0.42	0.42	0.37	0.37

Note: The instruments (% exch $enabled_t$ and dist to $exch_t$) are calculated at ED level where available, for the firms without ED they are at the county level. Coefficients and standard errors in parenthesis. Explanatory variables in the levels regressions are contemporaneous, in the growth regressions they are lagged by one period. All regressions include year dummies. Standard errors adjusted for clustering at the firm level in parenthesis; ^{a}, ^{b}, ^{c} indicate significance at 1, 5, 10%.

confirm the results presented above. The results described in this section but not reported are available from the authors on request.

6 Discussion and concluding remarks

In this paper we look at the effects of DSL adoption on firm productivity and productivity growth in a sample of Irish manufacturing firms in the period 2002-2009. We use a two-stage least squares estimator with geographical broadband availability as an instrument. While more productive firms are on average more likely to have a DSL broadband connection, adopting broadband is not associated with higher firm productivity or productivity growth. This is the case not only when all types of broadband connections are grouped together, but also when we specifically investigate the effects of the adoption of higher speed DSL broadband (greater than 2MBs) or other types of broadband including e.g. cable, leased line, fibre optic cable and frame relay. We also do not find a significant effect of broadband adoption on firm productivity (growth) when we split the sample into more homogenous groups of firms by size, ownership, internet usage, region or narrowly defined industry.

Our results are broadly consistent with van Leeuwen and Farooqui (2008) and Bertschek et al. (2011), who found no evidence that broadband adoption increased firm productivity *per se.*, in contrast to the more positive findings of Grimes et al. (2012). There remains little empirical support from firm-level econometric studies for the view that accelerated adoption of high speed broadband would significantly benefit industrial productivity, as discussed in (Kenny and Kenny, 2011).

Our work benefited from the availability of panel data on both firms' productivity and local supply of DSL broadband services, which allowed us to control for some unobserved heterogeneity and address concerns about endogeneity. This is an important feature of the paper, because we found evidence of reverse causation in broadband adoption.

One obvious extension to this strand of research is into the services sector. Given the nature of the output they produce and the IT-intensive production processes they often use, services firms might be more likely to experience significant productivity gains from broadband adoption than manufacturing firms. Due partly to availability of data and the greater difficulty of defining and measuring productivity in services, the productivity effects on such firms have received less attention to date.

References

Bertschek, Irene, Daniel Cerquera, and Gordon J. Klein (2011) 'More bits - more bucks? Measuring the impact of broadband internet on firm performance.' ZEW Discussion Paper 11-032, ZEW - Zentrum für Europäische Wirtschaftsforschung / Center for European Economic Research

Caves, Douglas W., Laurits R. Christensen, and W. Erwin Diewert (1982a) 'The economic theory of index numbers and the measurement of input, output and productivity.' *Econometrica* 50(6), 1393–1414

_ (1982b) 'Multilateral comparisons of output, input and productivity using superlative index numbers.' *Economic Journal* 92(365), 73–86

Central Statistics Office (2009) *Estimates of the capital stock of fixed assets* (Dublin: Stationary Office)

Czernich, Nina, Oliver Falck, Tobias Kretschmer, and Ludger Woessmann (2011) 'Broadband infrastructure and economic growth.' *The Economic Journal* 121(552), 505–532

Draca, Mirko, Raffaela Sadun, and John Van Reenen (2007) 'Productivity and ICTs: A review of the evidence.' In *The Oxford Handbook of Information and Communication Technologies,* ed. Robin Mansell, Chrisanthi Avgerou, Danny Quah, and Roger Silverstone (Oxford and New York: Oxford University Press) pp. 100–147

Griffith, Rachel, Stephen Redding, and Helen Simpson (2009) 'Technological catch-up and geographic proximity.' *Journal of Regional Science* 49(4), 689–720

