ICT and Exporting:

The effects of broadband on the extensive margin of business service exports

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Abstract
Over recent decades the global economy has witnessed rapid growth of international trade in services. This has been particularly true of service-intensive countries such as the UK. Developments in information and communication technologies are an obvious explanation for this. We provide empirical evidence for the effects of broadband use on the firm-extensive margin of UK service exports. To deal with the issue of causality we build a novel instrument that exploits exogenous variation in access to broadband technologies due to the historic telephone network. We find evidence for a causal effect from the internet on trade in business services, but no evidence for an effect on trade in services more generally.

Keywords: broadband, exports, services, instrumental variables

JEL codes: F14; L8; L25; O33

1. Introduction

Once viewed as largely non-tradable, international trade in services has grown rapidly over recent decades and now account for a substantial share of global trade (Francois and Hoeckman, 2010). By 2013 international trade in services had reached $4.7 trillion, a share of 20% of total world exports (UNCTAD, 2014). The rise in this trade has been particularly important for service-intensive countries such as the UK. In the decade between 1998 and 2008, UK service exports increased by 156% to $288 billion (see *Figure 1*). For the UK the growth in service exports was twice that of goods exports over the same period (BIS, 2011). Behind this aggregate growth there has been both expansions in the number of firms that export services, the firm-extensive margin (see Figure 2), as well as the value of exports per exporter, the firm intensive margin (see Figure 3).

But what accounts for this rise? Recent developments in information and communication technologies (ICT) are one commonly cited explanation (e.g. Grossman and Helpman, 2008, Baldwin and Nicoud, 2007, Fort, 2014).[1] Of these technologies, arguably the most important impacts on exports have come from the development of broadband internet. Broadband technologies have allowed for faster and more comprehensive information transmission, meaning that it is easier to collaborate and coordinate at a distance and therefore purchase and consume many service functions. These effects are likely to be particularly strong for services that are information intensive and rely for their delivery on communication networks. Services of this type are likely to include business services such as processing (such as accountancy, billing), financial analysis, marketing, product design, consultancy, management, medical functions (such as x-ray diagnostics) and R&D. Broadband has also encouraged firms to develop websites as part of their strategy for sales. These allow customers to more easily view the services that a firm offers, increasing the market potential of the firm. Together these have acted to lower the costs of entering into export markets and increased sales for those already exporting.

Consistent with this Figure 1 shows that the period of rapid diffusion of broadband in the UK from 1999 to 2008 corresponds closely to the period of growth in service exports. Or more formally, Freund and Weinhold (2004) found that the growth of trade is significantly correlated with growth in the use of the internet, while Freund and Weinhold (2002) find that exports of services to the U.S. grew more quickly from countries with deeper internet penetration. Clarke and Wallsten (2006) find a similar effect from internet penetration on exports from developing to developed countries. Correspondingly at the micro level Abramovksy and Griffith (2006), Clarke (2008), Ariu and Mion (2010) and Fort (2014) report evidence that firms that trade services internationally, including those from the UK, are more intensive users of ICT.

In this paper we utilise rich micro-data to consider whether broadband internet technology can explain the growth of UK service exports. A key empirical challenge that must be faced when answering this question is how to deal with the endogeneity of the type of internet connection adopted by firms. Firms do not adopt faster internet connections such as broadband at random, they choose to do so because of the expected

[1] There also exist alternative explanations: Breinlich et al. (2014) explore the shift to producing services by manufacturing firms in response to increased trade liberalisation. Lancheros and Demirel (2012) study the relationship between access to finance and service exports in India. There also exists evidence that firm characteristics affect the decision to export, see Vogel (2010), Minondo (2014), Temouri et al. (2013).

benefits that the technology might bring, including its effects on their ability to export. As noted in Lileeva and Trefler (2010), Bustos (2011) investment in new technologies and exporting are complementary activities. Exporting raises the return to investment in new technologies and the use of new technologies makes it more likely the firm will successfully export.

To address the issue of endogeneity we use a novel instrumental variable approach that exploits, for a short-time window, spatial differences in broadband availability and broadband speeds. This raises the likelihood that affected firms will use broadband technology, but does not (directly) affect the costs of exporting, allowing us to study the effects of broadband on service exports, at least for those who are compelled to use broadband because of the instrument. Our instruments are drawn from exogenous features of the historic subterraneous fibre-optic and copper wire telephone network, the infrastructure through which broadband internet services are delivered in the UK and area, and are based on related work in De Stefano (2014, 2015) which consider non-trade effects of ICT.

The telephone network is configured such that every firm (and household) is connected to a street cabinet. The cabling from these street-cabinets is in turn aggregated at the local telephone exchange, which is connected to the fibre-optic backbone of the network. Each firm is connected to a single, pre-determined street cabinet and therefore telephone exchange. There are 5,630 telephone exchanges in the UK, owned by the monopoly provider British Telecom (BT).[2] The locations for these exchanges were often decided at the birth of the telephone network back in the 19th century and its growth around the Second World War. Our focus is on the firm and its connection with the telephone exchange, the copper cabling between which is known as the local-loop.

During the time period that we study, broadband is affected by connections with the telephone exchange in two ways. Firstly, it coincides with the upgrading of telecoms infrastructure to support Asymmetric Digital Subscriber Line (ADSL) broadband, the most common broadband technology in the UK.[3] The roll out of alternative broadband technologies, such as cable or leased line, pre-dates our time period. ADSL offered internet connection speeds of up to 8mpbs, compared to 64kbps offered by the previous narrowband (dial-up) technology. To enable a local exchange to be ADSL ready required a number of modifications.[4] The large number of exchanges combined with limits to the number of BT engineers meant that the rollout of ADSL began at the end of 1999 and took until to 2007 to complete. BT began offering ADSL broadband services from 2000 onwards.

A second effect, which is the effect we focus on, occurs within the area of ADSL-enabled exchanges. ADSL broadband speeds are affected by the length and quality of the copper-cabling used to connect the firm to the exchange, the local-loop.[5] ADSL performance depends on a number of features of the local loop

[2] There are also 37 exchanges located near Kingston Upon Hull in England that are operated by Kingston Communications rather than BT, which are also excluded from the analysis.

[3] As in many other countries ADSL was seen as a cost-effective way of improving internet access speeds. British Telecom had a near monopoly on telephone infrastructure within the UK over this time period. Competition with BT by other firms existed in the billing of internet connections and other value added services such as email and web hosting but all of these suppliers used the BT network.

[4] This included the installation of ADSL equipment, but also air conditioning, connection to the internet backbone and a reliable electricity supply (Guardian, 2002).

[5] The quality of telephone calls could be maintained using copper wiring for distances up to 16 kilometres and there was no deterioration in quality up until 5 kilometres.

including the length of this cable, the diameter of the conductors in the wire, the metal used (usually copper but sometimes aluminium), the quality of the joints, other services provided in the same bundle of wires and noise ingress (much of which is at the customer premises). Holding these other factors constant, engineering tests by BT showed that for the earliest forms of ADSL connection speeds begin to deteriorate considerably for customers with a local-loop of greater than 2,000 metres, while those customers with a local-loop greater than 3,500 metres connections were usually deemed too far from the exchange to be offered broadband services.[6] We have data on the local loop distances for each firm in the UK.

It is worth noting immediately that these local loop distances did not affect the performance of the telephone[7], so is unlikely to have affected the historic choice of firms of where to locate compared to the telephone exchange. The effect of distance on broadband speeds is also apparent only for a short-time window. From late 2001 and into 2002 BT began to implement a technology called Rate Adaptive Digital Subscriber Line (RADSL).[8] This technology adjusted the speed of internet connections depending on the length and quality of the local loop, boosting connection speeds for those customers furthest from the telephone exchange and extended the qualifying distance to receive BT broadband from 3.5 to 5.5 kilometres. As we demonstrate later, RADSL reduces the importance of the length of the local loop for broadband adoption and we end the time period in 2002 as a consequence.

These two features of the telephone network, enablement of exchanges for ADSL and local loop lengths, generate two sources of variation in access to broadband networks that predict firm broadband adoption. Our preferred analysis focuses on the latter as a single instrument, that is, firm-specific variation in local loop lengths (i.e. variation in ADSL broadband speeds) within the area of enabled exchange areas. That the time period we study coincides with rollout of ADSL across the UK offers a potential alternative instrument with which to test for the effect of broadband on firm-export decisions. However, we do not focus on this approach out of concern that the timing of ADSL rollout may not satisfy the exclusion restrictions necessary for instrument validity. The ordering in which exchanges were enabled did not occur randomly, it was a commercial decision by BT. Exchanges with the greatest commercial return, greater numbers of potential customers and shorter average local loops, were therefore more likely to be enabled early on in the rollout programme.[9] The timing of enablement is potentially correlated with agglomeration economies, which will affect the performance of firms including its ability to export.

We use this to instrument for firms' decisions to use broadband to test for the effects of broadband technology on the extensive and intensive margins of service exports. The data we employ is from three main sources. Our source of firm level data is from the UK Office for National Statistics (ONS). Data on firm service trade transactions is from the *International Trade In Services Inquiry* (*ITIS*) and firm location and characteristics is from the *Annual Respondent's Database* (*ARD*) and *Business Structure Database* (BSD). These are the primary sources of UK firm-level data and have been used by Bloom et al (2012) and Breinlich

[6] This was explained as being disqualified due to poor line quality. This could also occur for customers with a local loop length of less than 3.5km if the line was deemed incapable of holding a broadband connection of sufficient speed.
[7] A telephone call could be maintained for up to 16 kilometres and at least 5 kilometres from the exchange (Macassey, 1985).
[8] This was also known as 'extended reach ADSL'. We have been unable to obtain information on the rollout of RADSL across the UK.
[9] ADSL was primarily targeted at households with exchange enablement allowing connection of many more homes than businesses (the mean exchange serves 4,740 households and 255 firms). But this does not satisfy concerns for this instrument.

and Criscuolo (2011) amongst others. *ITIS* provides information on the value of exports by type of service and by destination, allowing us to separate exports into its various firm and service-type extensive and intensive margins. Information on firm-level broadband adoption is contained within the *E-commerce Survey*, also from the ONS. We combine the firm-level data with information on the telecoms network made available by the Office of the Telecoms Regulator (*OFCOM*) and a UK-based telecoms data firm, *Point-Topic*. From *OFCOM* we have precise information on the day each local exchange was enabled for ADSL and its location.[10] The large number of exchanges indicates that the spatial variation we exploit is far more disaggregated than regional, local government or even city-level. There are 185 telephone exchanges in London for example. The data from *Point-Topic* contains information on local-loop lengths for 1.66 million postcodes (zip codes) in the UK along with the telephone exchange that the postcode is connected to.

We find only partial success in providing an explanation for the obvious correlation between service exports and broadband internet use in the UK that motivates the analysis. We find a strong effect of broadband on the extensive margin of firm exports, but only for those exporting businesses services and only for a small part of the population. The instruments are significantly correlated with the use of broadband by firms and pass the standard tests for weak instruments and over-identification. In the second stage we find that broadband significantly affects the propensity to exports only when we restrict the analysis to business services however. These services, it is argued, are information intensive and so were most likely to benefit from this new technology. Here we find that firms that were induced to use broadband because of the increased availability of the technology were between 64-66% more likely to export business services than firms that did not use the technology. Our explanation for the strength of this local average treatment effect is that the compliant firms' whose effect we capture are a small part of the population of firms, which we calculate to be around 5% of treated firms. In contrast, we find no consistent significant effect when we use total exports, a result which occurs even when we use data on exports from the ARD database, which is not restricted to service exports and is available for a larger number of firms. We can also reach no conclusions regarding the effects of broadband on the intensive margin of exports owing to a problem of weak instruments. Amongst those firms that export, we find that the instruments have the expected relationship with broadband use, but collectively do not have a sufficiently strong relationship. This holds irrespective of whether we use total service or just exports of business services. Bringing these results altogether we estimate that the causal impact of the internet of UK service exports in the period 2000 to 2002 was in the range £1.0-£1.4billion.

Within the paper we provide detail on the ADSL enablement programme by BT and deal with concerns that the effects of this rollout may contaminate the local loop variable that acts as our instrument for broadband use. To support the validity of the instruments we provide a range of supporting tests. Firstly, we demonstrate that the negative correlation between broadband adoption and the length of the local loop weakens as expected with the introduction of RADSL technologies over time. Second, we demonstrate that the instruments are not significantly correlated with ex-ante firm characteristics. This would tend to rule out the presence of unobserved exchange specific factors that are correlated with the timing of enablement and a range of performance indicators that have been found to be correlated with firm exports. Thirdly, we

[10] In our analysis we use data for 5,536 exchanges. Our micro data on firms excludes Northern Ireland.

perform a variant of Wooldridge's (2010) strict exogeneity test to examine lead effects in advance of ADSL enablement. We find no evidence of broadband adoption in anticipation of the arrival of ADSL. Finally, we test for the addition of other confounding factors, including agglomeration effects, and additional aspects of firm performance.

