THE PRODUCTIVITY IMPACT OF E-COMMERCE IN THE UK, 2001: EVIDENCE FROM MICRODATA*

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Abstract:

This paper considers the impact of e-commerce on establishment level productivity for all sectors of the economy, using data from the UK E-commerce survey. E-Commerce represents the operational application of technology in the production process and may be regarded as an innovation driven change in workplace practice. Using a production function approach to measuring productivity, we find that OLS estimation fails to adequately account for the selectivity bias amongst enterprises that use e-commerce. Using a treatment effect estimator, we find that both e-buying and e-selling have significant and positive impacts on productivity.

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The influence of information and communications technology (ICT) on the organisation of business processes, demand for skills and ultimately on productivity, has been the source of much research (Black and Lynch, 2001; 2004; Chun, 2003; O'Mahony and Vecchi, 2005). Atrostic and Nguyen (2002) discuss the nature of this pervading influence and argue that computers essentially have two productivity effects: a *direct effect*, as an input of the production process, and an *indirect* or *network impact* through the way in which they streamline the underlying business process. Much attention has been devoted to detecting the former, i.e. the direct productivity impact of ICT capital (Stiroh 2002; Lichtenberg 1995, Lichtenberg and Lehr 1999, Zwick 2003), with increasing success as the subtleties of time and heterogeneity are taken into consideration (O'Mahony and Vecchi, 2005). Attention is now turning to the indirect impact that ICT is having on the conduct of business; for example, changes in workplace practices (Black and Lynch, 2004), changes in the demand for skilled labour (O'Mahony *et al*, 2003), and the use of networks for buying and selling (E-commerce).

Enterprises started adopting E-commerce in the early 1970s using an industry standard called Electronic Data Interchange (EDI). As a structured way of exchanging data between companies, EDI mainly allowed enterprises to simplify their purchasing procedures, for example, by linking large retailers' stores to their suppliers. However EDI required setting up an expensive, private or dedicated network connection between parties (Eurostat, 2004). About 10 years ago, the Internet with its low-cost entry and ease of use, quickly changed how information was exchanged and removed the distance barriers for business partners. The idea of trading on the Internet has generated great interest especially among the smallest companies, formerly excluded from EDI usage (Gottardi *et al*. 2004).

The purpose in this paper is to examine the impact of e-commerce activity on the productivity performance of UK enterprises, using survey data from two sources: the Annual Business Inquiry (ABI), which contains financial information on 'reporting units' in both the manufacturing and service sectors, and an e-commerce survey specifically designed to elicit information about reporting units' use of the Internet in their production processes. We focus on Internet-based e-commerce, following a narrow OECD definition of electronic commerce transactions (OECD,

2002)[2]. E-commerce is therefore defined in this paper as the sale or purchase of goods or services, whether between businesses, households, individuals, governments, and other public or private organisations, over the Internet. The goods and services are ordered over those networks, but the payment and ultimate delivery of the good or service may be conducted on or off-line.

The importance of Internet trade has been growing rapidly over the last few years but an in-depth evaluation of this phenomenon has not yet been undertaken. Existing studies have looked at either the general impact of computer network use on productivity (Atrostic and Nguyen 2004) or at wider definition of e-commerce, including all transactions carried on via computer mediated network (Criscuolo and Waldron 2003). Also the scope of existing studies has mainly been limited to the manufacturing sector. In this paper we extend the analysis in two directions: we specifically look at the importance of e-buy and e-sell over the Internet and how it affects productivity and we take into account both the production and the service sectors, comparing the relative importance of Internet trade.

Another issue raised in existing studies is the endogeneity of the decision to buy and sell over the Internet. This problem has mainly been addressed with the use of past performance variables (Atrostic and Nguyen 2002, 2004). In this paper we investigate the possibility of using variables from the E-commerce survey that are not directly correlated with productivity but that are correlated with the decision to buy and sell on line. Our findings indicate that e-buying and e-selling have a strong impact on productivity both in the production and in the service sector, when issues of selectivity are taken into account. These conclusions are robust to different specifications of the instrument set.

This paper is organised as follows: the next section reviews recent empirical evidence on the indirect impact of ICT on performance. Section 2 provides an overview of e-commerce activity in the UK and a detailed description of the data used in the empirical analysis. Section 3 presents some descriptive analysis while section 4 outlines the modelling approaches that have been adopted in this paper. Section 5

[2] In April 2000, OECD member countries endorsed two definitions of electronic transactions, based on narrower and broader definitions of the communications structure. The method by which the order is placed or received, not the payment or channel of delivery determines whether the transaction is an Internet transaction (conducted over the Internet) or an electronic transaction (conducted over computer mediated networks).

presents the results and discusses the main empirical findings. Section 6 concludes the paper.

1. Computer networks and enterprise performance.

The use of e-commerce as a business process is changing the nature of trading, and the empirical literature is now focusing on the impact that these changes may have on productivity at the plant level (Atrostic and Nguyen, 2004). The evidence is still quite sparse as plant level data on the use of computer networks have only become available in recent years. However, the existing contributions mainly suggest a positive effect of computers network on performance. For example, Rowlatt (2001) argues that the use of computer networks should improve firm level efficiency because of a reduction in administrative costs, search costs, better supply chain management and enhanced information flows.

