R&D, Innovation & Exporting in Britain: An Empirical Analysis

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Abstract

This study considers the determinants of whether a firm exports, undertakes R&D and/or innovates, and, in particular, the contemporaneous links between these variables using three waves of the UK Community Innovation Survey. An instrumental variables procedure is employed to overcome problems of endogeneity. Given the key role of R&D, innovation and exporting in determining productivity, it is important that government understands these complex interactions between R&D, innovation and exporting and takes advantage of them when devising and implementing productivity-enhancing policies at the micro-level.

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R&D; innovation; exporting; endogeneity

1. Introduction

It is increasingly recognised in the more recent micro-econometrics literature that the link between exporting and productivity is not exogenous (as was first assumed in initial theoretical work by Bernard and Jensen, 1999, and Melitz, 2003). Firms improve their productivity prior to exporting, and potentially gain additional productivity benefits post-entry (Aw et al., 2011). In short, undertaking R&D and/or innovating are likely to both impact on the firm's decision to export or not, and in turn to be influenced by the experience of exporting (i.e., through a 'learning-by-exporting' effect). Hence, as Aw et al. (op. cit.) make clear: "… a key implication … is that … technology and export decisions are interdependent and both channels may endogenously affect the firm's future productivity" (p. 1313).

As is shown in the next section, there are now a growing number of papers that have begun to look at not just the (causal) links between exporting and productivity, but also whether there are (causal) links between R&D/innovation and exporting.[1] However, most studies only consider causality in one direction (the most popular being whether undertaking R&D/innovation results in firms having a higher probability of exporting), and they often do not allow for contemporaneous links between exporting and R&D/innovation. That is, an endogenous determining variable is usually dealt with by entering it into the model in lagged form. Moreover, and as far as we know, no study looks at contemporaneous links between all three variables: exporting, R&D, and innovation. And yet, we also know from data sources like the European Union Community Innovation Survey (the data source used here) that not all innovation is supported by R&D; some firms undertake R&D and do not innovate; and exporting does not necessarily require R&D/innovation beforehand, nor result in R&D/innovation post-entry. So, in this paper we provide a review of the theoretical reasons that have been put forward for (contemporaneous) links between all three variables, before proceeding (for the first time) to obtain empirical estimates of these links, in order to better understand the underlying processes that firms engage in with regard to improving their level of productivity. This is done using probit models for the three activities, and we instrument the dichotomous endogenous variables using other variables in the dataset.

[1] One advantage of looking at relationships between the underlying variables that help determine productivity is that (firm level) total factor productivity (TFP) is not directly observed in datasets (it has to be estimated, which invariably involves untested assumptions as well as other biases due to missing variables, etc.). Labour productivity is observed, but is not ideal as it is determined by TFP and by factor substitutions between labour, capital and other inputs into production.

A second contribution is that this study uses a much larger data set than is normally available, and takes account of the economic relationships between the three dependent variables over time. Three waves of the UK Community Innovation Survey (CIS) carried out in 2005, 2007 and 2009 were merged; giving a nationally representative account of the innovation activities of the reporting enterprises for the period covering 2002-2008.

Thirdly, we cover not just manufacturing but the service sector as well. Most of the previous work in this area has only had access to manufacturing data, but exporting and innovation activities have become increasingly important in the sale of marketed services, and there are interesting comparisons to be made through a consideration of the results across the two sectors.

We only deal with the issue of whether firms engage in exporting, R&D and/or innovation, and not how much is exported, spent on R&D or the proportion of sales obtained from new products. While such 'intensities' are interesting, it is our view that what is most important are the 'extensive' margins – i.e., the numbers involved in such activities.[2] From a policy perspective, increasing the take-up of these productivity-related activities (especially among those firms with the greatest potential for improvement), is more likely to increase overall aggregate UK productivity levels in the long-run, than existing firms already undertaking such activities doing more of them.

In the next section we review the literature on the relationship between R&D, innovation and exporting (concentrating on more recent micro-level studies); section 3 discusses the data used and our modelling strategy. The results are presented in section 4, followed by a summary and conclusion that also attempts to relate our findings to the policy options available to government in this area.