This paper contributes to three literatures. The first is the literature on the firm level determinants of export market participation, which is reviewed by Greenaway and Kneller (2007). The second, a rather small literature, concerns the effects of information and communication technologies on international trade, including trade in services, using micro data.[11] In general the effect of broadband on international trade is found to be positive in this literature. Ariu and Mion (2010) consider how industry changes in IT use affect the exports of Belgian firms, while Clarke (2008) studies the effect of internet use on the probability of exports, including those by service sector firms, in Central and Eastern Europe and Central Asia.[12] Of the papers using an instrumental variable approach perhaps the closest paper in approach to ours is that of Abramovksy and Griffith (2006). They consider for a cross-section of UK firms how internet use affects the propensity to outsource or trade services using an instrument based on the number of households that are connected to the internet at the region level. Fort (2014) considers a similar question using cross-industry differences in the codifiability of information in a difference-in-differences approach. As already described, the main contribution of this paper to this literature is the presentation of the first evidence on the effect of broadband on services exports using an instrumental variable approach based on the infrastructure of the internet.

The third somewhat larger literature explores the role of ICT on various aspects of firm performance. Prominent works here include that of Bresnahan et al (2002), Bloom et al (2005), Hubbard (2003), Bartel et al (2007), Brynjolfsson et al. (2008) and Bloom et al. (2014), while Draca et al (2006) and Cardona et al. (2013) provide recent reviews. Within this literature there exist a small number of studies that have used the timing of ADSL enablement, and distance from the exchange as instruments. However, in the absence of information of which telephone exchange a firm is attached to, these have often been based on much larger geographic units than are available to us, or use broadband adoption by households as a proxy. For instance, Haller and Lyons (2012) use ADSL exchange enablement to predict Irish firms' broadband adoption and the effect on productivity, with firm location at the electoral ward level. In a similar study for German firms, Berthschek et al (2013) use ADSL enablement to predict broadband adoption with firm location at the region level. Akerman et al (2013) use household adoption of ADSL as a treatment, and find that firms located in areas with higher household adoption experienced faster productivity growth and rising skilled worker wage premiums.[13] The exception to this is DeStefano et al. (2014, 2015) who also use ADSL enablement and distance from the telephone exchange to study the effects of ICT on productivity as well as employment, and

[11] Breinlich and Criscuolo (2011) provide a set of stylised facts about service exports for the UK using the same micro data as this paper. They find a similar set of patterns to trade in services as those found for trade in goods. The correlation with characteristics of the firm is provided in that paper and in Harris and Li (2009) using an alternative data source. Similar evidence for other countries can be found in Walter and Dell'mour (2010), Federico and Tosti (2012), Shepherd (2012), Temouri et al. (2013) and Minondo (2014).
[12] There is also an older literature using aggregate data on ICT and service exports which also finds positive effects (Freund and Weinhold, 2002; Clarke and Wallsten, 2006).
[13] Czernich (2012) uses distance from the exchange to predict German household broadband adoption and the effect on voting behaviour, with household location at the municipality level.

sales growth. Using the same instrument set as this paper, DeStefano et al. (2015) find a positive effect of ICT on firm sales. We extend this to consider the international dimensions of these sales as well as the type of service the firm exports.

The remainder of the paper is structured as follows. In the next section of the paper we briefly outline the data that we use within the study. Section 3 outlines the empirical methodology and Section 4 the instruments that we use. Within this section we provide initial evidence of a relationship between broadband use and the instruments along with various tests for instrument validity. In Section 5 we detail the main regression results including those for business services and the destination of exports. We use Section 6 to draw some conclusions from the paper.

2. Firm-Level Data

i. Sources

This paper utilises data from three main data sources. All of the information of firms, their exports, location and characteristics is from the UK Office for National Statistics through the Secure Data Service. These are the same primary sources of UK firm-level data and have been used by other authors including Bloom et al. (2012) and Breinlich and Criscuolo (2011). From the ONS we combine information from four datasets, which we combine using a set of unique identifiers. Further information on each of these datasets is provided in the Appendix to the paper and we provide only brief details here.

The primary data source on exports of services is the International Trade in Services Inquiry (*ITIS*). *ITIS* contains annual transaction-level data for the services trade of UK firms. From this we can calculate whether or not the firm exports (the firm-extensive margin), how much it exports (the firm-intensive) margin, what type of service it exports and the destination market. Of the types of service exports we focus on total service exports and exports of business services. A list of services included in these definitions can be found in Appendix Table A1).

GATS defines trade in services as service transactions between residents and non-residents of an economy (Breinlich and Criscuolo, 2011), and disaggregate these into four potential modes of supply. "Cross-border supply" (mode 1) are services provided from the territory of one country into the territory of another, i.e. services that are transmitted across countries. These are services received via telecommunications or postal infrastructure (WTO, 2014), examples include international outsourcing of UK business functions or consulting services provided to a foreign firm. "Consumption abroad" (mode 2) are services provided in one country to the service consumer of another, i.e. the consumer has travelled to another country to consume services. Consumption abroad encompasses tourism, international training courses, studying abroad and medical patients travelling to receive treatment in another country. "Commercial presence" (mode 3) is defined as services provided via commercial presence in another country. These are services through foreign affiliates or subsidiaries, such as bank branches or hotels in foreign countries. Finally, "movement of natural persons" (mode 4) reflect services provided through the presence of a natural person from another country, i.e. the producer has travelled to another country to produce services. These can include independent suppliers, such as consultants and health workers, or employees, such as foreign employees of consultancy firms or hospitals.

The definition of service trade in ITIS follow the IMF's Balance of Payments Manual (5th Edition) and feeds into the UK balance of payment statistics. ITIS records service transactions between UK firms and non-residents, where services are defined as products other than tangible goods. The survey questionnaires explicitly state that non-residents include any individual, organisation or enterprise that is not domiciled in the UK. ITIS data reflects mode 1 and 2, and to a lesser extent mode 4 (Kneller et al, 2010). ITIS does not provide information on mode 3 (commercial presence).

ITIS contains almost no information on firm characteristics. We obtain information on ICT, which includes the use of broadband by linking to the E-commerce Survey. This dataset acts as the biggest constraint on the sample size available to us. As detailed further in the Appendix, this data is available from the year 2000. There is also a substantial increase in the sample size of the survey between 2000 and 2001. The availability of data only from 2000, the increase in the sample size between 2000 and 2001 and our decision to end the sample period at the end of 2002 prevents us from studying the effect of the instruments on firms that switch into using broadband over this period. We note however that is substantial adoption over time. Figure 4 shows that in 2000, only 38% of firms had broadband access, by 2001 it was 63%, 73% by 2001 and 96% by 2005.[14]

Finally, we obtain location and other covariates from the Business Structure Database (BSD) and Annual Respondents' Database (ARD) respectively. These include the age of the firm, its ownership status (domestic or foreign), size, sales and whether it has multiple plants. Since 2000 the ARD also contains a question on exports and we use this as an alternative measure of firm exports. [15]

Table 1 describes the sample size of the merged data. The merged data commences in the year 2000, the first year of the E-commerce survey and finishes in 2005. Beyond 2005 ITIS has missing data and is difficult to use. The E-commerce survey has around 6,000 to 9,000 firm-level observations each year. The vast majority of these firms are also present in the BSD, with more than 94% of firms being matched in a given year. Only around 30% of the firms are also present in the ITIS data, with substantially fewer (14%) present in 2000. The difference has been observed by other researchers, as noted in ONS (2014), and occurs when linking the E-commerce survey to other databases. The resulting merged sample is fairly small, 13,099 firm-year observations spread over the six years. Despite the small sample size in the merged data, the data represents approximately 40% of the trade in raw ITIS data. Both the E-commerce survey and ITIS tend to sample large firms more frequently than smaller firms, meaning the union of the datasets will be directed towards larger firms. For reasons laid out in more detail below we do not use all of the observations available to, instead using the years 2000-2002, and in the estimation sample we have 3,362 firm-year observations.

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[14] The initial level of 38% adoption at the 2000 calendar year end may seem large as it is only one year after ADSL was launched in July 1999. However, as discussed earlier, the broadband measure in the e-commerce survey reflects any fixed broadband connection. Other types of broadband included in the measure, such as leased line and cable, had infrastructure rolled out before ADSL (see further discussion in section 4).

[15] Unfortunately the ARD contains almost no information on the type of service traded.

The second key data source used in this study is the ADSL Broadband Database which was made available by the office of the regulator for telecommunications in the UK, OFCOM. The ADSL dataset provides the location (postcode) and date for ADSL enablement for each telephone exchange in the UK. This data is combined with a third dataset purchased by a UK based telecom consultancy firm called *PointTopic*. This data is available at the postcode level, for which there are 1.66 million in the UK. It contains information on the telephone exchange that each postcode is connected to and the length of the local loop (the cable distance between the telephone exchange and the postcode). We merge these datasets with the micro data from the ONS based on the postcode of the firm.

ii. Summary Statistics

Summary statistics for the total merged data and the estimation sample are provided in Table 2.

A minority of firms in the sample trade services, 26% of firms are exporters (see Table 2). The proportion of exporters is relatively high, reflecting that ITIS and E-commerce Survey over-sample medium and large firms, with the smallest firms (that are less likely to trade services) less represented. The mean exporter sells £28m of services abroad. The data on employment and turnover again suggest the firms in the merged data are medium and large. The mean firm in the sample has 1,732 employees and average sales of £294million per year and nearly three quarters of the firms have multiple plants. The average firm is 20 years old and 29% of the firms are foreign owned. These summary statistics are very similar for the estimation sample. The obvious exception to this is the share of firms that have broadband, which is 61% in the estimation sample compared to 77% in the total sample. This reflects the fact that for this estimation sample we use data from closer to the start period when broadband use was less prevalent.

3. Estimation Strategy

In our empirical analysis we regress service trade (whether the firm exports or not and how much it exports) for firm i, in location l at time t (X_{ilt}) on the treatment, the use of broadband $(Broadband_{it})$. Our analysis focuses on the effects of broadband on the extensive margin of firm exports, although we also present results for the intensive margin. The broadband variable reflects whether the firm has any fixed broadband connection, meaning any broadband connection transmitted via a wire, which includes ADSL, cable and leased-line broadband (see the Appendix for further discussion):

$$X_{ilt} = \beta_0 + \beta_1 Broadband_{ilt} + \beta_2 Y_{ilt} + \beta_3 FE_{l,j,t} + \varepsilon_{ilt} \quad (1)$$

We include a vector of variables (Y_{ilt}) which control for the effects of firm age, foreign ownership and whether the firm has multiple plants. We use two-period lagged firm controls in preference to current measures, due to the potential for broadband to impact contemporaneous firm characteristics.[16] Lagged values of alternative variables such as employment or productivity would result in a loss in sample size of over a third and so are not included in the baseline estimation, although we test the sensitivity to this in Section 5.[17] In all of the regressions we include time dummies, to capture any common shocks that may affect exporting by all firms, and in the OLS version of the regressions we additionally include region and industry (denoted j) which capture regional differences in infrastructure, education or income, time trends or differences in the costs of trading services across industries. We denote these in equation (1) as $FE_{l,j,t}$.

To control for endogeneity we employ instrumental variable estimation. Our instrument captures differences in firms' ability to access broadband internet services by their cable-distance (local loop length) to the exchange, which affects broadband speeds. This instrument in denoted by Local Loop Distance in the first stage regression detailed as equation (2) below. In these IV regressions we compare differences in the probability of firms using broadband based on variations local loop distances within the area of exchanges enabled for ADSL, using pooled cross-section data between 2000 and 2002.

$$Broadband_{ilt} = \alpha_0 + \alpha_1 Local\ Loop\ Distance_{il} + \alpha_2 Y_{ilt} + \alpha_3 FE_t + \vartheta_{ilt} \quad (2)$$

Throughout the analysis we report standard errors that employ the Huber-White correction for heteroskedastic robust standard errors. We employ standard errors that are clustered at the firm-level to allow for correlation of standard errors within each firm.

4. Instrumental Variables

In this section of the paper we provide a description of the instrument that we use to explain firm broadband use. This includes a description of ADSL broadband technology, the period of the rollout programme that we study and initial evidence of their explanatory power and tests for instrument validity.

i. What is ADSL?

Asymmetric Digital Subscriber Line (ADSL) is the dominant form of broadband in the UK. In 2012 over 85% of firms and 55% of households had an ADSL connection (ONS, 2013a, 2013b). ADSL allows high-speed transmission of data along the pre-existing copper-line telephone network. The asymmetry that the technology generates between the upload versus download bandwidth means that the speeds offered by ADSL broadband were a substantial improvement on those provided by existing narrowband technologies, such as dial-up and ISDN. Dial-up only offered download speeds up to 64Kbits/second, with ISDN[18] offering speeds of up to 128Kbits/second, compared to up to 8,000Kbits/second for ADSL.