Whilst *purchases* are not perhaps made on-line to their perceived potential, an increasing number of consumers are using the Internet to research their intended purchases and are thus separating the search and the purchase elements of buying in a way not previously observed (The Economist, 2004). This use of e-commerce is likely to encourage further the use of branding and advertising. In terms of labour market impacts, it is evident that there is a skill bias in labour demand as companies developing e-commerce trades are likely to face an increasing need for computer literacy and a fall in the number of shop floor staff required.

In terms of e-commerce coverage, a recent survey (The Economist, *op cit*) indicated that whilst US e-commerce sales represented only 1.6 per cent of the retail market in 2003, this represents $55bn of sales, excluding some expanding areas of e-commerce, such as online travel and financial services, and represents a 26 per cent growth on the previous year. Thus it can be seen that, from a retail perspective alone, e-commerce is of increasing importance.

Clayton and Criscuolo (2002) highlight three main mechanisms through which e-commerce affects the business process. Firstly, they highlight the importance of e-commerce as a means of improving the effectiveness of research and development. They also point to the importance of e-commerce in improving commercial communication through access to wider markets. Finally, they emphasise the importance of e-commerce in improving the efficiency of business processes and of making the links between processes faster and more reliable.

In a recent study, Atrostic and Nguyen (2004) considered the impact of computer networks on productivity in the US manufacturing sector, using micro data predominantly for 1999. They found a positive and significant impact of computer networks on plant level labour productivity, suggesting that networks increase labour productivity by around 7.5 per cent. Motohashi (2003) provides evidence for the positive impact of different information networks on productivity in Japan. In the UK a recent study by Criscuolo and Waldron (2003), based on the Annual Business Inquiry, shows that buying on line positively affects labour and total factor productivity, while selling on-line has a negative impact on productivity. Their study is based on companies that use all computers mediated networks, including the Internet, and therefore it provides a useful reference for our analysis.

2. E-commerce in the UK

2.1. The E-commerce Survey and the Annual Business Inquiry.

The E-commerce survey is a stratified sample based on the Interdepartmental Business Register (IDBR) frame, which holds records on all UK businesses registered for VAT and PAYE[3]. It has been carried out on an annual basis since 2000. However the 2000 survey was refined and consequently, surveys for 2001 and 2002 are not directly comparable with it. The survey is part of an EU/OECD initiative to produce comparable data for all possible countries and so should be consistent with data collected elsewhere in Europe.

Williams (2001) and Clayton and Criscuolo (2002) provide a description of the data and highlight the characteristics that are most associated with e-commerce users; these are typically large firms in established multiplant enterprises which tend to be located in industries such as food, drink and tobacco and insurance services, as opposed to mining and quarrying.

In this paper data from the E-commerce survey 2001 are used. These include 2,780 enterprises in the production sector and 4,403 enterprises[4] in the service sector. In order to carry out any form of productivity analysis, data from the e-commerce survey has to be matched to the Annual Business Inquiry. The latter provides all information relative to output and factor inputs used in our analysis. The matching

[3] For more details on the E-commerce survey see Williams (2001).
[4] Note that the nature of the data collection and storage system means that enterprises are actually reporting units, which may contain more than one plant, but need not be a whole firm

procedure is based on linking the IDBR numbers which identify companies in both surveys. Matching the data for 2001 gives a cross section of 1,536 observations for manufacturing and 1,903 observations for services, summing to 3,439. Whilst this is a reduced sample, there appear to be sufficient observations to undertake some meaningful analysis in both the manufacturing and service sectors.

The matched sample exhibits many of the characteristics of the full e-commerce dataset, and a few trends may thus be described. In terms of regional location, over 30 per cent of these enterprises are located in the south east, with a broad split over the other 9 regions ranging from 3-8 per cent of enterprises. The age range is from 1 year to 22 years, since 22 years is the maximum age of any observation in the standard variables files as these begin in 1980. In addition, over 41 per cent of enterprises are 5 years old since they enter the dataset in 1997, which is when the service sectors were first included in the BDL files.

2.2 The matched data described.

Table 1 provides a summary of responses to key questions in the e-commerce survey 2001 from the matched sample (ABI and E-commerce). It can be seen that 99.5 and 98.6 per cent of production and service enterprises respectively use at least one PC. The result is not unsurprising given the year of the survey (2001 – quite late in Internet development terms).

The average percentage of employees reported by enterprises as being without Internet access is 28.5 per cent and 28.24 per cent for production and services, respectively. There is more disparity between the two sectors when one considers the percentage of employees using an Internet connection, at 27.15 and 36.14, respectively. Less than one percent in both sectors had no employees using the Internet, and 4.69 and 12.72 per cent of enterprises reported 100 per cent of their employees having access, in production and services respectively. On the face of it therefore, Internet access is pervasive in both sectors, although the Internet appears to have a bigger role to play in terms of employee coverage in the service sector, which is in line with expectations.

When asked how long their enterprise had been using the Internet, the average number of years was 3.43 and 3.32, respectively for production and services. Another question considers how the enterprises connect to the Internet. Whilst this may only be indicative of intensity of use, those enterprises with Broadband are presumably

more integrated into an e-commerce business plan than those who pay per minute through a land line. In the 2001 survey, we find that 26.17 per cent of production enterprise and 32.05 per cent of service enterprises connect to the Internet using broadband. These figures are not very different across the two sectors, but there is some suggestion that services again are more serious about the role that the Internet plays in their production process.