2. Relationship between R&D, Innovation and exporting

2.1 Theory

There is a well-established trade-innovation macroeconomic framework that offers at least two mainstream theoretical models to account for a relationship between R&D/innovation and exporting (with the causation running from the former to the latter). Usually little distinction

[2] In any event, the CIS surveys for 2005 and 2009 did not ask respondents to provide details on the amount sold overseas, while information is available in all the surveys on whether any exporting took place.

is made between R&D and innovation – the most common assumption being that innovation inputs (R&D) lead to new product and process outputs. Neo-endowment models concentrate on specialisation and thus competitive advantage on the basis of factor endowments, such as materials, skilled/unskilled labour, capital and technology (Davis, 1995); while neo-technology models (Greenhalgh, 1990; Greenhalgh et al., 1994) are an extension of conventional technology-based models based on, for example, product life cycle theory (Vernon, 1966; Krugman, 1979; Dollar, 1986) and the technology-gap theory of trade (Posner, 1961). More recent macroeconomic models (e.g., Grossman and Helpman, 1995) allow firms to improve the quality of their products, which shifts outward a country's export demand curve.

A parallel literature allows firms to learn from internationalisation and thus the possibility that causality runs from exporting to R&D and innovation. Such endogenous growth models (Romer, 1990; Grossman and Helpman, 1991; Young, 1991; Hobday, 1995; Aghion and Howitt, 1998) cover the need for firms to innovate to meet stronger competition/different standards in foreign markets, they allow for a 'learning-by-exporting' effect (through exposure to superior foreign technology and knowledge), and they allow for economies of scale and thus exporting firms to cover the large fixed costs of undertaking R&D (and innovating).

In contrast, theoretical modelling at the microeconomic level has (until recently) not formally considered how R&D and innovation are linked to exporting. Attempts to study the firm's decision to export (Bernard et al., 2003; Yeaple, 2005; Melitz, 2003), particularly based on a framework of sunk costs and firm-level heterogeneity, have assumed that a firm's productivity is exogenous. Recently, however, theoretical efforts have been made to endogenise firm heterogeneity (e.g., Aw et. al., 2011; Bustos, 2011; Atkeson and Burstein, 2010) with firms needing to engage in productivity enhancing activities (such as R&D and/or producing innovations) prior to exporting and 'post-entry' productivity enhancing feedbacks from exporting which lead to two-way causal relationships between R&D/innovation and exporting. Indeed as the return to undertaking R&D/innovation and exporting increases with the producer's underlying productivity, higher-productivity producers will tend to self-select into exporting and R&D/innovation activities. In addition, undertaking exporting and R&D/innovation also directly affects future productivity, reinforcing endogeneity through the selection effect (as Aw et. al., p.3, state: "… each activity alters the future return from undertaking the other activity, thus current R&D directly impacts the probability of exporting and current exporting alters the return to R&D"). In contrast, literature from the strategic management area has long assumed productivity to be endogenous; e.g., that innovating firms have incentives to expand into other markets (e.g., through exporting) so as to earn higher returns from their investment, as the appropriability regime is improved when the product market widens (e.g. Teece, 1986). This resource-based approach (Penrose, 1959; Barney, 1991) has been explicitly employed in recent empirical studies (viz. Dhanaraj and Beamish, 2003; and Lopez Rodriguez and Garcia Rodriguez, 2005; Harris and Li, 2009), offering new insights into this export-innovation relationship, in light of the development of a firm's technological capacity.

In this paper we wish to model the following structural relationships, taking account of the potential simultaneous relationships between them:

$$\begin{aligned} EXP_{it} &= f(INN_{it}, R\&D_{it}, X_{it}^{1}) + u_{it}^{1} \\ R\&D_{it} &= f(INN_{it}, EXP_{it}, X_{it}^{2}) + u_{it}^{2} \\ INN_{it} &= f(EXP_{it}, R\&D_{it}, X_{it}^{3}) + u_{it}^{3} \end{aligned} \qquad (1)$$

where EXP_{it}, $R\&D_{it}$, and INN_{it} refer to whether firm *i* exports, spends on research and development, and/or introduces a product and/or process innovation during *t*. The X_{it} are vectors of other (exogenous) variables. We shall discuss the modelling strategy adopted in section 3.2 below; in this sub-section we set out the theoretical underpinning for this model based on the extant literature.