[16] Notice that using two period lagged values is consistent with using values in 1998 (prior to ADSL diffusion), for observations at the start of the sample period (2000). Two period lags are preferred to using 1998 values throughout due to higher sample sizes and consistency across repeated cross-sections.

[17] The short time frame used for estimation also prevents us from including firm fixed effects.

[18] ISDN is a narrowband technology that, like dial-up, operates through the telephone network. Essentially it involves installing a second telephone line to the premises, allowing one line to operate as a dedicated data line and the other can operate for telephone

ADSL broadband infrastructure relies on the pre-existing telephone network, which was installed in the 19th and early 20th centuries in the UK. The UK provides an unusual case compared to many other countries since BT had a monopoly on the telecoms infrastructure.[19] The telephone network has a tree-like configuration. Each household and business is connected to a single, pre-determined street cabinet. These connections are aggregated at the street cabinet, which are in turn aggregated at the telephone exchange (see Figure 5). Each street cabinet is connected to a single telephone exchange and the exchange is then connected directly to the fibre-optic backbone of the network. The cable between the telephone exchange and the customer features prominently within our analysis and is known as the local loop. The lack of inter-connections in backbone cabling beyond the telephone exchange means that it is not possible for households/businesses to switch telephone exchanges. The network is structured such that the geographic areas covered by an exchange are relatively small, often sub-city level. There are 5,536 BT telephone exchanges in the UK and London has 185 exchanges (a population of 7.2 million in 2000). The mean exchange is connected to 4,470 households and 250 business premises.

To enable a telephone exchange for ADSL, equipment has to be installed in the local telephone exchange that allows the aggregation of the signals from all the ADSL users connected to that exchange (called "DSLAM" equipment). The exchange also requires a reliable electricity supply and air-conditioning; the latter may necessitate an extension to the building to accommodate it. For rural areas there can be an additional cost of upgrading to a fibre optic backbone connection, this can be the most substantial cost for such exchanges (Guardian, 2002). Finally, within the customer's premises a modem with a line splitter is required; the line splitter allows simultaneous use of the line for telephone calls and ADSL broadband.

ADSL broadband speeds depend on the length of this cable, the diameter of the conductors in the wire, the metal used (usually copper but sometimes aluminium), the quality of the joints, other services provided in the same bundle of wires and noise ingress (much of which is at the customer premises). Engineering tests by BT showed that when measured in the absence of these additional factors, for the earliest form of ADSL, connection speeds deteriorate for cable-lengths beyond 2,000 metres. At the start of the ADSL enablement programme, BT would not connect customers with a cable-distance greater than 3,500 metres unless they had a high-quality line. At these cable distances, connection speeds were close to those of narrowband. Speeds could be upgraded by replacing copper wiring with fibre-optic cables, but the subterraneous nature of much of the telephone network means this is very costly and was not done until after our data period.[20] For information, Figure 6 shows the effect of distance on ADSL speeds.

Importantly for the validity of our instrument, cable distance from the telephone exchange did not substantially affect the quality of voice calls. The signal for voice calls is boosted by loading coils and could

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calls or, when not in use, a secondary data connection. The speeds are up to 128Kbits/second, double those of dial-up, when the secondary line is not being used for telephone calls.

[19] The ability of other providers to install their own ADSL equipment, so-called Local Loop Unbundling, was negligible until at least 2005 (Cadman, 2012). In August 2000 telecoms regulator Oftel mandated BT to fully unbundle their local loop and in 2001 that BT to offer access to the telephone network on "cost-orientated terms". However, as of 2003 the UK had one of the highest unbundling charges in Europe such that by the end of 2002 only 200 exchanges were equipped for an unbundled local loop. There had been very little takeup of fully unbundled (telephone) lines (1,600 by mid-October 2002). This was not the case in other European countries, for example by 2005 the proportion of unbundled telephone lines in France was more than 55%, with similar figures for Germany (60%), Italy (45%) and Spain (25%).

[20] Using fibre optic wiring to connect homes to local exchanges did not occur in the UK until 2009.

potentially be maintained for up to 16 kilometres, with no deterioration for distance below 5 kilometres from the exchange (Macassey, 1985). Loading coils are not compatible with ADSL.

From June 2001 to 2002 BT trialled and then implemented a technology called Rate Adaptive Digital Subscriber Line (RADSL).[21] This technology adjusted the speed of internet connections depending on the length and quality of the local loop. This modified the effect of cable distance on connection speeds for all customers and extended the qualifying distance to receive BT broadband from 3.5 to 5.5 kilometres. Again this required some, albeit comparatively modest, changes to the exchange and was made available to customers free of charge. We use the historical nature of the telephone network combined with the weak effect of distance on telephone calls to argue that the cable distance from the telephone exchange was from the perspective firm export decisions as good as randomly assigned. That is, it provides a valid instrument to test for the effects of broadband use of the export decision of firms.

ii. UK ADSL Rollout

The introduction of RADSL leads us to focus the analysis on the period from 2000 to the end of 2002, when local loop distance had the strongest effect on ADSL broadband connection speeds. As this period coincides with the rollout of ADSL enablement by BT and therefore the telephone exchanges that we include in the analysis varies with time, a legitimate concern must be that the commercial factors that drove the choice of which exchanges were enabled at which point in time are correlated with our choice of instrument for broadband. We take this issue seriously within the paper and provide supporting evidence that this is not the case. We begin this process with a discussion of ADSL enablement in the UK.

The UK started to rollout ADSL infrastructure in July 1999, which was later than many other countries such as Germany and USA (BBC News, 2002). BT had been testing ADSL since 1994, but news articles at the time argue that BT delayed the rollout of ADSL to protect their existing monopoly on narrowband technologies such as dial-up and ISDN (BBC News, 1999). The rollout commenced at short notice, as of February 1999 BT had not informed the public of any rollout plans, and from 2000, customers could purchase ADSL broadband services.

The rollout of ADSL infrastructure across telephone exchanges was not simultaneous. Constraints on the availability of BT engineers required to upgrade exchanges as well as install modems into customer premises, meant the rollout proceeded sequentially (BBC News, 1999). Initially, the target of BT was to provide broad geographic coverage, rolling out ADSL infrastructure to various cities and urban areas across the UK. The decision does not appear to have been made simply on city-size and income however. In July 1999, BT announced the first cities to be upgraded would comprise London, Cardiff, Belfast, Coventry, Birmingham, Manchester, Leeds, Newcastle, Edinburgh and Glasgow. The second group of cities announced in February 2000, included Hastings, Brighton, Aberdeen, Basingstoke, Carlisle, Chelmsford, Liverpool, Oxford, Portsmouth, Nottingham, York, Swindon, Royal Tunbridge Wells, Winchester and Ashford. The first cities include the capitals of the Wales, Scotland and N. Ireland (Cardiff, Edinburgh and Belfast), whose

[21] This was also known as 'extended reach ADSL'. We have been unable to obtain information on the rollout of RADSL across the UK.

enablement occurred before larger and more affluent cities such as Liverpool (4th largest city in the UK), Bristol (5th largest), Sheffield (6th largest) and Leicester (10th largest) (population data per 2011 census). The second group also include a number of small towns, outside the 100 largest towns and cities in the UK, such as Ashford with a population of 67,528, Carlisle with 75,306 and Royal Tunbridge Wells with 57,772 (2011 census data). From discussion with key players involved with the telecoms industry at that time we have learnt that important determinants of the timing of enablement for any given exchange was instead the number of customers connected to that exchange and the average length of the local loop. Figure 7 to Figure 10 show the ADSL enabled exchanges for the calendar year ends of 1999, 2001, 2003 and 2005.

Ex-post the rollout took place in two distinct phases, which we label "wave 1" and "wave 2". In November 2001, because of lower than anticipated household demand, BT announced the cessation of ADSL rollout. Again from discussions with industry experts it is evident that this break was ex-ante unplanned by BT and is unlikely to be anticipated by customers. At this point, BT had enabled approximately 20% of the 5,536 exchanges in the UK. BT resumed the rollout in July 2002 with a demand driven system. Households and firms had to register their interest with BT, and when the number of registrations exceeded a threshold, the exchange was ADSL enabled. BT also removed the need for engineers to install modems in customer premises, allowing self-installation. In April 2004, BT scrapped the registration scheme, and then pursued a policy of "universal access", meaning a target of ADSL being available to 99.6% of households and firms by summer 2005.

The two phases can be seen clearly from a graph of exchange enablement over time (Figure 11). Enablement begins in 1999, ceases in 2002, before resuming rapidly in 2003 onwards. By 2005 98% of all exchanges had been ADSL-enabled. As already noted larger exchanges, those with more households and firms connected, were on average enabled earlier than smaller exchanges. Figure 12 plots the size of each exchange (the number of business and household premises connected to an exchange) against ADSL enablement date, and shows best fit lines for wave 1 and wave 2 separately. The correlation with exchange size is far more obvious for wave 2, where there is a much clearer, stronger effect on timing of exchange enablement. To ensure comparability we restrict the enabled exchanges that we consider within the empirical analysis to wave 1 exchanges.

iii. UK Rollout of Other Broadband Technologies

During the time period, 2000 to 2002, there were there are no other substantial contemporaneous changes in UK broadband technology that may contaminate the analysis. The main alternative technologies for high-speed broadband access at this time were cable and, for businesses, leased line connections. Cable broadband utilises the network originally installed for cable television, which in the UK was installed before the rollout of ADSL took place. The cable network was rolled out in the UK in the early 1990s with the expansion ceasing by 1998 and thereafter, the number of premises eligible for cable broadband has remained broadly constant (Oftel, 2001).

Leased line access requires a permanent, dedicated fibre-optic connection between the customer and the local exchange. These differ from ADSL primarily in that they do not rely on the pre-existing telephone copper wiring to connect the premises to the exchange and offer higher connection speeds. However the high cost of installation makes this an option only for the largest firms. In August 2000 a leased line connection costs €3000-€150,000 per year depending on the length of the cable and the information capacity offered (Oftel, 2000). Leased line connections have been available since the before the 1990s and so again do not overlap with the timing of ADSL rollout (Oftel, 2001).

iv. Instrument Construction

Using the insights from the ADSL broadband rollout within the UK we create two potential instruments for firm's broadband adoption. The first instrument uses the year of enablement of local telephone exchanges for ADSL broadband. This data, made available by the Office of the Telecoms Regulator (OFCOM), details for every BT exchange in the UK the day that the exchange was ADSL enabled. The second instrument, which is our preferred measure, uses the length of the local loop made available from the *Point-Topic* database. Here we anticipate that because of lower anticipated broadband speeds, firms further from the exchange are less likely to adopt broadband. The median firm in the sample is 2.81km from their local exchange, see Table 3. The distances that we exploit are therefore relatively short, with the 95th percentile of local loop distances just 5.32 km. ADSL speeds decay for firms located more than 2km in terms of cable-distance from the exchange. In the sample a little under 75% of firms are located at least 2km away from their local exchange.

v. First-Stage Results

In this section we consider the strength of the instruments to predict firm broadband adoption decisions. We find the instruments are strong predictors of broadband decisions of firms and the estimated coefficients always have the expected sign and a plausible magnitude (see Table 4). Regressions 1 and 2 show the first-stage results when including both distance and ADSL as instruments and regressions and regressions 3 and 4 when we restrict the sample to include firms that are connected to wave 1 enabled exchanges and therefore uses local-loop distance as a single instrument. In regressions 1 and 3 we include just the instruments and in regressions 2 and 4 include lagged firm variables as well as year effects.

ADSL availability and local-loop distance are strong predictors of broadband access in all four regressions. According to the estimates from regression 2, being connected to an ADSL enabled exchange increases the probability of broadband access by 15.2% for firms that are right next to the exchange. As expected, those further from the exchanges, with slower expected broadband speeds, are less likely to adopt. The median firm (with a cable distance 2.81km from the exchange) is 8.5%[22] less likely to use broadband than a firm right next to the exchange. At the 99th percentile of distance (5.89km) ADSL speeds are very close to those from narrowband connections. According to the estimates from regression 2 for firms at this distance the probability that they use broadband is also close to 0%.

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[22] 8.5% is calculated as 0.083*ln(2.81).

Regressions 3-4 closely mirror regressions 1-2, with the estimated effect of distance and other firms controls only marginally different (8.3% less likely at the mean). The results from regressions 3 and 4 are important as they indicate that the historical cable-distance between firms' and their local telephone exchange are strong predictor of the likelihood of adopting broadband and that are findings are not dependent on differences in the timing of enablement.