Of the enterprises in the survey, 83.27 per cent and 84.87 per cent had a website in production and services, respectively. This figure shows that the two sectors are very similar in the use of this Internet devise.

2.2.1 Do you use the Internet for placing/receiving orders?

It can be seen that 35.48 and 39.73 per cent of production and service enterprises are engaged in buying over the Internet, though the figure for selling over the Internet is much lower; 14 and 21.44 per cent, respectively. However, when we consider the mean figure given as the percentage of all orders that are placed/received over the Internet, this does not vary drastically between the two. Placing orders over the Internet accounts for on average 1.16 and 2.20 per cent of all orders, and 1.30 and 1.11 per cent of all orders received. In both sectors, between 60-65 per cent of enterprises did no buying over the Internet and 78-86 per cent did no selling over the Internet.

In terms of sales to households via the Internet, the mean figure was very low, less than 0.5% in both sectors, although the maximum proportion of sales received reported was 12 per cent in production and 60 per cent in services. The mean percentage of orders received from businesses was also very low – 1.10 in manufacturing and 0.66 in services. It is interesting to see that this is higher for manufacturing. The highest proportion of sales to businesses carried out over the Internet was over 90 per cent in manufacturing and 100 per cent in services; these may be the result of outliers.

Receiving and making payments via the Internet are consistently done by manufacturing and services, with over 58 per cent of enterprises saying they did receive payments via the Internet. This figure is slightly higher for the making of payments, with over 68 per cent of enterprises making payments over the Internet.

Table 1

Summary of results from the E-commerce questionnaire,

Matched samples 2001

Q no.	Question	format	% Production (n=1536)	% services (n=1903)
q010	Did your enterprise use PCs	yes/no	>99%	98.63
q021	mean % employees without Internet	%	28.5	28.24
	100% employees without Internet	%	>99%	>98%
q022	mean % of employees using Internet	%	27.15	36.14
	100% of employees using Internet	%	4.69	12.72
q051	mean no of years using Internet	no.	3.43	3.32
q052	mean no of months using Internet	no.	1.69	1.72
q061	how do you connect?	% with broadband	26.17	32.05
q080	do you have a website?	yes/no	83.27	84.87
q090	Do you use the Internet for placing orders?	yes/no	35.48	39.73
q101	mean % of orders from the Internet as a % of all orders	%	1.16	2.2
	0% of orders from the Internet	%	65.42	60.27
q110	Do you use the Internet for receiving orders?	yes/no	14	21.44
q121	mean % of orders received from Internet as a % of all orders	%	1.3	1.11
	0% of orders received from the Internet	%	86	78.56
q128	mean % of orders from households	%	0.038	0.44
	max% of orders from households	%	12	60
q129	mean % of orders from businesses	%	1.1	0.66
	max% of orders from businesses	%	93.3	100
q160	use Internet etc for receiving payment	yes/no	62.63	58.01
q170	use Internet etc for making payment	yes/no	70.7	68
q181	link to suppliers' systems	yes/no	16.67	23.33
q182	reordering of replacement supplies	yes/no	14.26	17.71
q183	link customers' systems	yes/no	26.5	15.5
q184	invoicing and payment system	yes/no	35.74	34.42
q185	production/service operation	yes/no	22.01	19.39
q186	logistics system	yes/no	23.57	19.81
q187	marketing	yes/no	7.75	11.61

Source: ONS

The survey also asked a series of questions about the (electronic) links that enterprises had with other aspects of their production process. These included links to suppliers systems, reordering of replacement supplies, links to customer systems, invoice and payment systems, production/service operations, logistic and marketing. Table 1 contains details on these (q160-187), but the most popular is the invoicing and payment system. The least used are marketing links, which are particularly low in the production sector. This suggests that the Internet is proving to be useful as a logistical tool, linking suppliers to customers, but not as a means of promoting the business, e.g. through advertising etc.

2.2.2 Capital stock data.

Data contained in the ABI include net capital expenditure on buildings, plant and machinery and vehicles in any year. However, these investment data as they stand do not provide capital stock figures, which are necessary in order to run full total factor productivity production functions. In this study we use capital stock data as estimated by Martin (2002) for the production sector and extended by the ONS to the service sector. The construction of capital stock data is based on the Perpetual Inventory Method (PIM), following a geometric depreciation rate to investment. Where values are missing over time, straight-line interpolation has been used. Starting values have been derived from investment stock aggregates from ONS's historical series dating back to 1948, at the 2-digit level.