Existing explanations that justify the structural model in equation (1) are as follows. With respect to why innovation and/or R&D should determine exporting, we have already alluded to the argument that firms need to engage in productivity enhancing activities (such as R&D and/or producing innovations) prior to exporting in order to achieve the necessary level of productivity to overcome entry barriers that protect more competitive export markets; while continuing levels of such investment is necessary to maintain a presence in such markets (see Bernard and Jensen, 2004 and Greenaway and Kneller, 2007, for reviews). Product innovation can be a means of facilitating entry, as can process innovations that improve existing technologies. It is necessary to include R&D as a separate determinant of exporting because R&D can be undertaken not just to support innovation but also to increase a firm's (intangible) knowledge assets, through increasing the absorptive capacity of the firm (the ability to internalise external knowledge).[3] This is the 'second face' of R&D as

[3] Note, as explained below in section 3.1 (when discussing the data used in this study), we include direct measures of absorptive capacity into the X_{it}, noting that R&D has often been used in the literature as an imperfect and incomplete proxy for absorptive capacity. However, we find in our empirical work that our direct measures of absorptive capacity (based mostly on the sources of information and level of cooperation undertaken by firms in pursuit of innovation-related activities) play a key role in determining R&D and innovation *but not exporting*;

developed by Cohen and Levinthal (1989, 1990), and tested by, inter alia, Griffith et al. (2004), Kneller (2005), Cameron et al. (2005), and Lokshin et al. (2008).

Including exporting as a determinant of R&D and/or innovation is traditionally justified by a 'learning-by-exporting' effect (e.g., Aw et. al., 2011, p. 1317). Firms that operate in more competitive export markets, and thus have access to (and knowledge of) these markets comprising better technologies and/or higher quality products, can obtain an additional (current and future) productivity benefit if they can internalise this additional knowledge and expertise. Direct information on technical and product development is often provided by customers and suppliers (Salomon and Shaver, 2005; Clerides et. al. 1998) that can stimulate the firm's own innovation outputs. The probability of undertaking R&D is also likely to be boosted by exporting because it is necessary to increase the capacity of the firm to absorb the useful knowledge obtained from exporting.[4,5]

Having R&D as a determinant of innovation is easily justified by reference to the literature that treats R&D as an input into the innovation production function (e.g., Geroski, 1990; Harris and Trainor, 1995; Mairesse and Mohnen, 2002). The reasons for why innovation should determine R&D are less well documented. However, some of the arguments for why innovation may exhibit persistence – a relationship that has received greater attention in the literature (see , e.g. Geroski et al., 1997; Malerba and Orsenigo, 1999; Peters, 2009) - can also be used to explain why innovation may have an impact on R&D. For example, Mansfield (1969) argued that successful innovation increases a firm's technological opportunities, thereby making further innovations more likely. As a result, the potential returns to R&D are raised. Another argument for an impact of innovation on R&D is that, because of their inherent riskiness, firms may find it difficult to obtain funding for innovation projects from external sources (Peters, 2009). If successful innovations lead to increased profitability and therefore access to internal funding, this will allow firms to undertake more R&D.

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this empirical result provides new insights into how theoretically to incorporate absorptive capacity: absorptive capacity determines R&D and innovation, and R&D helps firms to overcome the initial (sunk) costs of exporting. Therefore, there is an indirect impact of absorptive capacity on exporting through R&D but no direct impact. This also helps to justify further the importance of the relationship between the three key variables considered here.

[4] Atkeson and Burstein (2010) model this in a different, but comparable, fashion: due to experience gained through current exporting there is an expectation of *lower* future fixed costs in the export market, and this increases a firm's incentive to invest in current R&D.

[5] While exporting leading to innovation is clearly an 'learning-by-exporting' effect (as the firm has gained new/extra information and/or knowledge overseas), strictly speaking exporting leading to R&D should not be called a 'learning-by-exporting' effect as it has not gained direct knowledge about how to undertake R&D from exporting, although the firm does now undertake R&D so that it can internalize the knowledge it can get from exporting.