Grimes, Arthur, Cleo Ren, and Philip Stevens (2012) 'The need for speed: impacts of internet connectivity on firm productivity.' *Journal of Productivity Analysis* 37(2), 187–201

Hagén, Hans-Olof, Jennie Glantz, and Malin Nilsson (2008) 'ICT use, broadband and productivity.' In 'Yearbook on Productivity' (Statistics Sweden) pp. 37–70

Holt, Lynne, and Mark Jamison (2009) 'Broadband and contributions to economic growth: Lessons from the US experience.' *Telecommunications Policy* 33(10,11), 575–581

Howell, Bronwyn, and Arthur Grimes (2010) 'Productivity questions for public sector fast fibre network financiers.' *Communications & Strategies* 1(78), 127–146

Kenny, Robert, and Charles Kenny (2011) 'Superfast broadband: is it really worth a subsidy?' *info* 13, 3–29

Kretschmer, Tobias (2012) 'Information and communication technologies and productivity growth: A survey of the literature.' OECD Digital Economy Papers 195, OECD Publishing

Robinson, Catherine, Lucy Stokes, Edwin Stuivenwold, and Bart van Ark (2003) 'Eu productivity and competitiveness: An industry perspective.' In *Can Europe resume the catching-up process?,* ed. Mary O'Mahony and Bart van Ark (Luxembourg: Office for Official Publications of the European Communities)

Solow, Robert (1987) 'We'd better watch out, Review of S.S. Cohen and J. Zysman, Manufacturing Matters: The myth of the post-industrial economy.' New York Times Book Review

van Leeuwen, George, and Shikeb Farooqui (2008) 'ICT investment and productivity.' In 'Eurostat Final Report "Information Society: ICT impact assessment by linking data from different sources"' pp. 163–189

A Appendix

A.1 Detailed information on the data and cleaning

Data checking and cleaning

CIP

Variables in the CIP data are checked for a number of different measurement issues: industry (NACE), county and ownership changes are ignored if they revert in the following year. A similar procedure applies where first or last observations differ from those after or before. Since the employment variable refers to employment in the first week of September this may be zero whereas wages may be positive. Where this is the case only in a single year, employment is estimated based on previous or following observations. Sales are checked for digit issues based on large changes in sales per employee and deviations from mean. Fuels, materials and wages are checked for large changes from one year to the next and whether they exceed turnover both individually as well as taken together. Export and import shares are checked for big changes from year to year as well as for once-off zero observations.

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Data are checked for logical inconsistencies. For example, a firm may be reporting a positive share of employees using computers but claiming it is not using computers, similarly for the share of employees using the internet and having an internet connection. In some instances this requires assigning a type of connection in line with previous or following observations; in other cases the share of employees using computers is set to zero. The types of connection(s) are checked for changes over time and for firms reporting four or more different types of connections, this is mainly to avoid that firms which report having a type of DSL connection in one year revert back to a modem or ISDN connection in later years. The DSL connection types are harmonised over time as far as possible again based on changes over time and typically not allowing firms that reported a connection faster than 2MBs in one year to report both a connection with less than 2MBs and one with at least 2MBs in following years.

Change in industry classification

The official European industry classification changed from NACE rev. 1.1 to NACE rev. 2 between 2007 and 2008. Parts of our analysis require a classification that is consistent over time, thus we bring all firms to the NACE rev 1.1 classification. For the year 2008 the firms in the CIP were coded according to both classifications. We use this information for firms that are present in both 2008 and 2009 if their NACE rev. 2 classification did not change between the two years. Using this method we are able to obtain NACE rev 1.1. codes for 95.6% of firms in 2009. For the remaining firms we use the concordance table provided by Eurostat. For a further 2.2% of firms there is a one-to-one match between the old and the new classification. For the few remaining firms there are up to 21 potential matches from the new to the old classification; however, for most of these firms there are only two or three possible matches. To these firms we assign the NACE rev. 1.1. code that firms with this NACE rev. 2 code are most frequently matched to based on the observations that have both codes assigned in 2008.