3. Financial performance of matched firms over time

In addition to the initial match for 2001, it has been possible to use the IDBR link to match this one year of E-commerce data to previous years of the ABI, and thus it is possible to consider the financial performance of these plants over a short time period by constructing a panel. Table 2 below provides information on our ability to link these records in each year by broad sectors. One would expect to see a gradual decline in the proportion of enterprises identified as one goes further back over time, primarily because of closures. In this respect, there are grounds to suggest that this sample captures only winners over time, i.e. those who survive. It is worth noting that whilst it has been possible to identify a considerable proportion of matches in each year, this does not mean that the same plants are continuously captured over time. For example, it is perfectly possible amongst the sampled plants that they leave and re-enter the ABI over time. However, the figures over time show that a similar proportion of plants are detected by sector, which suggests that broadly the same plants are being identified over time, with perhaps some marginal mismatching from one year to the next. Table 2 also provides an overview of the age profile of reporting units in 2001, by sector. It can be seen that the youngest reporting units, on average, are located in the other services sector, and are a little over 4 years old, again, a function of the start of the survey. Oldest reporting units are located in the production sector and are on average 14 years old. This is a big difference, and may in part be explained by the relative differences in average scale between the sectors. It is also manifest in the very high 'survival' rates from 2001 back to 1997.

Table 2

Number of matches - e-commerce2001 with ABI over time

Sector	**2001**	**2000**	**1999**	**1998**	**1997**	**Mean Age**
Catering	66	53	49	66	48	4.77
Construction	107	94	83	137	107	6.63
Motor trade	143	103	83	175	128	4.93
Property	39	28	23	44	29	4.61
Production	1536	1309	1354	1741	1272	14.03
Retail trade	169	160	149	170	113	4.59
Other Services	1044	711	803	894	561	4.1
Wholesale	335	235	226	449	252	5.56
SUM	**3439**	**2693**	**2770**	**3676**	**2510**	

Source: ONS

3.1 Some general trends in the data

Figure 1 presents the firms' average rate of productivity growth (2000-2001), by industry. The figure shows a high degree of heterogeneity across the economy, with a large number of industries being characterised by a negative productivity or very low rate of productivity growth. These figures are consistent with the downward trend in the British economy between 2000 and 2001, as documented in the National Accounts (National Accounts 2002).

The best performing industries, with a productivity growth bigger than or equal to 1%, are Oil Refining, Electricity and Gas, Air Transport and the motor vehicles and motorcycles section of Retail Trade. This is consistent with previous research showing that productivity growth in the EU is mainly confined to non-ICT intensive sectors (Van Ark *et al.* 2003). Within manufacturing, only Oil refining and Chemicals display some noticeable productivity growth, while the other industries are characterised by rates very close to zero or negative. This supports existing evidence on the slowdown of productivity growth in the UK and in the rest of Europe after 1995 (Rincon and Vecchi 2004, Basu et al. 2003, Daveri 2002).

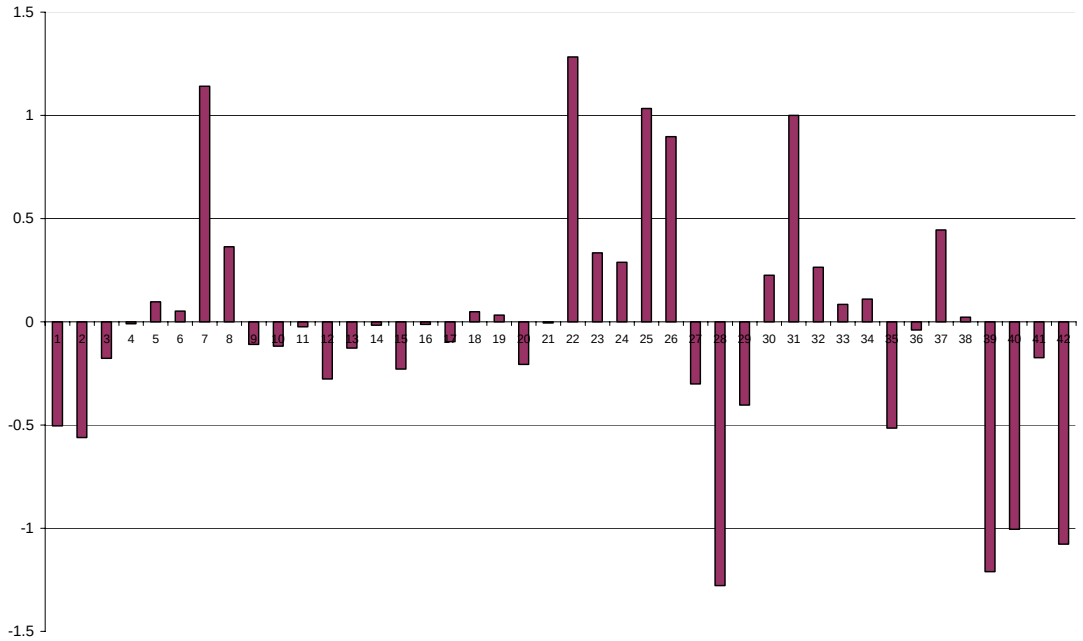

Fig. 1

Labour Productivity Growth by Industry, 2000-2001
Source: ONS

NOTE: 1=Textile 2=Clothing 3=Leather & Footwear 4=Wood & Furniture 5=Paper 6=Printing & Publishing 7=Oil refining 8=Chemicals 9=Rubber & Plastic 10=Non-Metallic Mineral Products 11=Basic metals 12=Metal products 13=Metal engineering 14=Office machinery 15=Electrical machinery 16=Radio, television and communication equipment 17=Instrument engineering 18=Motor vehicles 19=Other transport equipment 20=Manufacturing NEC 21=Recycling 22=Electr & Gas 23=Water supply 24=Construction 25=Retail trade-Motor 26=Wholesale trade 27=Retail trade excluding motor 28=Hotels & Catering 29=Railway & Other Inland Transport 30=Water transport 31= Air Transport 32=Supporting transport activities 33=Communication 34=Auxiliary to financial intermediation 35=Real Estate activities 36=Renting machinery equipment 37=Computer & related activities 38=R&D 39=Other business activities 40=Health and social work 41=Entertainment 32=Other personal services.