But why should some firms engage in none, some, or all of these three activities (and why should relationships be at least in part contemporaneous)? Part of the answer is to do with the variables comprising X_{it} in equation (1); various time-varying demand and supply conditions linked to the specific product of each firm will impact on whether it is profitable to engage in exporting (e.g., the export demand curve firms' face), R&D (e.g., technological opportunities that can vary across products/industries, and expertise within firms), and innovating (e.g., oligopolistic market conditions and rivals behaviour vary). In addition, all three activities incur additional sunk and/or fixed costs,[6] and the latter are likely to vary across the activities concerned (e.g., Aw. et. al., 2011, assume that the costs of undertaking R&D are larger than the costs of exporting). However, incurring such costs allows the firm to improve their technology, which reduces their marginal costs of production (such productivity gains can be associated with lower costs of production and/or quality gains – i.e., with physical and/or revenue productivity improvements). Thus firms must choose between higher fixed costs/lower marginal costs (i.e., they invest in some 'mix' of the three activities considered here), or lower fixed costs/higher marginal costs (when they do not invest). The choice of investing or not is thus based on the level of sunk costs and whether it is profitable to incur these costs, which is (in large part) dependent on (endogenous) productivity (which of course is determined by past net investments in technology). So in Bustos (2011), this results in the sorting of firms in terms of their productivity, with low productivity firms not exporting (and not investing in better technology), medium productivity firms exporting (but not investing in better technology), and high productivity firms exporting (and investing to lower their marginal costs, by improving productivity). It is likely that a more complicated version of the Bustos approach, with different types of investment to improve technology (with different levels of sunk costs) explicitly included, could be developed to explain the 'mix' of the three activities that firms' invest in.[7]

Because investments in exporting, R&D and producing innovation outputs (involving sunk/fixed costs) all exhibit persistence (i.e., they are 'path-dependent'), and with each type of investment impacting on future productivity, we should expect that firms' make contemporaneous decisions with respect to these variables. There may be timing issues that

[6] Sunk start-up costs cover the barriers to entry into initially undertaking there activities; fixed costs are incurred post-entry and in this sense act as a barrier to exit.

[7] Note also it is usually assumed that the different types of investment are complementary; all involve the firm in acquiring knowledge and expertise in order to improve its (current and future) productivity and undertaking a 'mix' of investments will bring increasing returns. However, as Aw et. al. (2011) point out, if these activities are substitutes, then it is possible to end up with a situation where, say, non-exporters are more likely to undertake R&D (doing both results in diminishing returns).

lead to lagged relationships between these variables; for example, there may be a (considerable) lag between R&D and the introduction of an innovation. Moreover, R&D does not always lead to a successful innovation, while some product and/or process innovations do not always require formal R&D to be undertaken (i.e., some innovations may be developed outside the firm and introduced without the need for R&D investment itself). However, this is (mostly) an empirical issue of whether relationships are contemporaneous, lagged, or truncated; we do not impose a priori any restrictions that are likely to lead to biased results if relevant contemporaneous relationships are not allowed.[8]

2.2 Empirical evidence

Ample evidence has been provided at the macroeconomic level, regarding the linkage between a country's export performance and its creativity/innovation. A uniformly positive correlation has led to a consensus that a nation's exports are positively associated with its knowledge accumulation/innovative activities (for more recent studies see Fagerberg, 1988; Greenhalgh, 1990; Verspagen and Wakelin, 1997; Narula and Wakelin, 1998; Leon-Ledesma, 2005; DiPietro and Anoruo, 2006; and Salim and Bloch, 2009). For instance, using data for Australia, Salim and Bloch (op. cit.) have recently applied causality analysis to show that business expenditure on R&D Granger-causes exports.