Turning to the control variables, foreign owned firms are 11% more likely to have broadband and multi-plant firms are 9% more likely. The coefficient on the age variables indicates that this has only as minor effect on the broadband decision. Firms 10% older are only 0.4% more likely to have broadband.[23] The findings for foreign ownership and size (multiple-plants) are consistent with the literature (e.g. Haller and Siedschlag, 2011). However, other studies generally find younger firms are more likely to have broadband (e.g. Haller and Siedschlag, 2011) or there is no relationship (e.g. Haller and Lyons, 2012). This could result from age correlating with size and productivity, which are not included in the baseline as control variables (because of reductions in sample size of up to 50% as discussed in section 3). In unreported results we find evidence this is the case.

vi. Instrument Validity

Unfortunately, it is not possible to directly test whether an instrument is valid, that is, uncorrelated with service exports other than through broadband adoption. Objections to the instruments that we use could be raised on the grounds that the local loop distance is not randomly assigned and that the instrument fails the exclusion restriction.

An argument against the randomness of local loop distances is that the location of telephone exchanges, even though determined well before broadband had been conceived, were chosen to be close to centres of population and commerce. To aid with the laying of the network cables they were also often at major cross-roads. If the geographic factors that determine the location of telephone exchanges are also factors that determine where firms choose to locate, then cable distances to the exchange will be an outcome of the firms' decision process.

Of the potential confounding factors that might be present in our context, and therefore invalidate the exclusion restriction, the main concern is again the presence of unobserved geographic factors that are correlated with the timing of enablement or the location of firms and telephone exchanges and therefore the use of broadband and the exports of firms. Telephone exchanges have a limit to their capacity and therefore larger clusters of firms or households require greater numbers of telephone exchanges to be built. The number of telephone exchanges within an area is also likely to affect the length of the local loop; the greater the density of businesses and households the shorter local-loop lengths will be. It has also been shown that agglomerations are more likely to share information about how to export but also be more productive (Greenaway and Kneller, 2009; Koenig, 2009, Koenig et al., 2010, Martin et al., 2011) and share information about technologies, which would raise the likelihood that they use broadband. It therefore

[23] 0.4% is calculated as 0.037*ln(1.1).

follows that agglomerations of households and businesses help predict shorter local loop lengths, the use of broadband and the decision to export.[24] Such concerns remain even though the exchanges enabled before the end of 2002 (and within wave 1) are within the largely urban areas, are relatively small in size and the cable-distances we exploit are relatively short.

In an attempt to deal with this issue, in Section 4 we motivated our restriction on telephone exchange to those that were enabled under wave 1 of the ADSL rollout on the grounds that the characteristics of exchanges enabled within wave 1 were clearly different from those within wave 2 and were enabled according to different criteria. BT has not shared the criteria for the timing of enablement within wave 1 however and it remains possible therefore that there were some determinants that we are unaware of which are correlated with aspects of firm performance including their exports and it is this effect we capture even when we use local loop distance as a single instrument. To provide support for the validity of our instruments in the remainder of this section we provide a number of supporting test.

Narrowband and the Introduction of RADSL

Two claims made throughout the paper are that cable-distance affects the speed of broadband connection speeds lowering the likelihood that firms will use the technology and that this effect declines over time with the introduction of RADSL. Given that at longer cable distances broadband connection speeds approach those of cheaper technologies such as IDSN and narrowband, if the first claim holds we would expect to find the opposite relationship between cable distance and the use of this alternative internet technology. If it does not then this would be indicative of the presence of other potential confounding factors. To test the second claim, it would be expected that as RADSL becomes more prevalent, in a regression of broadband use the coefficient on cable distance would decline in magnitude over time. Again if this does not hold this would indicate the presence of geographic confounding factors, assuming that their effects do not decay quickly across time.

In regressions 5 and 6 in Table 4 we report the results from a regression in which we regress the likelihood that the firm uses narrowband on ADSL enablement, cable-distance, firm characteristics and year, industry and region controls. The results for the enablement of the exchange and local loop distance mirror those in the first four regressions in the table. We find that ADSL enablement reduces the likelihood that a firm uses narrowband internet connections, while firm that are more distant from the exchange are more likely to use narrowband.

In Table 5 we present a regression for the probability of exporting and cable-distance within the area of enabled exchanges by each year from 2000 to 2005. The results from this table are again supportive of our instrument and the view that our cable-distance variable is a suitable instrument for a short time window. We find a significant negative effect of local-loop distance for the years 2001 (regression 8) to 2004 (regression 11), the estimated coefficient for which declines over time in a manner consistent with the rollout of RADSL. By 2005 (regression 12) the effect of local loop distance is not distinguishable from zero.

[24] Although these agglomeration economies would have to affect exporters of business services only.

The estimated coefficient is also insignificant for 2000 (regression 6). This is against our expectations, but it may be because ADSL services only became available around the middle of that year and the regression is therefore affected by firms using leased line or cable broadband connections. It may also be because of noted weaknesses in the E-commerce survey for this year, which was a pilot survey in this year.

Pre-ADSL Firm Characteristics

Under an assumption that any unobservable geographic factors that make our instrument invalid are unlikely to change quickly across time but likely to be correlated with a range of firm performance variables, not just exports, their potential as an alternative explanation for the power of our instruments can also be tested by taking advantage of the panel data available to us. That is, we examine whether the instruments are correlated with a number of the firm characteristics others have found to predict service exports using data before ADSL rollout took place. If local loop distance or the timing of ADSL enablement is correlated with these characteristics, this would question the validity of our instruments. We can do this for both the timing of enablement and the local loop distance variable.

We use the panel structure of the data to measure firm characteristics in 1998, just one year before the start of ADSL rollout.[25] As firm characteristics we include labour productivity,[26] measures of firm size (gross value added, turnover, employment, having multiple plants), foreign ownership and (contemporaneous) firm age.[27] Note that for these regressions we do not restrict ourselves to the sample used in the main regression analyses (those who have broadband adoption data for example). Instead, we use all firms for which the data is available.

The evidence in Table 6 suggests that the timing of ADSL enablement is not completely orthogonal to ex-ante firm characteristics. Ex-ante, firms connected to enabled wave 1 exchanges were on average no larger (in terms of employment, turnover or gross value added) than firms connected to non-enabled exchanges. Firms connected to enabled exchanges are also not consistently ex-ante no more likely to be foreign owned, have multiple plants, be older/younger or be located closer to the exchange. There is some evidence that firms are more productive however, which suggests that the application of some caution in using this instrument is warranted.

For the cable-distance instrument we restrict the data to only areas with enabled exchanges since the cable-distance effects are only present once ADSL is available to the firm. In Table 7 we find no evidence for systematic ex-ante differences between firms' performance characteristics and how far they are located from their local (enabled) telephone exchange. There are no significant differences in their size, in terms of employment, turnover and value added, or their productivity. There is some evidence that firms closer to

[25] We could also have used 1997, the first year that the service sector was included in the ARD, however the sample sizes are substantially lower and the results are similar (these are not reported for brevity).

[26] Labour productivity, defined as gross value added per employee, is included in preference to Total Factor Productivity to maintain a reasonable sample size, since capital stock data is only available for a minority of firms, for a fuller discussion see DeStefano et al. (2014).

[27] Note firm age is included contemporaneously, rather than the lagged value at 1998, since firm age cannot be affect by the broadband roll out.

exchanges are more be multi-plant, more likely to be foreign owned to differ in age. These are all included as control variables within the IV regressions that we report later. Cable-distance to the (enabled) exchange therefore seems to be a plausible instrument.

Anticipation effects

As a final validity check on using ADSL enablement, we examine the predictive power of future ADSL enablement in the first-stage (i.e. lead effects). While we do not favour this variable as an instrument, as already noted a concern when using the local loop distance as an instrument for broadband use in a pooled cross section framework is that the set of enabled exchanges in not constant across time because of BT's enablement programme. If broadband adoption is correlated with future ADSL enablement then this may indicate anticipation effects, again invalidating its use as an instrument. In addition this may also reflect differences in unobserved firm or local area trends that affect broadband adoption independently of ADSL enablement, violating instrument validity if these unobservables are correlated with firm trade.

To make this test as demanding as possible we use data from the entire sample period for which we have data (2000-2005) and use exchanges in both wave 1 and wave 2. We therefore include firms that were attached to exchanges enabled right at the end of the sample period and therefore would have had the opportunity to observe the adoption practices and any success from those firms attached to exchanges enabled earlier. Despite this we do not find any predictive power of lead ADSL enablement (Table 8) as a predictor of the use of broadband by the firm. Both the one and two period leads of ADSL enablement are not different from zero at conventional significance levels. It appears as though ADSL enablement was not anticipated by firms, as would be expected given the short announcement dates. We find the same result when we restrict the observations to the sample we use for estimations.[28]

5. Baseline Results

Having established that our instruments are correlated with the use of broadband by firms during the period of ADSL rollout before the introduction of RADSL we next consider the effect of broadband use on the firm-extensive margin of exports. We present our main set of results in Table 9 and use those in Table 10 and Table 11 to test for robustness. Within Table 9 the first three regressions (regressions 25-27) are estimated using OLS and the remaining 6 (regressions 28-33) are the instrumental variable versions. Regressions 28-30 use both the timing of enablement and the distance from the telephone exchange as instruments for the time period 2000-2002 for firms connected to exchanges enabled during wave 1, while regressions 31-33 restricts the sample to enabled exchanges and use local-loop distance as a single instrument. In each set of three regressions we rotate the measure of services trade to the total services trade data drawn from *ITIS*, exports data from the *ARD* and finally exports of business services again drawn from *ITIS.* We include lagged

[28] Because the time period ends in 2002 we are restricted to testing a lead effect of one-year only. For this reason we choose not to report these regressions, but they are available from the authors on request.

firm controls and year fixed effects in all of the regressions, while the OLS regressions 25-27 additionally include a full set of region and industry dummies.

In terms of unreported firm covariates, as one would expect, being foreign owned is positively correlated with the propensity to export and the value of exports, which is consistent with the findings of Breinlich and Criscuolo (2011) using broadly similar UK data. Foreign owned firms are 11% more likely to export services than domestically owned firms in regression 25. We find no significant correlations between export propensities and firm age or having multiple plants, except for regression 27 where age is significant.

In the OLS regressions we find that service exports are highly correlated with firms' use of broadband. According to the results reported in regression 25, firms with broadband connections are 10% more likely to export services than those without such connections. This falls to 7.2% in regression 26 when we use data drawn from the *ARD* and 4.4% when we concentrate on the probability of exporting business services in regression 27. Nevertheless the significant positive relationship is in line with the aggregate data presented in Figure 1 and with regression evidence presented elsewhere in the literature.

In the IV regressions in Table 9 we find more mixed evidence regarding the effects of broadband on exporting decisions. The first-stage results mirror those in section 4; the instruments are strong predictors of broadband access, with F-statistics around (in the case of regressions 28-30) the rule-of-thumb of 10 suggested by Staiger and Stock (1997) and well above this in our preferred specification in which we use local loop distance as a single instrument (regressions 31-33). The Stock and Yogo (2005) critical values for the Cragg-Donald F-statistic are presented for broad guidance, as these assume homoskedastic errors. Under the Stock-Yogo test, the instrument seems a little weaker than suggested by the rule-of-thumb and has a bias of less than 15%. The Hansen J-statistic cannot reject the null of jointly valid instruments in regressions 28-30. Altogether these statistical tests again provide support for the choice of instruments

In the second stage the coefficient for broadband differs across the six IV regressions. Most obviously broadband is found to have a significant and positive effect on the firm-extensive margin only when we focus on business service exports. In regressions 30 and 33 the magnitude of the effect is large but very consistent in magnitude. According to these findings the local average treatment effect we identify suggests that the probability of exporting for those induced to use broadband because of the instrument is in the range 64% to 66%.

For total exports of services in regressions 28-29 and the ARD definition of exports in 31-32, we find a (weak) significant effect from broadband in regression 28 only. A weaker relationship for total service exports is perhaps expected. Total exports include a wide variety of types including telecommunication services, technical services such as construction and business services such as advertising, legal services and research and development. These differ in their mode of delivery and the degree with which they rely on the speed and reliability of information provision, with business services arguably the most information intensive of these. Our results suggest that differences in the extent of access to broadband services generated through telecoms infrastructure affected the use of broadband by UK firms and significantly increased their likelihood of exporting business services.

We consider the sensitivity of these findings to the way that the instrument is constructed in regression 34 (Table 10). Thus far we have used local-loop distance in its linear form. As Section 4 describes, the effect is non-linear; internet speeds are affected by cable lengths of greater than 2 kilometres. The decision to include the variable in this way was motivated by the role that other factors, such as the quality of the cable-material, noise ingress in the customers internal network, have on connection speeds. In regression 34 we take a simpler approach and model distance as a simple dummy variable, which we construct according to whether the firm is above or below the mean (2.78 km) distance from the telephone exchange. Using an instrument constructed in this way we continue to find similar results. In the first stage, firms that are located furthest from the exchange are significantly less likely to use broadband, and in the second stage the use of broadband has a strong effect on the propensity to export business services. The F-statistics on the instrument in the first-stage remain well above 10, consistent with the view that local loop distance is a strong instrument for the decision to use broadband or not.