The retail sector, excluding the sale of motor vehicles, is characterised by a negative labour productivity growth. This is in sharp contrast with the high productivity performance of the retail sector in the USA in recent years (7.9% between 1995 and 2002 - McGuckin et al. 2004). In fact, Wholesale, Retail trade and Financial Services, three of the main ICT using industries, account for much of the overall US-EU gap in productivity growth since 1995 (O'Mahony and Van Ark 2003, Van Ark *et al*. 2003).

Table 3 compares labour productivity growth between firms that trade and firms that do not trade on the Internet in the year 2001. The table shows that companies that have used the e-commerce technology have outperformed companies that have opted for more traditional means of trade.

Table 3
Labour productivity growth in E-trade and non E-trade firms

Year	Total	E-buy	E-sell	E-buy & E-sell	No E-trade
1998	-0.001	0.132	0.151	0.155	-0.097
1999	-0.002	0.141	0.171	0.217	-0.111
2000	-0.006	0.099	0.117	0.127	-0.095
2001	0.001	0.146	0.228	0.239	-0.128

Source: ONS

The productivity gains have been particularly high in the last year and firms that have chosen to buy and sell on the Internet have experienced the highest productivity growth. Given that we could only use e-commerce data for 2001 and we do not know when firms started to trade on the Internet it is difficult to discern a cause

and effect relationship. Nevertheless the table shows that good performance firms are the ones that have traded on the Internet and they are likely to have invested more in advanced communication technology, consistently with existing evidence (Brynjolfsson and Hitt 1993, 1996a, 1996b and Stolarick 1999a).

4. Modelling productivity

3.1 Production function estimation

In this paper, a gross output specification of the production function is used, following Baily (1986) who shows that value added models yield biased estimates of TFP at the plant level. Output is therefore recognised as the better measure of productivity (Atrostic and Nguyen, 2004).

We start by specifying the following log linear (Cobb-Douglas) production function:

(1) $$Ln(Q_i) = \alpha_0 + \alpha_1 Ln(L_i) + \alpha_2 Ln(K_i) + \alpha_3 Ln(M_i) + \varepsilon_i ,$$

where Q is gross output, L, K, and M are numbers employed, value of capital and intermediate goods respectively.

We look at the impact of buying and selling goods on the Internet, by including in equation (1) the corresponding indicators (Z_{ij}) from the E-commerce survey:

(2) $$Ln(Q_i) = \alpha_0 + \alpha_1 Ln(L_i) + \alpha_2 Ln(K_i) + \alpha_3 Ln(M_i) + \alpha_4 Z_{ij} + \\ + \alpha_5 Multi + \alpha_6 FO + \alpha_7 Age + \sum \gamma_i Ind + \sum \gamma_r Reg + \varepsilon_i$$

$$j = 1,..,3,$$

$$i = 1,...,41$$

$$r = 1,..,10,$$

where j=1-4 corresponds respectively to *e-buy* (q090), *e-sell* (q110), and a linear combination of the two defined as *e-trade*.. This includes all companies that either buy or sell on the Internet. This indicator has been constructed in order to capture the total impact of e-buy and e-sell on productivity.

A priori it is difficult to predict the sign of the effect of e-buy and e-sell. Trading over the Internet allows a firm to reach a wider audience both in the selling and in the purchasing of intermediate inputs, which can have a positive impact on productivity. On the other hand, the tougher competition and the higher price

transparency might negatively affect productivity. The *e-trade* variable is designed to capture the net effect. All three variables are included in equation (2) as dummies equal to 1 when the relevant characteristic is present and zero otherwise.

Following Atrostic and Nguyen (2004) and Zwick (2003), equation (2) also includes a set of control variables to account for plant's heterogeneity: *Multi*, which detects whether the reporting unit is a multi-plant organisation, *FO* indicates whether the plant is foreign owned and *Age* is the age of the reporting unit. Finally, 10 regional (*Reg*) dummy variables have been included, along with 41 2-digit industry dummies (*Ind*).

4.2 Correcting for endogeneity

Equation (2) can be estimated by Ordinary Least Squares (OLS). However, this technique is likely to produce inconsistent estimates as the decision of trading on the web is not orthogonal to the error term, i.e. it is endogenous (Atrostic and Nguyen 2002, 2004). The sign of this correlation is not known *a priori*. McGuckin et al. (1998) found that adopting advance communication technology is positively related to plant's productivity performance. On the other hand, Stolarick (1999b) and Atrostic and Nguyen (2002) found that less productive plants invested more in computer equipment, compared to more productive ones, possibly in an attempt to improve their performance. Moreover, it is relatively well established that e-buying and e-selling are part of advanced communications technology and therefore they are not independent of the plant's performance.