In contrast, empirical studies at the firm level are an attempt to disentangle this export-innovation/R&D relationship, taking into account the heterogeneity of firm characteristics amongst exporting and non-exporting firms.[9] Various empirical studies have emphasised the role of technology and innovation as one of the major factors contributing to facilitating entry into global markets, and thereafter maintaining competitiveness and boosting export performance. For instance, studies covering UK and Irish firms include: Wakelin (1998), Roper and Love (2001), Bleaney and Wakelin (2002), Gourlay and Seaton (2004), Hanley (2004), Roper et al. (2006), Girma et al. (2008), Harris and Li (2009, 2010) and Ganotakis and Love (2012); for Canadian manufacturing firms, Bagchi-Sen (2001), and Lefebvre and

[8] Note, Ganotakis and Love (2012) employ a recursive model where R&D determines innovation and then innovation determines exporting. Our approach encompasses this, since if the recursive approach is valid we would expect to find that our empirical work would confirm such a structure. However, if (as argued above) there are reasons for R&D directly impacting on exporting (through a 'two-faces of R&D' approach) and we impose the recursive model, the result is a misspecified model that should lead to biased and/or potentially misleading parameter estimates.

[9] Note, we only cover studies that directly consider the relationship between R&D/innovation and exporting; the parallel literature covering the productivity-exporting nexus is surveyed in, for example, Greenaway and Kneller (2007) and Wagner (2007).

Lefebvre (2001); for Italian manufacturing firms, Sterlacchini (1999) and Basile (2001); for Spanish manufacturing, Cassiman and Martinez-Ros (2007), Lopez Rodriguez and Garcia Rodriguez (2005) and Caldera (2010); for Germany, Lachenmaier and Wößmann (2006) and Becker and Egger (2009); for Belgium, Van Beveren and Vandenbussche (2010); in comparative studies, Roper and Love (2002), for both UK and German manufacturing plants and Dhanaraj and Beamish (2003) for US and Canadian firms; in the context of the rest of the world, Hirsch and Bijaoui (1985) for Israel; Alvarez (2001) for Chilean manufacturing firms (although in this study innovation had no impact on whether a plant exported); Zhao and Li (1997) and Guan and Ma (2003) for China and lastly, Ozcelik and Taymaz (2004) for Turkish Manufacturing firms. Most of these studies deal with manufacturing, although Gourlay et al. (2005), Love and Mansury (2009), and Harris and Li (2009, 2010) found that R&D and/or innovation impacted on exporting services in the UK or the US.
It is important to note that (with the exception of Zhao and Li, 1997) none of these studies directly tested for a simultaneous relationship allowing exporting to determine innovation/R&D (and vice versa) although some allowed for a potentially endogenous feedback by instrumenting innovation/R&D (e.g., Cassiman and Martinez-Ros, 2007; Caldera, 2010; Harris and Li, 2009; Van Beveren and Vandenbussche, 2010; Ganotakis and Love, 2011)[10,11] while others (e.g., Girma et al., 2008; Damijan et al., 2010) modelled jointly the decision to export and undertake R&D, but entered only lagged values of the potentially endogenous variable in each model.[12]

Evidence on causality going from exporting to innovativeness also exists; as stated above the conventional approach to testing this 'learning-by-exporting' hypothesis is to analyse performance-related variables (such as labour productivity, TFP, average variable costs and the like) as proxies of a firm's learning behaviour. However, Salomon and Shaver (2005) advocate that using innovation as a measure of learning provides a "more direct

[10] Cassiman and Martinez-Ros (2007) used industry and time dummies as instruments for innovation; Caldera (2009) uses whether the firm received public support for R&D; Harris and Li (2009, 2010) used instruments such as firm size and age, firm-level absorptive capacity, location, industry sector, and ownership when taking account of the potential endogeneity of R&D; Van Beveren and Vandenbussche (2010) use R&D and training as instruments; while Ganotakis and Love (2012) also use R&D as well as government support and collaborative agreements with suppliers/customers. The use of R&D as an instrument (implying R&D did not impact on exporting, which was determined by innovation, but R&D did determine innovation) is discussed again later.
[11] Some studies have used a 'matching' approach instead, to take account of selection effects; e.g., Becker and Egger (2009) and Damijan *et al.* (2010). These studies compare exporting performance for innovators and non-innovators, where the two innovator sub-groups comprise firms with similar characteristics.
[12] Some, like Alvarez (2001) do consider whether exports impact on the probability of innovating (and vice versa) but without any control for potential endogeneity between the variables. Others (e.g., Love and Mansury, 2009) consider the simultaneous relationship between exporting intensity and labour productivity, with innovation included as an exogenous determinant of exporting intensity.