Table 10: Variable definitions

Variable	Description	Source
age_{it}	One plus the difference between the current year and the year the firm was first established or first recorded on the CSO's business register or the year of the first observation - whichever is smallest.	CIP/BR
$foreign_{it}$	Dummy equal to 1 if the firm's ultimate beneficial owner is located outside Ireland.	CIP
K_{it}	Capital stocks. Capital stocks are calculated based on capital investments using the perpetual inventory method, where firm i 's stock of capital asset x at time t is obtained from investments I and depreciation δ_x as: $CS_{xit} = (1-\frac{\delta_x}{2})[I_{xt} + (1-\delta_x)I_{xt-1} + (1-\delta_x)^2 I_{xt-2} + \ldots]$. Assets are buildings, machinery and equipment, transport equipment and other assets. From 1999 other assets are further broken down into software, computer equipment and other assets. Asset lives, implied depreciation rates and deflators are those underlying CSO's calculations of industry level capital stocks (Central Statistics Office, 2009). Total capital stock for each firm is the sum over individual assets. Capital stocks are calculated from 1985 onwards to make sure that they are driven as much as possible by firm's capital acquisitions rather than by starting stocks. The sampling frame in the Census of Industrial Production was different until 1990, however, for the mostly larger firms that are still in operation after 1991 the data are comparable. Starting stocks in 1985 and for firms that entered after 1985 are obtained by breaking down the previous year's end of year industry level capital stock obtained from CSO to the firm level using the firm's share in industry-level fuel use.[5]	CIP
exch enabled	Share of business addresses enabled for DSL broadband in the firm's electoral division in the relevant year.	EIRCOM
$exporter_{it}$	Dummy equal to 1 if the firm reports a positive share of exports.	CIP
dist to exch	Average Euclidean distance from business addresses to their local exchanges in the firm's electoral division in the relevant year.	EIRCOM
DSL	DSL any type, DSL$<$ 2MBs, DSL$\geq$ 2MBs, DSL other. See Section 3.	ICT
$importer_{it}$	Dummy equal to 1 if the firm reports positive share of material imports.	CIP
L_{it}	Number of employees.	CIP
M_{it}	Total purchases of materials in 1000EUR deflated with the wholesale price index for intermediate industries except energy.	CIP
$manage_{it}$	Share of managerial and technical employees.	CIP
$multi_{it}$	Dummy equal to 1 if the firm is a multi-unit enterprise, i.e. has several local units in Ireland.	CIP
$shempuwww_{it}$	Share of employees using the internet.	ICT
$size_{it}$	Log number of employees.	CIP
Q_{it}	Turnover (sales) in 1000EUR deflated using wholesale/producer price indices at the 2-3 digit NACE (Rev. 1.1/Rev. 2) level.	CIP

Note: CIP - Census of Industrial Production, BR - Business Register, ICT - Survey of E-commerce and ICT. All price indices are obtained from CSO and the base year is 2000.