Another possible source of correlation between e-buying and e-selling and the error term is unmeasured pre-existing characteristics of the selected firms (Barnow *et al.*, 1981), such as good management and/or IT skills. Therefore, to obtain consistent estimates of the parameters of equation (2), we instrument the firm's decision to trade on the Internet using a treatment effect estimator (Maddala 1983)[5]. Our instrument set includes variables from the E-commerce survey that are correlated with the decision to buy/sell on the Internet but uncorrelated with establishment productivity, as proved by initial correlation analysis[6]. These variables are: the presence in the firm of a broadband connection (*Broadband*); the percentage of employees that have Internet access (*Webusers*); the number of years the enterprise has been using the Internet

[5] This is an extension of Heckman selection model (Heckman 1979).
[6] Results of the preliminary correlation analysis are available from the authors on request.

(*Experience*) and a measure of the use of electronically linked business process, (*Intense*). The latter is an indicator that summarises the information of several e-commerce variables related to the use of electronic links with suppliers/customers/other parts of the organisation (q160-q187 from table 1)[7]. This score is based on a scale of 0 to 9, with 9 being the most intensive. It is hoped that by combining a number of these technologies into one measure, a more holistic impression of technology take-up is gained. This score was initially included in the production function estimation as previous descriptive analysis showed that firms with linked business processes are characterised by higher labour productivity (Goodridge and Clayton 2004). However, when controlling for various factors such as firm's size, factor inputs and firm's location in industry/region, the intense indicator was never significantly different from zero and it was therefore dropped. Its inclusion in the instrument sets intends to capture the likely correlation between linked business process and e-trade.

The instrument set also includes lagged output ($Output_{t-1}$) to evaluate the impact of past performance on the probability of trading on the Internet. Hence, our instrument equation is specified as a Probit regression:

$$
\begin{aligned}
& Pr(Z_j = 1 | W_i) = \beta_{0j} + \beta_{1j} Broadband + \beta_{2j} Webusers + \beta_{3j} Experience \\
& + \beta_{4j} Intense + \beta_{5j} Output_{t-1} + \\
& + \beta_{6j} Multi + \beta_{7j} FO + \beta_{8j} Age + \sum \gamma_i Ind + \sum \gamma_r Reg + \varepsilon_i u_j \\
& j = 1,..,4,
\end{aligned}
\tag{3}
$$

where W_i is the instrument set. Equation (3) also includes the same set of control variables included in equation (2), i.e. dummies for foreign ownership, multi-plant firms, age of firms, regions and industry. Equation (2) and Equation (3) are estimated jointly using full maximum likelihood procedure.

5. Empirical analysis

5.2 Ordinary Least Squares Results

[7] The construction of an indicator that summarises several survey variables follows Forth and Mason (2003) and McGuckin et al (1998), both of whom construct a measure based on new technologies adopted. Forth and Mason (*op cit*) refer to their measure as a connectivity measure, derived from the IBS survey and based on a number of Internet-style technologies. By constructing an indicator we address the collinearity problem that is likely to arise when we try to include several variables from survey data. In our case, the correlation between the variables included in the *Intense* indicator is above 0.5 in most instances.

In the first instance, we estimate a cross sectional model for 2001 following equation (2), using OLS. This was estimated for the full data set and for production and services separately. In all cases, the control variables discussed in the previous section are included but are not reported in the results contained in Table 4 below.

The results presented in Table 4 reveal that the coefficients on labour, capital and intermediates are relatively similar in production and service sectors and they suggest the presence of constant or slightly decreasing returns to scale. The capital and labour coefficients are quite small compared to prior knowledge of factor shares but this is likely caused by the inclusion of intermediate materials.

Table 4

Cross section OLS results

	All Sectors		Production		Services	
Buying on the WEB						
Constant	1.441*	(.099)	1.444*	(.131)	1.459*	(.241)
Emp	0.252*	(.016)	0.210*	(.024)	0.266*	(.020)
K (2001)	0.124*	(.022)	0.092*	(.031)	0.156*	(.031)
Inter	0.636*	(.024)	0.688*	(.039)	0.598*	(.032)
e-buy	-0.014	(.017)	-0.010	(.019)	-0.018	(.028)
			Selling on the WEB			
Constant	1.445*	(.099)	1.445*	(.132)	1.451*	(.237)
Emp	0.252*	(.017)	0.209*	(.024)	0.266*	(.021)
K (2001)	0.123*	(.022)	0.092*	(.031)	0.155*	(.031)
Inter	0.635*	(.024)	0.688*	(.039)	0.598*	(.032)
e-sell	0.012	(.019)	0.007	(.019)	0.006	(.030)
Using the WEB for selling or buying						
Constant	1.439*	(.099)	1.444*	(.131)	1.452*	(.240)
Emp	0.253*	(.016)	0.210*	(.024)	0.266*	(.021)
K (2001)	0.124*	(.022)	0.092*	(.031)	0.156*	(.031)
Inter	0.636*	(.024)	0.688*	(.039)	0.599*	(.032)
e-trade	-0.008	(.018)	-0.006	(.019)	-0.015	(.029)
Observations	2435		1188		1247	