A second advantage of writing the instrument in this way is that it allows us to provide a simple quantification of the likely size of the compliant population for whom our LATE estimate applies to. In our case it would appear that compliant sub-population is rather small. Under an assumption that there are no defiers in the sample, which would seem a reasonable assumption in our case, then a simple estimate of the compliant sub-population is around 5% of the treated population.[29]

Robustness

That we find an effect from broadband only for business service exports would again seem to indicate that potential confounding factors that are an alternative explanation for our findings are not a problem, or at least the list of potential variables that it could contain is much diminished. While one can never rule out such a possibility, this difference across types of service exports restricts the set of confounding factors that this might be to exclude common shocks, agglomeration or other common geographic factors. In regressions 35 to 37 we consider these possibilities further.

In regressions 35 and 36 we consider the role of agglomeration effects. We consider this possibility by adding to the regression the log of the number of households (regression 35) and businesses (regression 36) connected to each exchange using information drawn from the *PointTopic* database. In the first stage regressions we find that the number of households helps to predict the use of broadband internet by firms and is unrelated to the number of business premises that are connected to the exchange. In the second stage we find a significant positive effect from larger clusters of businesses in the area of an exchange on the probability of exporting, but no effect from the number of households. Together these results indicate that agglomeration economies are not an explanation of our findings. We continue to find that the instruments have power in the first stage regression and the large positive effect of broadband use on the extensive margin of business exports is also retained.

[29] This number is calculated from a regression of the treatment variable (broadband) on the instrument (local loop distance dummy).

In regression 37 we test whether we capture other the effect of other changes to firm performance. If broadband improves the performance of the firm, or they introduce other types of organisational change then the effect might be indirect. These improvements in the firm may pull firms into exporting. We consider this as a possible explanation of our results by including the employment. We find that if anything this serves to increase the importance of broadband on the likelihood of exporting. Firms using broadband are now 76% more likely to export business services. Unexpectedly we find that employment itself has a negative effect on exporting.

In the baseline analysis we have assumed that the probability of exporting is the same across all destinations. In unreported results (available upon request), we next extend the extensive margin to exploit the destination dimension of the *ITIS* data. Although there are far more firm-country observations (compared to just firm observations in the baseline), the standard errors are clustered at the firm-level. The strength of the instruments is identical to the baseline extensive margin first-stage. Similarly, the second stage IV estimates suggest that firms with broadband access because of their proximity to an ADSL enabled exchange are 7.5% more likely to export business services than those without broadband.

In the discussion of the likely effects of broadband on the ability of firms to export, it was anticipated that this was likely to impact most clearly on the costs of entry into export markets. Firms could develop websites that enabled improved connections with foreign customers, there could be an increase in the range of services that could be exported etc. In principle there may also be an effect on the variable costs of exporting and therefore the volume of exports for a firm. In the final table of results (Table 11) we explore whether the use of broadband also impacts on the firm-intensive margin. In Table 11 we present evidence for total exports and business service exports using the *ITIS* dataset and report OLS (regressions 39 and 42) as well as estimations using both instruments (regressions 40 and 43) and a local loop length as a single instrument (regressions 41 and 44). Here the analysis is restricted to firms that export, explaining the drop in the number of observations compared to earlier tables.

According to OLS estimates the effect on the intensive margin is strong and significant for both total service exports and business service exports. In regression 39 we find that exporters with broadband export on average 120% more services than firms with no broadband access, while in regression 42 the effect is an estimated 168%.[30] The results in the table also make clear we are unable to determine the causal impact of broadband using the telecoms infrastructure to generate possible instrumental variables however. The first-stage results differ from those presented for the extensive margin and are generally quite weak predictors of broadband access, with F-statistics around 4–7. This is well below the Staiger-Stock rule-of-thumb. We therefore cannot infer anything about the effect of broadband on export volumes from these regressions and refrain from doing so.

[30] Since the model is log-linear, 120% is calculated as exp(0.788)-1.

6. Discussion and Conclusions

Broadband is diffusing rapidly throughout the world, with investment in broadband infrastructure a key priority for several country governments. The popular press and economics literature abounds with anecdotal evidence about how broadband has enabled services to become tradable for the first time. Indeed, for the UK, services trade has grown rapidly in recent years and the timing coincides closely with the increased use of ICT technologies and diffusion of broadband internet in particular.

This paper presents the first evidence concerning the effect of broadband adoption on UK service exports. We combine newly available firm-level broadband adoption data with detailed international service transaction data to measure service trade across firms with and without broadband access. To account for the endogeneity of broadband adoption, we construct novel instrumental variables that have not previously been used in the literature on ICT and service trade. In particular, we use precise geographic data on firm location to capture fine geographical differences in the timing of ADSL broadband availability and, in our preferred specification, likely broadband speeds based on cable distances from the exchange. The instruments perform well, strongly predicting firm broadband adoption and we perform a battery of (indirect) validity tests that support the robustness of the identification.

Could the growth in international services trade be caused by firms' use of broadband technology? Our analysis suggests the answer is yes, at least for a rather small compliant population who exported business services. Using this estimate of the compliant population (5%), the estimated effect on the probability of exporting from our regression estimates (0.55-0.75), the size of the treated population (1570 firms) and the average export sales (£24.19 million) would suggest a causal effect of the internet on UK business service exports between 2000 and 2002 in the range of £1.0-£1.4 billion. This is a small share of the total services exports from the UK. However, we do not find any robust effect of broadband on service exports more generally, suggesting the effect on other, less information-intensive types of services is rather mute. Our instruments do not have power to explain how much firms export, for this, further empirical analysis is warranted.

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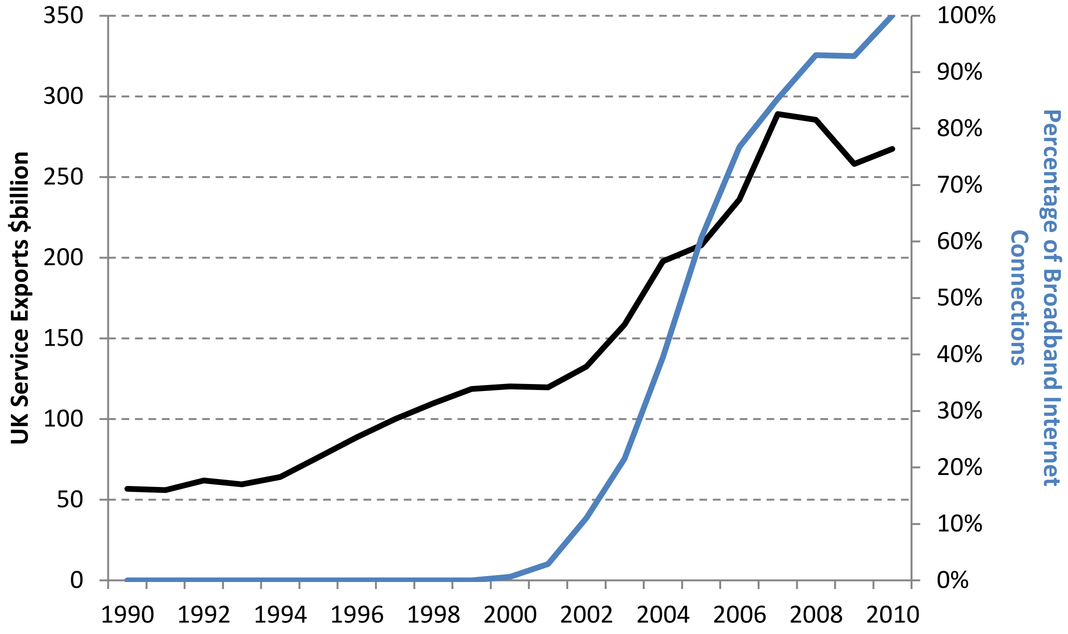
Figures