appraisal of the phenomenon", showing that firms can strategically access foreign knowledge bases and enhance innovation capabilities through engaging in exporting activities. This positive impact of exporting on learning/knowledge accumulation is also documented in Cassiman and Veugelers (1999), Bishop and Wiseman (1999), Alvarez (2001) and Blind and Jungmittag (2004). Crespi *et al.* (2008) have found that exporters in the UK engage in relatively more learning from clients, and that this subsequently leads to higher productivity growth. Others have found that entering export markets has no impact on innovation (e.g., Baldwin and Gu, 2004, for Canada); rather firms that export are better innovators pre- and post-entry. More recently, Damijan et al. (2010), and Van Beveren and Vandenbussche (2010) find that exporting positively impacts on a firm's innovativeness. Girma et al. (2008) found this was also the case for Irish firms, but not British exporters; and Zhao and Li (1997) found a two-way causal relationship between exporting intensity and R&D spending in a sample of Chinese firms. Others provide evidence in favour of exporting having an impact on innovation/R&D but in less direct terms; Aw et al. (2011) found that exporting boosts productivity, with exporting firms investing in R&D having higher productivity when compared to exporters not investing in R&D. Criscuolo et al. (2010) also found that exporters had more innovation outputs than non-exporters, although most of the greater innovativeness was due to higher R&D by such firms rather than exporting per se. The studies of both Aw et al. (op. cit.) and Criscuolo et al. (op. cit.) suggest that exporting alone is not enough; it needs to be accompanied by R&D to generate productivity gains. More recently, using data on Italian manufacturing firms, Hall et al. (2008) found that international competition fostered R&D intensity, which was especially true in high-tech firms.

3. Data and modelling strategy

3.1 Data

This study uses three waves of the UK Community Innovation Survey (CIS) carried out in 2005, 2007 and 2009, covering activities in 2002-2004, 2004-2006, and 2006-2008 (referred to as CIS4/5/6, respectively). This is a nationally representative survey carried out by the Office for National Statistics (ONS) on behalf of the UK Government, covering the innovation activities of the reporting unit for a 3-year period.[13] We merged each survey with

[13] See http://www.bis.gov.uk/policies/science/science-innovation-analysis/cis/ for details on the questionnaires used, sampling design, and 'official' analysis of the UK CIS data. Note, as the CIS is based on a sample drawn

the ONS Annual Respondents Database (ARD) for 2004, 2006 and 2007 (the 2008 ARD data not being available at the time of our analysis) using comparable reporting unit information in the ARD covering additional variables such as the age of the establishment, ownership characteristics, and capital stock.[14] Table 1 sets out the list of variables we use in the current study, along with the source of the datasets. Note, the establishment's R&D activity is defined as intramural R&D, or acquired external R&D or acquired other external knowledge (such as licences to use intellectual property).[15]

(Table 1 about here)

Of particular importance is the absorptive capacity of the establishment. No direct information on this variable is available, but CIS contains information on key elements of internal and external knowledge that can be related to absorptive capacity. 'Internal' absorptive capacity is proxied using data on the impact on business performance of the implementation of new or significantly changed corporate strategies; advanced management techniques (e.g. knowledge management, Investors in People, JIT and Sigma 6); organisational structures (e.g. introduction of cross-functional teams, outsourcing of major business functions); and marketing concepts/strategies[16]. 'External' absorptive capacity was proxied using data on the relative importance of different sources of information used for *innovation related* activities and/or the types of cooperation partner on innovation activities. Sources of information can be grouped under the following sub-headings with associated elements: market – suppliers customers; competitors; consultants, commercial labs/R&D enterprises; institutional – universities; government/public research organisations; other – conferences, trade fairs, exhibitions; scientific journals and trade/technical publications;

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from the ONS Inter-departmental Business Register (IDBR), weights can be constructed to provide nationally representative information.