*= significant at the 5% level, ** at the 10% level. All specifications include the following control variables: age of the reporting unit, dummies for Multiplant, Foreign Ownership, Industry and Region.
Source: ONS

The OLS results suggest that e-buy has a negative impact on productivity while e-sell has a positive effect. However, our coefficient estimates are not

significantly different from zero at the 5% significance level. The coefficient estimates for the control variables (not shown) imply that being part of a multi plant organisation and being foreign owned does not have very high levels of significance, nor do they particularly reflect *a priori* assumptions with their signs. The age of the reporting unit has an average impact of 0.2%, significant at the 10% level, on the productivity of companies operating in the production sector, while it is not statistically significant for those firms operating in the service sector. The coefficients on the industry dummies show a high degree of heterogeneity across the economy and they largely reflect the trends depicted in Figure 1 above, showing positive and significant coefficients, for example, in Utilities, Construction, Motor Retail Trade and Wholesale Trade.

Overall, our OLS results show that buying and selling on the Internet have no effect on productivity. This conclusion diverges from the evidence of the large use that companies make of the Internet and the large amount of goods and services that are traded daily on the Web[8]. The most likely explanation of our results is the endogeneity of the decision to trade on the Internet. To address this issue we need to consider an instrumental variable estimation. This is the focus of the next section.

5.3 Selection bias and its impact on the effect of e-buy and e-sell on productivity

In this section the decision of trading on the Internet is instrumented using the specification discussed in section 4.2, equation (3). The estimates of the production function based on the treatment effect model are presented in table 5. The estimation of the probability of buying and selling on the Internet (our instrument equation) is presented in Appendix table A.1[9].

The inclusion of the treatment effect changes our initial results dramatically. All 4 indicators of trading on the Internet have a strong and positive impact on productivity, when we consider the whole sample. Some differences emerge when we look at the Service and Production sectors separately. E-buy is not significant in Services, while it has a strong impact on Production companies. The results also indicate that the productivity effect of buying on the Web is higher than selling on the

[8] Internet sales in 2000 in the UK were estimated as being worth nearly £60billion, representing 2 percent of total sales, while sales via all electronic networks totalled £160 billion, or 5.8 per cent of sales (Rowlatt 2001).

[9] Contrary to Atrostic and Nguyen (2004) we find that past performance is positively correlated to the probability of e-trade, both in production and in services.

Web (respectively 0.302 and 0.224 for the whole sample, 0.342 and 0.242 for production).

The impact of productivity is even higher when the e-buy and e-sell are considered jointly, using the e-trade indicator. The inclusion of the latter aims at correcting for another potential misspecification in the results based on a single side of the trade, i.e. if both selling and buying positively affect productivity, each equation is omitting an important variable and therefore the coefficient estimates on e-buying and e-selling can be affected by an omitted variable bias. Table 5 shows that our combined variable is positive and significant and its effect is higher than the average impact of e-buy and e-sell in all specification. This contrasts with the findings of Criscuolo and Clayton (2003) who found opposing signs to buying and selling using computer mediated networks[10].

The results of a likelihood ratio test are also reported in table 5. This tests the null that the errors in the two equations (the production function and the treatment equation) are uncorrelated. Rejection of the null implies that selectivity bias is important and it largely affects the OLS results without treatment. Failure to reject the null hypothesis, on the other hand, makes the treatment effect estimator equivalent to the simple OLS. The null is rejected at the 5% significance level most cases. It is worth noting that the estimated coefficients on employment, capital and intermediate materials are only marginally affected by the treatment, suggesting stability in their measurement.

[10]Also note that Criscuolo and Waldron (2003) focus on the manufacturing sector and do not distinguish between the use of the Internet and other mediated networks. Their evidence is based on OLS regression and it does not correct for endogeneity.

Table 5

The impact of trading on the Internet on firms' productivity performance. Treatment effect estimator

	All Sectors	Production	Services
Buying on the Web			
Constant	1.588* (.158)	1.539* (.160)	2.049* (.122)
Emp	0.260* (.015)	0.214* (.020)	0.277* (.019)
K (2001)	0.110* (.022)	0.078* (.026)	0.139* (.032)
Inter	0.621* (.030)	0.684* (.038)	0.585* (.043)
e-buy	0.324† (.196)	0.342* (.097)	0.296 (.326)
L. ratio test	2.270 (.132)	11.51* (.001)	0.680 (.408)
Selling on the WEB			
Constant	1.637* (.131)	1.533* (.151)	2.466* (.179)
Emp	0.257* (.014)	0.221* (.019)	0.263* (.019)
K (2001)	0.115* (.024)	0.087* (.033)	0.139* (.031)
Inter	0.621* (.029)	0.680* (.043)	0.581* (.038)
e-sell	0.247* (.108)	0.243* (.113)	0.365* (.142)
L. ratio test	3.990* (.045)	4.550* (.033)	4.370* (.037)
Using the WEB for buying or selling			
Constant	1.710* (.160)	1.544* (.163)	2.172* (.117)
Emp	0.254* (.014)	0.217* (.020)	0.267* (.019)
K (2001)	0.107* (.022)	0.077* (.026)	0.132* (.031)
Inter	0.613* (.030)	0.680* (.039)	0.568* (.043)
e-trade	0.389* (.106)	0.349* (.096)	0.454* (.152)
L. ratio test	9.22* (.002)	12.15* (.001)	5.710* (0.017)
Observations	1983	979	1004