Figure 1: Broadband Diffusion and UK Service Exports



Source: Author's Calculations based on IMF data (current prices) and ITU Data

Figure 2: UK Service Trade – Firm Extensive Margin

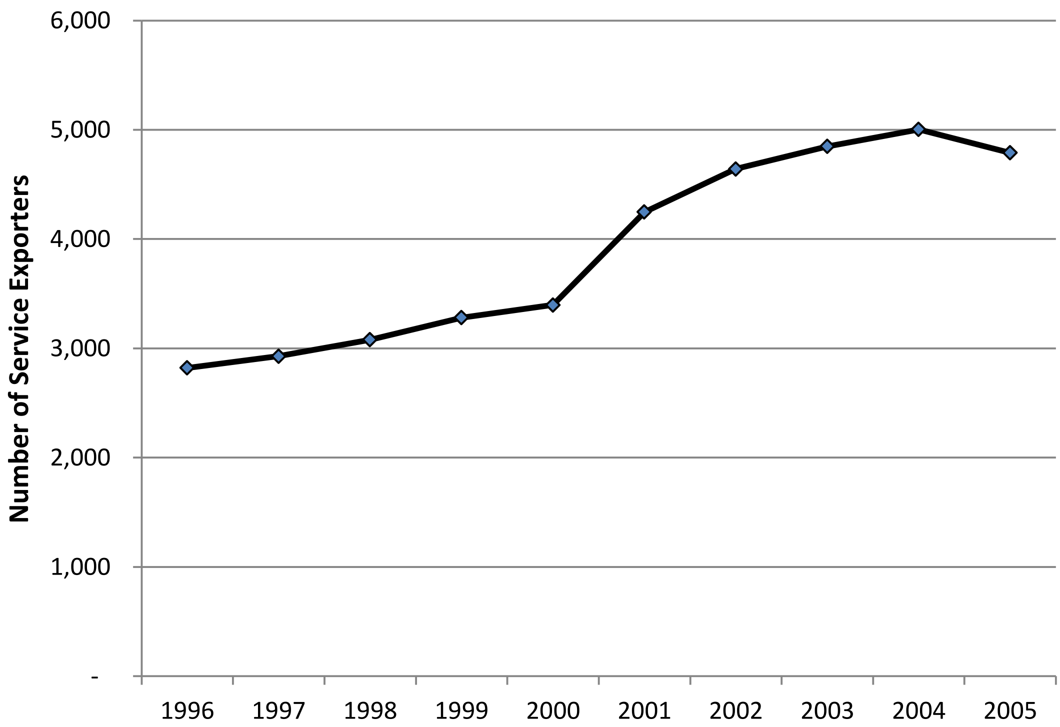


Figure 3: UK Service Trade – Firm Intensive Margin

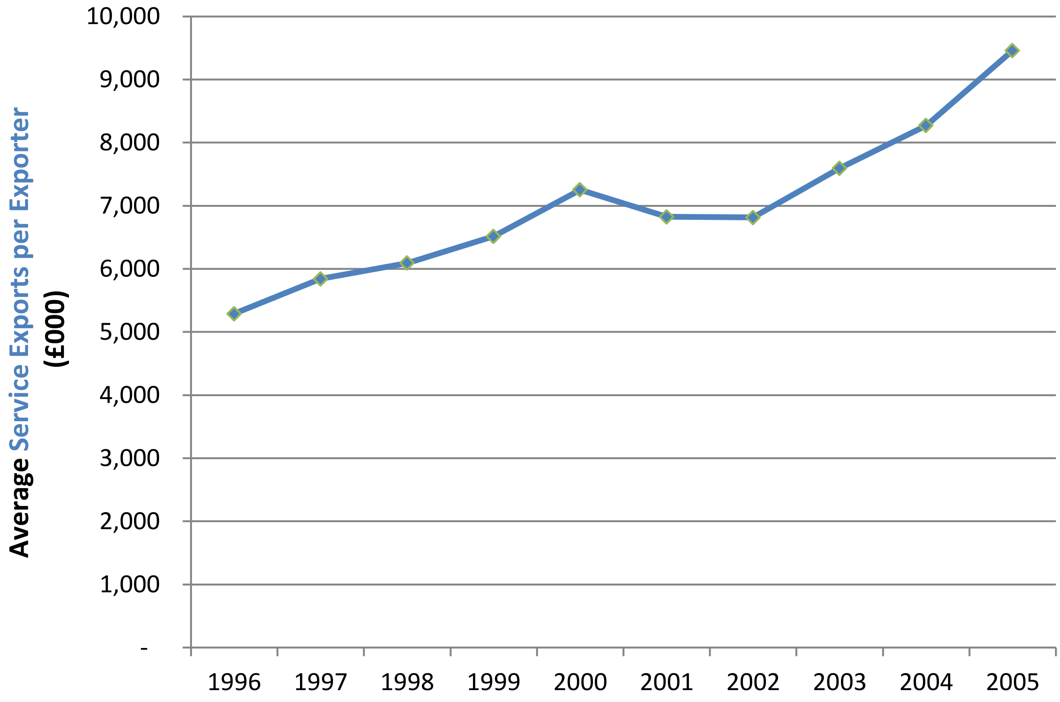


Figure 4: Broadband Adoption over Time

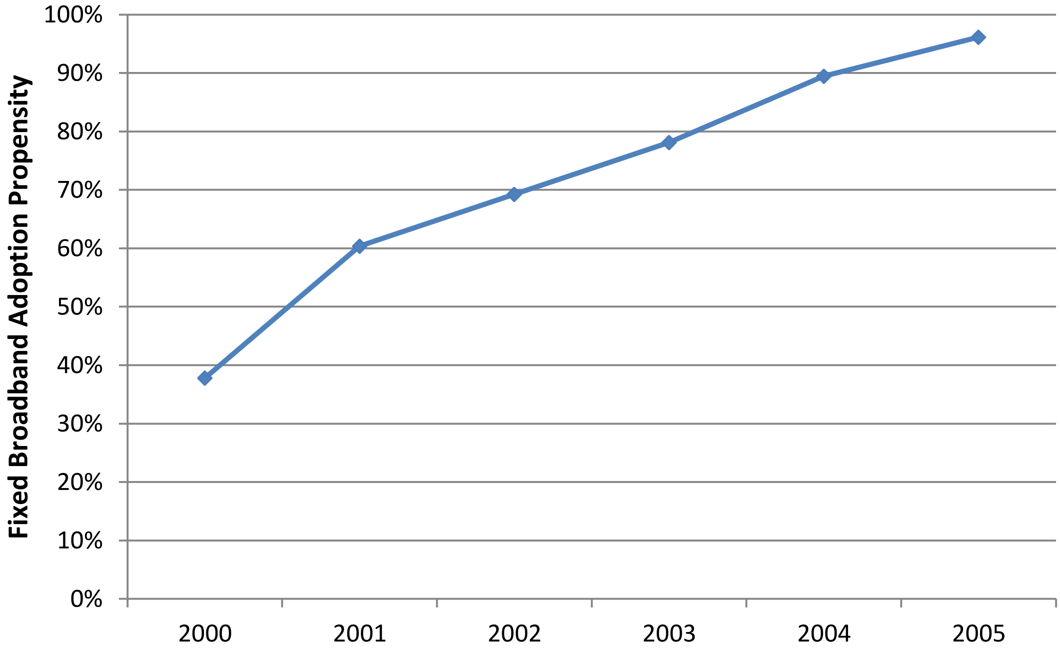


Figure 5: UK Telephone Network

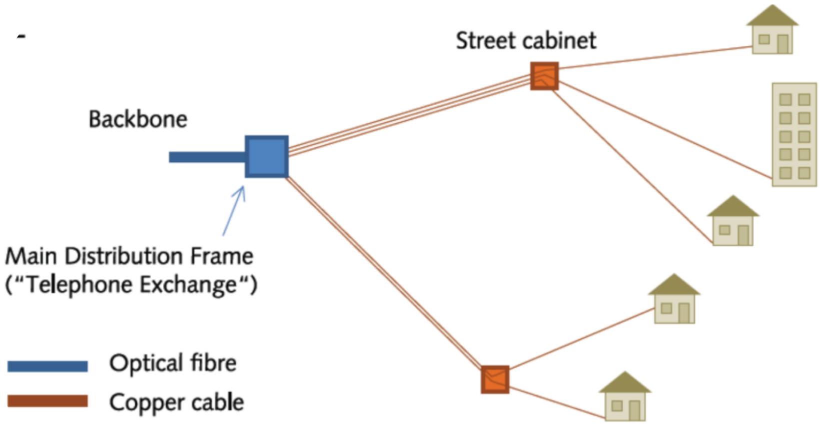


Figure 6: How Cable Distance Affects ADSL Speeds

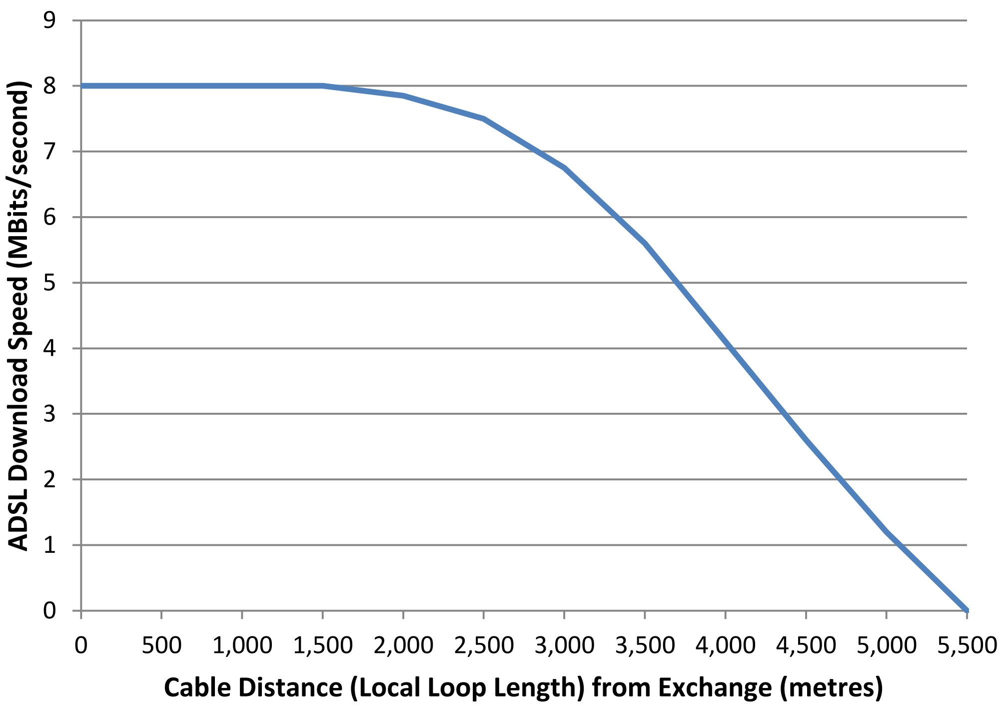


Figure 7: Exchanges Enabled by 1999

Figure 9: Exchanges Enabled by 2001

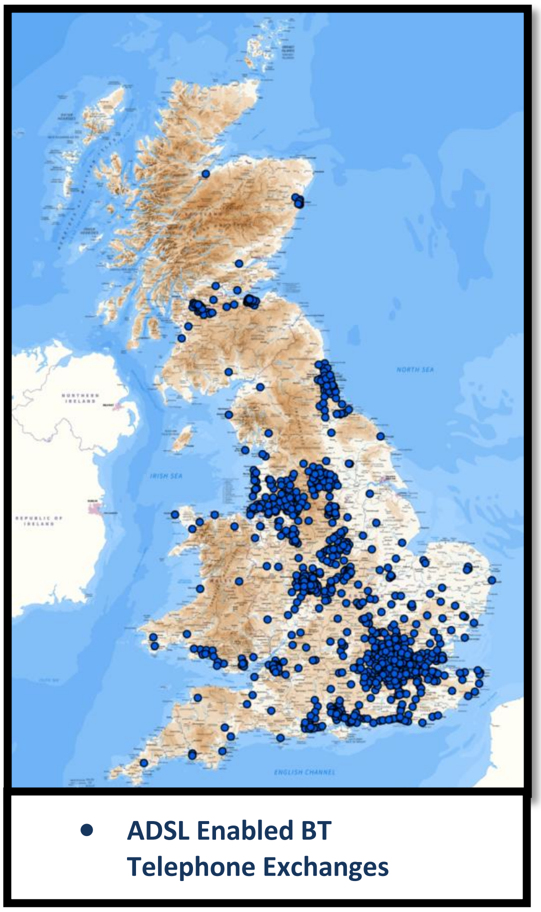


Figure 8: Exchanges Enabled by 2003

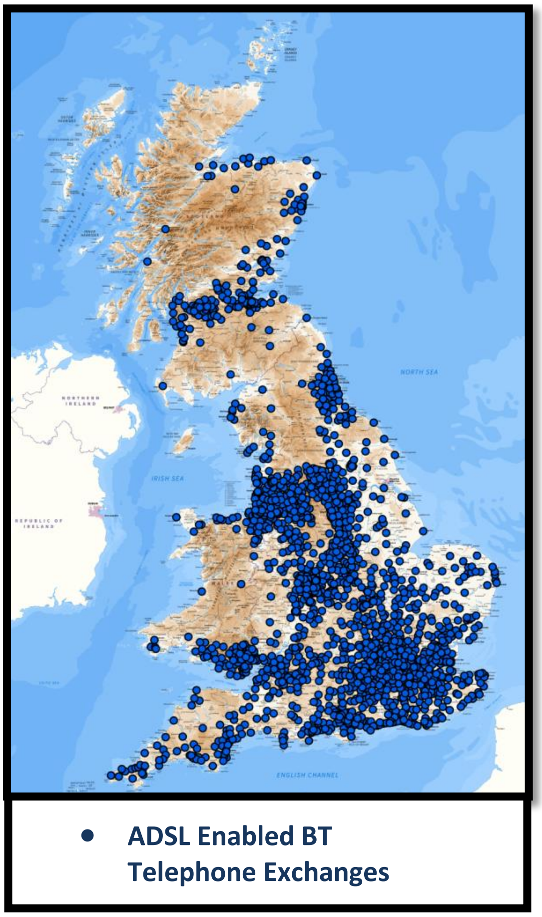


Figure 10: Exchanges Enabled by 2005

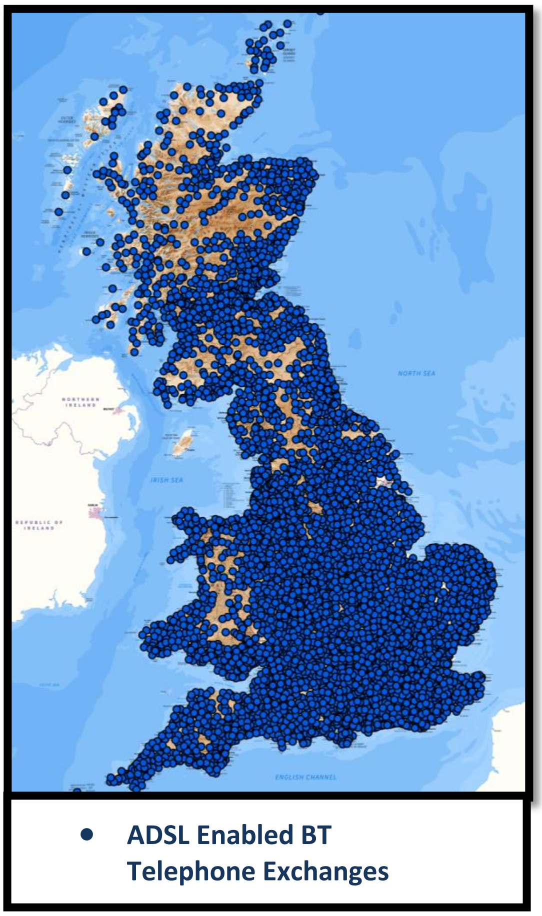


Figure 11: ADSL Enabled Exchanges per Half Year

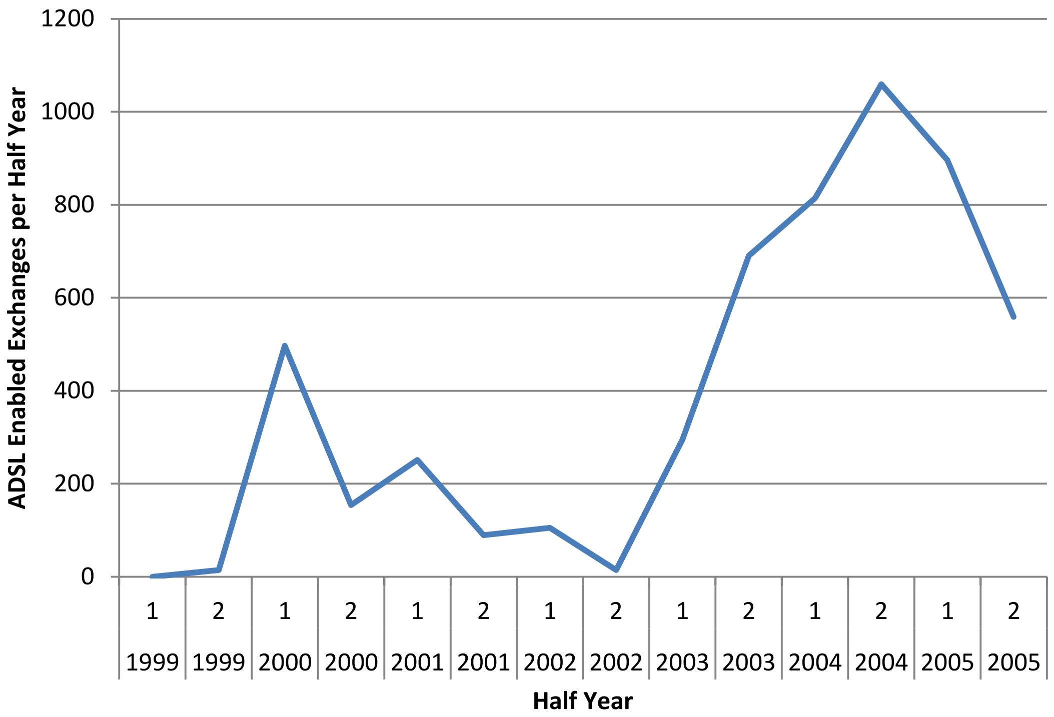


Figure 12: ADSL Enabled Exchanges by Exchange Size

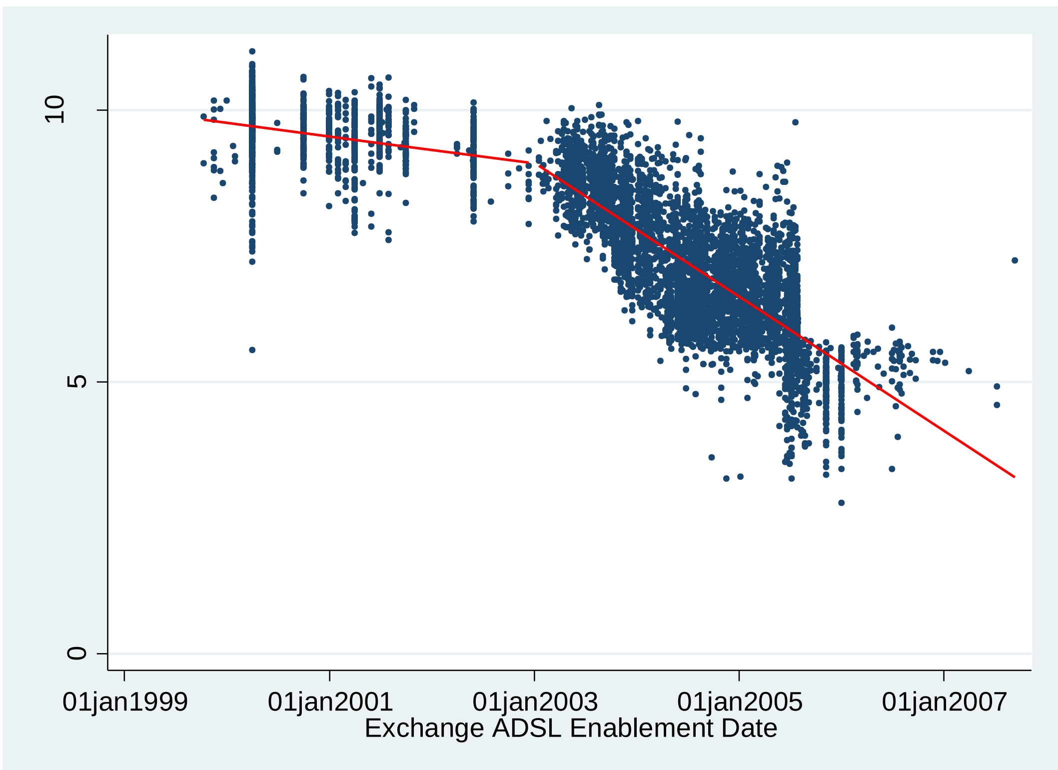


Table 1: Merged Data Sample Sizes

Year	In E-commerce at year t				Total No. of Firms
	BSD / ARD at year t		Not in BSD / ARD at year t		
	ITIS at t	not in ITIS at t	ITIS at t	not in ITIS at t	
2000	862	5,260	15	234	6,371
2001	2,308	4,413	67	422	7,210
2002	1,882	4,591	120	489	7,082
2003	2,609	6,405	35	416	9,465
2004	2,724	6,189	38	372	9,323
2005	2,714	4,191	96	268	7,269
Total	13,099	31,049	371	2,201	46,720

Table 2: Summary Statistics: Full Sample and Estimation Sample

Full Sample	*Mean*	*Std. Dev*	*Obs.*
Fixed Broadband	0.77	0.42	13,099
Proportion of Exporting Firms	0.26	0.44	13,099
Exports for Exporters (£000)	27,620	108,716	3,395
Employment	1,732	6,670	13,099
Sales (£000)	294,145	1,685,918	13,099
Age (Years)	20	9	13,099
Foreign	0.29	0.45	13,099
Multi-Plant	0.74	0.44	13,099

Estimation Sample	*Mean*	*Std. Dev*	*Obs.*
Fixed Broadband	0.61	0.49	3,362
Proportion of Exporting Firms	0.27	0.44	3,362
Exports for Exporters (£000)	24,190	89,543	895
Employment	1,912	7,522	3,362
Sales (£000)	287,445	1,126,022	3,362
Age (Years)	19	8	3,362
Foreign	0.28	0.45	3,362
Multi-Plant	0.75	0.44	3,362

Notes: All values deflated using producer prices at 2 digit industry level, constant 2007 prices.

Table 3: Distribution of Local Loop Length (Cable Distances) from Local Telephone Exchange to the Firm

	Full Sample	*Estimation Sample*
Percentile	*Cable Distance from Local Exchange (km)*	
1%	0.72	0.70
5%	0.99	0.96
10%	1.29	1.23
25%	2.00	1.93
50%	2.96	2.81
75%	4.26	4.05
90%	5.09	4.91
95%	5.46	5.32
99%	6.58	5.89

Table 4: First Stage Estimation: Probability of Internet Use

Regression number:	1	2	3	4	5	6
Internet Technology	Broadband		Broadband		Narrowband	
Sample	Wave 1 Exchanges		ADSL Enabled Wave 1 Exchanges		Wave 1 Exchanges	
ADSL Enabled	0.173***	0.152***			-0.165***	
	(0.047)	(0.050)			-(0.047)	
*ADSL Enabled *Cable Distance*	-0.074***	-0.083***	-0.075***	-0.080***	0.091***	0.088***
	(0.024)	(0.026)	(0.024)	(0.027)	-(0.025)	-(0.025)
Foreign at t-2		0.108***		0.105***	-0.098***	-0.089***
		(0.022)		(0.022)	-(0.019)	-(0.020)
Age		0.037**		0.043**	-0.034**	-0.037**
		(0.018)		(0.019)	-(0.017)	-(0.018)
Multi-Plant at t-2		0.088***		0.084***	-0.052***	-0.051**
		(0.021)		(0.022)	-(0.019)	-(0.020)
Region FE		Y		Y	Y	Y
2-digit Industry FE		Y		Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	3,787	3,362	3,549	3,138	3,362	3,138

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of broadband internet use by the firm (0= not using broadband; 1= using broadband), except regressions 5 and 6 which are linear probability regressions for firm use of narrowband (0= not using narrowband; 1= using narrowband). Wave 1 exchanges are BT owned exchanges enabled between 1999 and June 2002.

Table 5: First Stage Estimation –Effect of Cable Distance Across Years

Regression No.	7	8	9	10	11	12
Years	2000	2001	2002	2003	2004	2005
Dependent Variable	*Probability of Firm Exporting*					
*ADSL Enabled *Cable Distance*	-0.041	-0.084**	-0.075**	-0.062***	-0.027*	-0.001
	(0.062)	(0.033)	(0.032)	(0.023)	(0.016)	(0.010)
Observations	501	1,650	1,398	2,264	2,627	2,662

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of whether the firm exports (0= not exports; 1= exports). Sample includes BT telephone exchanges enabled for ADSL up to and including the sample year.