[14] Reporting units in the IDBR have unique codes, allowing us to merge almost every surveyed unit in the CIS with data in the ARD; only establishments in Northern Ireland and certain sectors (such as financial services) were omitted because they are outside the scope of the ARD carried out in Great Britain by the ONS. Because we only had data from the 2007 ARD, a very small number of reporting units from CIS6 that started operations in 2008 could not be merged and therefore are omitted from the analysis. Note, from this point on we shall refer to the establishment rather than reporting unit. The latter is the accounting unit of the company that provides the ONS with the data it requires; for a single-plant enterprise, establishment and plant (or local unit) are the same – which covers about two-thirds of the respondents in CIS. For multi-plant firms, the establishment can comprise several plants, and larger multi-plant firms may return several reporting units to the ONS (see Harris, 2002, and Robjohns, 2006).

[15] There is other spending that is categorised in CIS, such as acquisition of machinery and equipment (including computer hardware), training and marketing in connection with product and process innovation, but we chose to exclude these from our narrower and more traditional definition of R&D after some initial analysis of the data (see Harris and Li, 2010, especially Chapter 3) and by comparing the CIS totals with those obtained from the BERD.

[16] For each set of information, respondents were asked whether the change had taken place in the three-year period up to 2004, 2006, and 2008, respectively across CIS4/5/6.

professional and industry associations; technical, industry or service standards.[17] Co-operation partners comprised similar elements: suppliers; customers; competitors; commercial labs/R&D enterprises; universities; and government/public research organizations.[18]

To obtain measures of absorptive capacity, we use the approach taken by Harris and Li (2009) and undertake a factor analysis for each CIS wave using all the (26) variables listed above. Based on the Kaiser criterion (Kaiser, 1960), five principal components were retained (with eigenvalues greater than 1), accounting for between 61-69% of the combined variance of the variables. In order to obtain a clearer picture of the correlation between those variables related to absorptive capacity and the five factors extracted, the factor loadings matrix for each CIS wave was transformed using the technique of variance-maximising orthogonal rotation (which maximises the variability of the "new" factor, while minimising the variance around the new variable). All 26 input variables used to measure absorptive capacity are supported by the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy – most of the KMO values are above 90% and an overall KMO value of between 83-94% across the different CIS waves suggests the contribution of the raw variables was adequately accounted for.[19]

Based on the correlations between these 26 underlying variables and the five varimax-rotated common factors (each with a mean of zero and standard deviation of 1), we were able to interpret these factors as capturing the establishment's capabilities of exploiting external sources of knowledge; co-operating with external bodies at the national level; implementing new corporate strategies and management techniques; building up partnerships with other enterprises or institutions at the international level; and acquiring and absorbing codified scientific knowledge from research partners respectively (which we have labeled 'global specialized knowledge' below). The different factor analyses undertaken using CIS4/5/6 resulted in very similar outcomes, which helps to validate the approach we have taken to measuring absorptive capacity.[20]

Various hypotheses on the components of absorptive capacity have been put forward in the literature (particularly, in management studies), such as human capital, external network of knowledge and HRM practices as in Vinding (2006), and potential and realised

[17] For each element, respondents were asked to rank from 0 'not used' to 3'high importance'. We recoded these to 1 (medium and high importance) and 0 (low importance or not used).
[18] Respondents were asked to state if they had collaborated with any of these based on the location of the partner which we grouped into national (i.e., UK) or international (i.e., other European or other countries). Thus we had two measures for each element.
[19] Historically, the following labels are given to different ranges of KMO values: 0.9-1 Marvellous, 0.8-0.89 Meritorious, 0.7-0.79 Middling, 0.6-0.69 Mediocre, 0.5-0.59 Miserable, 0-0.49 Unacceptable.
[20] Full details on the factor analysis are available in the appendix