Table 11: Productivity definitions

Productivity measure	Description
TFP_{it}	See section 2. TFP is calculated for all firms in the CIP over the period 2001 to 2009.
$TFPindex_{it}$	We use a superlative index number approach and define TFP as $$TFPindex_{it} = \ln \frac{Q_{it}}{\bar{Q}_j} - \sum_{z=M,K,L} \sigma_i^z \ln \frac{x_{it}^z}{\bar{x}_j^z},$$ where a bar above a variable denotes the geometric mean of that variable over all establishments in the same 3-digit industry averaged over all years. $\bar{Q}_j$ and $\bar{x}_j$ are the geometric means of output and use of production factor z in industry j . The variable $\sigma_i^z = (\alpha_i^z + \bar{\alpha}_i^z)/2$ is the average of the factor share in firm i andthe geometric mean factor share. We impose constant returns to scale so that $\sum_z \sigma_i^z = 1$.
LP_{it}	Labour productivity defined as $\ln(Y_{it}/L_{it})$.
ΔTFP_{it}	$TFP_{it} - TFP_{it-1}$. Observations in the top and bottom .25 percentile of the distribution are dropped. ΔTFP is calculated for all firms in the CIP over the period 2002 to 2009.
$\Delta TFPindex_{it}$	The measure of TFP is derived from a flexible translog specification of the production technology. $$\Delta TFPindex_{it} = \Delta \ln Q_{it} - \sum_{z=M,K,L} \widetilde{\alpha_{it}^z} \Delta \ln x_{it}^z,$$ where x_{it}^z is the quantity used of factor z in plant i at time t. The Divisia share $\widetilde{\alpha_{it}^z}$ is defined as $\widetilde{\alpha_{it}^z} = (\alpha_{it}^z + \alpha_{it-1}^z)/2$ where α_{it}^z is the cost share of factor z relative to total output value Q in plant i at time t. We impose constant returns to scale.
ΔLP_{it}	$LP_{it} - LP_{it-1}$.

A.2 Additional Tables

Table 12: Productivity and covariates by type of connection for sample of firms with full-length ED codes - Means and standard deviations

	all firms	no DSL	DSL any type	DSL $\geq$ 2MBs	DSL other	DSL < 2MBs
TFP	2.460 (0.427)	2.407 (0.352)	2.521 (0.493)	2.494 (0.465)	2.613 (0.555)	2.481 (0.449)
ΔTFP	-0.005 (0.231)	-0.003 (0.244)	-0.008 (0.214)	-0.013 (0.211)	0.005 (0.228)	-0.016 (0.199)
$TFPindex$	-0.052 (0.591)	-0.040 (0.569)	-0.066 (0.615)	-0.092 (0.582)	-0.045 (0.637)	-0.055 (0.631)
$\Delta TFPindex$	-0.011 (0.246)	-0.005 (0.255)	-0.018 (0.236)	-0.032 (0.239)	-0.010 (0.246)	-0.013 (0.213)
LP	4.928 (0.818)	4.753 (0.702)	5.129 (0.892)	5.072 (0.897)	5.331 (0.957)	5.073 (0.823)
ΔLP	0.008 (0.267)	0.015 (0.279)	0.000 (0.252)	-0.016 (0.247)	0.015 (0.246)	-0.000 (0.256)
size	3.732 (1.064)	3.406 (0.842)	4.107 (1.165)	4.121 (1.162)	4.383 (1.224)	3.954 (1.135)
$\ln age$	2.892 (0.672)	2.821 (0.687)	2.973 (0.646)	2.994 (0.633)	2.961 (0.641)	2.980 (0.676)
manage	0.146 (0.117)	0.131 (0.094)	0.164 (0.137)	0.162 (0.128)	0.174 (0.162)	0.155 (0.122)
shempuwww	0.266 (0.236)	0.192 (0.191)	0.351 (0.255)	0.356 (0.250)	0.392 (0.279)	0.322 (0.238)
multi	0.036 (0.186)	0.023 (0.151)	0.051 (0.219)	0.054 (0.226)	0.058 (0.235)	0.057 (0.232)
foreign	0.250 (0.433)	0.147 (0.354)	0.370 (0.483)	0.338 (0.473)	0.479 (0.500)	0.318 (0.466)
exporter	0.696 (0.460)	0.618 (0.486)	0.786 (0.411)	0.786 (0.410)	0.828 (0.377)	0.753 (0.432)
importer	0.800 (0.400)	0.747 (0.435)	0.862 (0.345)	0.874 (0.332)	0.880 (0.325)	0.829 (0.377)
Obs	5555	2972	2583	1037	891	842

Note: Categories <2MBs, $\geq$2MBs and other are nearly but not fully mutually exclusive.