Table 6: Validity of Enablement Instrument –Wave 1 (2000-2002)

Regression No.	13	14	15	16
Dependent Variable	Probability of Exchange Enablement			
Employment in 1998	0.004			
	(0.005)			
Turnover in 1998		0.004		
		(0.004)		
Gross Value Added in 1998			0.010	
			(0.006)	
Labour Productivity in 1998				0.030**
				(0.012)
Foreign in 1998	0.036*	0.035	0.033	0.023
	(0.021)	(0.021)	(0.022)	(0.023)
Age	-0.005	-0.005	-0.001	-0.006
	(0.013)	(0.014)	(0.017)	(0.017)
Multi-Plant in 1998	0.008	0.01	0.018	0.021
	(0.015)	(0.014)	(0.017)	(0.018)
Distance in 1998	-0.035	-0.035	-0.021	-0.009
	(0.026)	(0.026)	(0.030)	(0.029)
Region FE	Y	Y	Y	Y
2-digit Industry FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	4,486	4,480	2,861	2,555

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. Wave 1 exchanges are BT owned exchanges enabled between 1999 and June 2002. Reported coefficients are marginal effects from a Logit regression.

Table 7: Validity of Cable Distance Instrument – Wave 1 Enabled Exchanges (2000-2002)

Regression No.	17	18	19	20
Dependent Variable	Cable Distance from Local Exchange			
Employment in 1998	-0.001			
	(0.004)			
Turnover in 1998		-0.002		
		(0.004)		
Gross Value Add in 1998			-0.006	
			(0.006)	
Labour Productivity in 1998				-0.005
				(0.010)
Foreign in 1998	0.032*	0.034**	0.025	0.023
	(0.017)	(0.017)	(0.019)	(0.020)
Age	-0.016	-0.014	-0.031*	-0.032*
	(0.014)	(0.014)	(0.017)	(0.018)
Multi-Plant in 1998	-0.023	-0.022*	-0.019	-0.025
	(0.014)	(0.013)	(0.016)	(0.017)
Region FE	Y	Y	Y	Y
2-digit Industry FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	10,022	10,002	6,370	5,545

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. Wave 1 exchanges are BT owned exchanges enabled between 1999 and June 2002. Reported coefficients are marginal effects from a Logit regression.

Table 8: Probability of Broadband Adoption: Lead Effects

Regression No.	21	22	23	24
Sample	Waves 1 and 2 (2000-2005)			
ADSL Enabled at t	0.055***	0.045**	0.055***	0.045**
	(0.021)	(0.022)	(0.021)	(0.022)
ADSL Enabled at t+1	0.004	0.000	0.006	0.002
	(0.025)	(0.026)	(0.027)	(0.028)
ADSL Enabled at t+2			-0.005	-0.005
			(0.035)	(0.036)
Foreign at t-2		-0.043**		-0.043**
		(0.022)		(0.022)
Age				
Multi-Plant at t-2		0.01		0.01
		(0.024)		(0.024)
Region FE		Y		Y
2-digit Industry FE		Y		Y
Year FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Observations	12,903	11,697	12,903	11,697

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of broadband internet use by the firm (0= not using broadband; 1= using broadband). Sample consists of all BT exchanges between 1999 and 2005.

Table 9: Service Exports – Firm Extensive Margin

Regression Number	25	26	27	28	29	30	31	32	33
Estimation Method: Sample	OLS: Wave 1 Exchanges			IV: Wave 1 Exchanges			IV: Wave 1 Enabled Exchanges		
Export Data	ITIS: Total Service Exports	ARD	ITIS: Business Service Exports	ITIS: Total Service Exports	ARD	ITIS: Business Service Exports	ITIS: Total Service Exports	ARD	ITIS: Business Service Exports
Second stage:									
Broadband	0.098***	0.072***	0.044***	0.508*	0.266	0.635**	0.438	0.282	0.658**
	(0.016)	(0.011)	(0.013)	(0.279)	(0.188)	(0.251)	(0.302)	(0.229)	(0.287)
First stage:									
ADSL Enabled				0.183***	0.171***	0.183***			
				(0.048)	(0.038)	(0.048)			
*ADSL Enabled * Cable Distance*				-0.089***	-0.078***	-0.089***	-0.090***	-0.077***	-0.090***
				(0.025)	(0.021)	(0.025)	(0.025)	(0.021)	(0.025)
Firm Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y
Region FE	Y	Y	Y	-	-	-	-	-	-
2-digit Industry FE	Y	Y	Y	-	-	-	-	-	-
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cragg-Donald F-stat.				9.13	11.82	9.13	14.51	15.70	14.51
Kleinbergn Paap F-stat.				8.03	10.21	8.03	12.42	13.23	12.42
J Test				0.55	0.92	0.94			
Observations	3,362	5,146	3,362	3,362	5,140	3,362	3,138	4,720	3,138

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of the extensive margin of exports (0= not exports; 1= exports). Sample consists of all BT exchanges enabled between 1999 and June 2002. In all regressions we include firm level controls for age, foreign ownership and multi-plant status (all lagged two time periods).