Note: a'*' indicates rejection of the null hypothesis at 5% significance level, a '‡' indicates rejection at 10% significance level. All specifications include the following control variables: age of the reporting unit, dummies for Multiplant, Foreign Ownership, Industry and Region. Source: ONS

The interpretation of the coefficients presented in Table 5 is less straightforward compared the OLS results, where we simply include 0-1 dummies for those firms that trade on the Internet. In the treatment effect estimator trading on the Internet is a continuous variable. A better understanding can be achieved by comparing the productivity impacts of trading on the Internet on firms at two points in the predicted probability of doing e-trade (Atrostic and Nguyen 2004). We present

this comparison in table 6, using the total sample of firms that either buy or sell on the Internet (e-trade).

The results in table 6 show that in the total sample, for example, firms in the 99th percentile of the probability distribution (more likely to trade on the Internet) have over a 30% increase in productivity compared to firms on the 1st percentile (less likely to trade on the Internet). The productivity gain is stronger in the Service than in the Production sector where the difference between the 1st and the 99th percentile is 40% and 24.4% respectively.

Table 6

The impact of e-trade on firms' productivity

(Based on the treatment effect estimator)

Percentiles (%) of Pr (E-Trade)	Percent increase in labour productivity.
Total	
1% (0.097) vs. 99% (0.892)	30.8%
5% (0.179) vs 99% (0.892)	27.6%
1% (0.097) vs 10% (0.234)	5.3%
10% (0.234) vs 90% (0.741)	19.7%
25% (0.333) vs 75% (0.608)	10.7%
Production	
1% (0.112) vs. 99% (0.812)	24.4%
5% (0.177) vs 99% (0.812)	22.2%
1% (0.112) vs 10% (0.214)	3.5%
10%(0.214) vs 90% (0.643)	14.9%
25%(0.298) vs 75% (0.528)	8%
Services	
1% (0.097) vs. 99% (0.979)	40%
5% (0.215) vs 99% (0.979)	34.7%
1% (0.097) vs 10% (0.313)	9.8%
10% (0.313) vs 90% (0.904)	26.8%
25% (0.481) vs 75% (0.817)	15.2%

Source: ONS

6. Conclusions

This paper has focused on the indirect impact of ICT on productivity and specifically on the effect of buying and selling over the Internet on companies' performance. Our results show that whilst the OLS regressions suggest very little impact from e-buying or selling, when selectivity biases are taken into account both have a large and positive impact on enterprise level productivity.

The paper has also highlighted the difference between production and service sectors in the use and the impact of e-commerce. Among companies operating in the production sector we find that both e-buying and e-selling have a positive effect on productivity, while in the service sector selling on the Internet is comparatively more important in improving productivity performance. This shows that for these companies the Internet has been an excellent device for expanding their business but that more can be done to enhance the productivity impact of buying on the Internet.

The present work only covers one cross section of data. However, we believe that e-commerce is having a substantial effect on the growth of productivity, and as such, a more appropriate way to capture its full impact is to consider growth rather than levels. More year of data for the E-commerce survey are gradually becoming available therefore further research can look at how the behaviour of British enterprises with regards to the use of the Internet is developing and how these developments affect productivity.

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Appendix

Table A.1

Instrument equation estimates

(Probit regression)

		e-buy	*e-sell*	*e-trade*
Total	Constant	-1.979* (.773)	-3.632* (.521)	-2.841* (.510)
	Output-1	0.087 (.086)	0.153* (.053)	0.174* (.054)
	Experience	0.069* (.030)	0.010 (.019)	0.050* (.021)
	Intense	0.058* (.021)	0.124* (.021)	0.074* (.019)
	Webusers	0.321* (.121)	0.349* (.116)	0.304* (.113)
	Broadband	0.105 (.116)	0.113 (.140)	0.095 (.096)
Production	Constant	-2.052* (.572)	-2.996* (.709)	-1.926* (.579)
	Output-1	0.107† (.058)	0.143* (.071)	0.119* (.056)
	Experience	0.055* (.025)	0.028 (.027)	0.047* (.023)
	Intense	0.065* (.023)	0.133* (.034)	0.078* (.025)
	Webusers	0.044 (.161)	0.408† (.230)	0.106 (.171)
	Broadband	0.151 (.117)	-0.426* (.181)	0.035 (.112)
Services	Constant	-1.141 (1.131)	-3.394* (.687)	-2.275* (.714)
	Output-1	0.071 (.129)	0.195* (.063)	0.223* (.071)
	Experience	0.085† (.044)	-0.001 (.025)	0.054† (.030)
	Intense	0.053* (.026)	0.108* (.027)	0.071* (.024)
	Webusers	0.430* (.134)	0.278* (.138)	0.385* (.135)
	Broadband	0.073 (.183)	0.527* (.207)	0.136 (.138)

Note: a'*' indicates rejection of the null hypothesis at 5% significance level, a '‡' indicates rejection at 10% significance level. All specifications include the following control variables: age of the reporting unit, dummies for Multiplant, Foreign Ownership, Industry and Region. Source: ONS