Table 10: Robustness: Firm-extensive Margin for Business Services Exports

Regression number	34	35	36	37	38
Estimation Method: Sample	IV: Wave 1 Enabled Exchanges				
Second Stage:					
Broadband	0.551**	0.660**	0.585**	0.755**	0.075**
	(0.251)	(0.331)	(0.271)	(0.343)	(0.03)
No. of Households in Exchange Area		-0.004			
		(0.015)			
No. of Businesses in Exchange Area			0.035***		
			(0.009)		
Ln(employment)				-0.046**	
				(0.021)	
First stage:					
*ADSL Enabled **	-0.069***	-0.078***	-0.092***	-0.079***	-0.032***
Cable Distance	(0.018)	(0.025)	(0.026)	(0.025)	(0.01)
No. of Households in Exchange Area		-0.033***			
		(0.009)			
No. of Businesses in Exchange Area			-0.013		
			(0.010)		
Ln(employment)				0.057***	
				(0.006)	
Firm Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Country FE	-	-	-	-	Y
Cragg-Donald F-statistic	16.83	10.78	15.06	11.47	2442.16
Kleinbergn Paap F-statistic	14.18	9.36	12.89	9.79	10.58
Observations	3,138	3,128	3,128	3,137	725,522

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of the extensive margin of business service exports (0= not exports; 1= exports). Sample consists of all BT enabled exchanges in 1999 to June 2002. In all regressions we include firm level controls for age, foreign ownership and multi-plant status (all lagged two time periods). Cable distance dummy equals 0 if cable-distance between the telephone exchange and the firm is greater than the mean distance of 2.81km, and equals one if greater. Regression 38 uses firm-country-extensive margin.

Table 11: Firm Intensive Margin

Regression number	39	40	41	42	43	44
Sample	Wave 1 Exchanges		Wave 1 Enabled Exchanges	Wave 1 Exchanges		Wave 1 Enabled Exchanges
Estimation Method	OLS	IV		OLS	IV	
Export Measure	ITIS: Total Service Exports			ITIS: Business Services Exports		
Second Stage:						
Broadband	0.788***	13.031**	8.893**	0.987***	10.762	1.425
	(0.213)	(5.835)	(4.122)	(0.272)	(13.451)	(2.589)
First stage:						
ADSL Enabled		0.215***			0.283**	
		(0.082)			(0.109)	
*ADSL Enabled * Cable Distance*		-0.117***	-0.114***		-0.171***	-0.164***
		(0.044)	(0.044)		(0.061)	(0.061)
Firm Controls	Y	Y	Y	Y	Y	Y
Region FE	Y	-	-	Y	-	-
2-digit Industry FE	Y	-	-	Y	-	-
Year FE	Y	Y	Y	Y	Y	Y
Cragg-Donald F-stat.		4.56	7.45		4.65	7.79
Kleinbergn Paap F-stat.		4.20	6.74		4.43	7.20
J Test		0.29			0.10	
Observations	895	895	825	488	488	450

Notes: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% of significance. Clustered standard errors are reported in parenthesis. All regressions are a linear probability model of the extensive margin of exports (0= not exports; 1= exports). Wave 1 consists of all BT exchanges enabled between 1999 and June 2002. In all regressions we include firm level controls for age, foreign ownership and multi-plant status (all lagged two time periods).

Appendix

International Trade in Services Inquiry (ITIS)

ITIS contains transaction-level data for services transactions between UK firms and the rest of the world and is the main input into the Balance of Payments statistics. ITIS is a statutory inquiry that has been collected since 1996 and covers firms with more than 10 employees. The sampling methodology comprises three parts and results in data containing mainly large firms. First, a stratified random sample of firms in industries with a high propensity to trade services are selected[31], the sampling frame is taken from a live register of all UK firms (Interdepartmental Business Register). Secondly, the stratified sample is supplemented with firms who are identified as service traders using filter questions in other surveys; from 2000 this has been collected from the ARD. Finally, the sample is supplemented with firms with trade flows in previous surveys exceeding £500,000.

The data comprises two parts, annual and quarterly surveys, with firms with the largest historic trade flows surveyed on a quarterly basis. The annual survey is further divided into two; one annual survey is specifically for the film and television industry, with remaining industries captured by the main annual survey. In 2003 the response rate was 90% and 85% for the annual and quarterly surveys respectively. Those sampled firms that did not record any services trade are recorded as "nil returns" and stored as separate datasets. The sample sizes recorded in ITIS increased substantially in 2001 with a doubling of the sample size for the annual surveys from around 10,000 to 20,000, this compares to around 650 quarterly surveys each year.

ITIS records service transactions disaggregated into around 30 service products. Consequently, there are therefore far fewer categories of services than typically recorded by goods trade transaction data. The service categories are consistent for the period 1996-2003. In 2004 new service codes were introduced. The new service codes were introduced for the 2005 annual survey onwards; however there are complications with the quarterly survey. The new codes were introduced for some firms in the final quarterly survey of 2004 and for the remainder in either of the first two quarters of 2005. Fortunately the ONS has provided trade data that has taken these changes into account, recording trade under the old classification up to 2004 and the new classification post-2005 for all firms[32]. We follow Kneller et al (2010) and reclassify service codes to be consistent across all years of the data.

The ITIS data notes for each transaction the respective destination / source market. The countries listed do not always correspond exactly to the UN classification of countries, and there is some aggregation required to allow matching with country-level data (on GDP etc.). For instance, Abu Dhabi, Sharjah, Dubai and United Arab Emirates are listed as separate countries in ITIS whereas under the UN classification these are pooled together as United Arab Emirates. Furthermore, some markets are not recorded specifically. These are either listed as unknown or recorded as broader country groupings, such as European Union, Africa, Oceania etc. We recode all these imprecise country listings into a single category reflecting unknown markets. These unknown markets are excluded from the analysis of country-level margins, and account for 3.4% of total service exports in 2000.

Table A1: Service Codes Used in ITIS

1996-2003 Service Codes		2004-2005 Service Codes
A	**Business Services**	

[31] These high propensity industries include consultancies, the music and computer industry and production sector

[32] In the past the ONS did not provide data that had consistent service codes across time. In order to obtain consistent service classifications, earlier research such as Kneller et al (2010), used the raw trade data combined with a file provided by the ONS that documents for each firm which quarter the new service codes were introduced. I have used the method of Kneller et al (2010) applied to the raw trade data to spot check that the ONS has corrected the service codes appropriately.

1	Legal Services	11	Legal Services
2	Accounting and Auditing	5	Accountancy, Auditing, Bookkeeping and Tax Consulting Services
3	Management Consulting and Public Relations	7/8/10	Management Consulting / Public Relations / Other Business Management Services
4	Advertising	6	Advertising
5	Market Research and Polling	12	Market Research and Public Opinion Polling
6	Research and Development	16	Research and Development
7/8	Insurance	29-36	Insurance
9	Financial Services	27	Financial Services
10	Insurance Brokering	28	Auxiliary Insurance Services
11	Property Management	15	Property Management
12/50	Services between Related Enterprises	17	Services between Related Enterprises
13	Procurement	14	Procurement
14	Publishing Services	23	Publishing Services
15	Recruitment and Training	9/41	Recruitment / Training and Education Services
19	Other Business Services	18	Other Business and Professional Services
B	**Telecommunication Services**		
21	Telephone Services	20	Telecommunication Services
22/23	Postal and Courier Services	19	Postal and Courier Services
24	Computer Services	21	Computer Services
25	Information Services	22/24	News Agency Services / Other Information Provision Services
C	**Technical Services**		
31	Architectural Services	47	Architectural Services
32	Engineering Services	48	Engineering Services
33	Surveying Services	49	Surveying Services
34	Construction Services	25/26	Construction Services (inside and outside UK)
35	Agricultural Services	1	Agricultural Services
36	Mining Services	2	Mining Services
37	Other Technical Services	3/4/50	Waste Treatment / Other On-Site Processing Services / Other Technical Services
D	**Miscellaneous Services**		
41	Operational Leasing	13	Operational Leasing
E	**Cultural Services**		
42/43	TV, Radio/Music Related Services	39	Audio-Visual and Related Services
44	Other Cultural and Recreational Services	40/42	Health Services / Other Personal, Cultural and Recreational Services
F	**Royalties and License Fees**		
45	Payments / Receipts for the use of	43/44	Use of Franchises / Other Royalties and

	Intangible Assets		License Fees
45	Payments / Receipts for the outright purchase or sale of Intangible Assets	45/46	Purchases and Sales of Franchises / Royalties and Licenses
G	**Trade Related Services**		
48	Commission from Trade in Goods (Merchanting)	37	Merchanting
47/49	Earnings from Trade in Goods / Earnings from Trade in Commodities	38	Other Trade-Related Services
51	Any other Trade in Services not shown elsewhere	51	Other Trade in Services

E-commerce Survey

The E-commerce survey contains firm-level information on ICT usage and E-commerce, including broadband use, the treatment variable. The survey was first introduced in the year 2000 and is available annually thereafter. The surveys are dispatched in February[33], with the surveys questions relating to the previous calendar year and technology adoption relating to the year end[34].

The survey covers all firms with more than 10 employees for the 2000 survey and all firms (of any size) for later surveys. The sample has been selected using stratified random sampling with the sampling frame taken from a live register of all UK firms (Interdepartmental Business Register). The strata are defined by industry and employment, such that larger firms are over-represented. The sample sizes have changed a little over the period, with over 7,000 firms sampled in 2000 and 2005 thereafter and 9-10,000 firms surveyed for 2001-2004.

Table A2 summarises the questions asked on internet connection type by survey year. We aggregate all analogue modem, narrowband and ISDN responses into a single category labelled "Narrowband". By grouping these connection types, I am defining narrowband as referring to all connections with speeds less than 128Kbits/second, which is consistent with the definitions used in the E-commerce survey for 2002-2004. Similarly, we aggregate DSL, xDSL, Cable or DSL, Other Broadband Connections > 2Mbps, Other Fixed Broadband Connection and Other Fixed Internet Connection into a single category labelled "Fixed Broadband".

Table A2: E-Commerce Survey Questions on Internet Connection Type

My Classification	**Survey Year**			
	2000	2001	2002-2004	2005
	Firms may specify **more than one** of the following:	Firms specify their **primary** connection:	Firms specify their **primary** connection:	Firms may specify **more than one** of the following:
Narrowband	(1) Analogue modem (2) ISDN	(1) Analogue modem (2) ISDN	(1) Narrowband (Dial-up and ISDN)	(1) Narrowband (2) ISDN
Fixed Broadband	(3) xDSL (ADSL,..)	(3) xDSL (ADSL, SDSL etc.) or	(2) Cable or DSL	(3) DSL

[33] Surveys are dispatched in February for the 2000-2005 surveys, and dispatched in January in later years.
[34] The technology adoption questions ask either about the previous December or the last working day of the year.

	(4) Other Broadband Connection > 2Mbps (please specify)	Other Fixed Connection <2Mbps (4) Other Broadband Connection > 2Mbps (5) Other Connection (please specify)	(3) Other Fixed Broadband Connection	(4) Other Fixed Internet Connection e.g. Cable, Leased line
	(5) Mobile Phone		(4) Wireless or Satellite Broadband	(5) Mobile Connection
Unknown			(5) Unknown	

Business Structure Database (BSD)

The Business Structure Database is utilised to provide our main measure of firm location as well as firm age as a control variable. The BSD provides demographic information, such as age, for virtually every local unit (plant-level) and enterprise unit (group-level) in the UK, but does not provide any information at the reporting-unit level. Unlike the other databases which are linked at the reporting-unit level, the BSD can only be completely matched to other data at the enterprise level, with unique enterprise reference numbers permitting matching to the ARD and via the ARD to the other datasets[35].

Annual Respondents' Database (ARD)

The ARD is one of the primary sources of firm-level information in the UK. It provides information on firm-level covariates. The ARD is a statutory survey that since 1997 covers all sectors of the economy (aside from finance), prior to 1997 the ARD did not cover the service sector. The ARD is a stratified random sample of all firms in the UK economy, with the strata defined by employment, industry and region and again the sample is drawn from the IBDR.

The ARD is disaggregated into two levels of information, the reporting-unit (firm-level) and local-unit (plant-level). I rely on the reporting unit data for additional firm covariates, such as foreign ownership and having multiple plants. Reporting-unit level information comprises of two elements a selected and non-selected sample. The selected sample are those firms surveyed and we have detailed financial information on inputs and sales. There are approximately 50,000 selected firms each year. The non-selected firms represent those in the sampling frame that are not surveyed, approximately 1.5-2million firms each year, and provides extremely limited information, essentially only on firm employment and industry. Together the selected and non-selected samples represent the universe of firms in the IBDR.

From 2000 the selected ARD survey contains a question asking firms to report their service imports and exports. We utilise this as an alternative source of information on service exports. Unfortunately this does not provide any information on the type of service nor the origin/destination country, so cannot be used to analyse other trade margins.

[35] The local-unit data contains a unique reference number that in principle would allow matching of the BSD to the ARD local-unit files. However, we have found this to be consistent for only around 80% of local units.