absorptive capacity as re-conceptualised by Zahra and George (2002). Nevertheless, there continues to be an imbalance between the relative abundance of various definitions of absorptive capacity and a deficiency of empirical estimates of this concept, with R&D-related variables most commonly used as proxies (e.g. Cohen and Levinthal, 1990; Arora and Gambardella, 1990; Veugelers, 1997; Cassiman and Veugelers, 2002; Belderbos et al., 2004). However, given the path-dependent nature of absorptive capacity, R&D fails to capture the realisation and accumulation of absorptive capacity, not to mention its distinct elements (Schmidt, 2005). Indeed, our a priori expectation is that absorptive capacity (as measured here) is available with different intensities to all firms (not just those engage in R&D), and it is itself a determinant of R&D (and innovation), something that is largely confirmed by our empirical results (see also footnote 3). Thus, whilst allowing R&D to be potentially endogenous, we treat the 'path-dependent' absorptive capacity as predetermined in our empirical models, i.e. such capacity takes a (relatively) long time to build.

Others have taken a different approach with regard to how the above variables used to measure 'external' absorptive capacity should be classified. For example, Dachs et al. (2008) use the information on sources of knowledge from suppliers and customers to compute a variable that attempts to capture vertical spillovers (of knowledge). We have chosen not to take a similar approach. The pragmatic reason is that in our statistical analysis (Section 4) we find these spillover measures are generally insignificant in the models determining exporting, innovation and R&D, whereas our measures of absorptive capacity are found to be important determinants. In addition, the proportion of establishments that stated that such sources of knowledge had 'high' importance is relatively small; taken together, over 90% of establishments have a zero value for spillovers; whereas the absorptive capacity measures are based on much more information and span a greater range. Lastly, there is a high correlation between these types of spillover measures and our measures of absorptive capacity; therefore it is clear that knowledge spillover effects will be captured within the absorptive capacity measures we use in this study. Indeed, by definition absorptive capacity captures the ability of firms to internalise external knowledge spillovers.

Most other variables included in Table 1 are self-explanatory. In particular, industrial agglomeration is included to take account of any Marshall-Romer external (dis)economies of scale (Henderson, 2003; David and Rosenbloom, 1990). The greater the clustering of an industry within the area in which the establishment operates, the greater are the potential benefits from spillover impacts. Conversely, greater agglomeration may lead to congestion, and therefore lower productivity. The diversification index is included to pick up urbanisation economies associated with operating in an area with a large number of different industries (Jacobs, 1970, 1986). Higher diversification is usually assumed to have positive benefits to producers through spillover effects. The Herfindahl index of industrial concentration is measured at the 5-digit 1992 SIC level to take account of any market power and hence competition effects (which are expected to be associated with the propensity to both export, innovate and to undertake R&D). The variable that measures if the establishment belongs to an enterprise operating in more than one (5-digit) industry (multi-industry) is included to proxy for any economies of scope. The data on the age of establishments and their capital-labour ratios were obtained from the ARD and from updating the series on plant & machinery capital stocks computed by Harris and Drinkwater (2000) and extended to cover the service sectors (see Harris and Moffat, 2011). In addition, information is available on whether the establishment was located in a particular Government Office region and/or city.[21]

(Table 2 about here)

All the data are weighted to ensure they are representative of the UK distribution of establishments (i.e. rather than just the CIS4/5/6 samples).[22] Table 2 reports the (weighted) mean values for the pooled CIS-ARD data covering all three CIS waves, spilt into manufacturing and non-manufacturing sectors. There are two sets of means for each sector; the first refers to all the pooled data available while the second refers to just the data used in the model estimation carried out below. When modelling the relationships between R&D, innovation and exporting, we allow for lagged values to enter and therefore only those establishments that have at least two consecutive observations in the dataset are retained. That is, we make use of the panel data attributes of the pooled dataset, which results in the loss of a large number of observations that were either only sampled once, or they feature in non-adjacent CIS waves (mostly the former). By including both the full (weighted) dataset and the (weighted) data used when modeling, we are able to show that there is little indication of any bias from using the restricted dataset; the mean values for the vast majority of variables are very similar (cf. data columns 1 – 2, and 3 – 4). Only the measure of industry agglomeration

[21] The major cities we identify were either capitals or they met the criteria of (in 2001) employing over 250,000 with a population density of 20+ persons per hectare; or they had employment over 100,000 and densities of 30+ persons per hectare. The full list of cities included was: London, Cardiff, Edinburgh, Tyneside, Manchester, Liverpool, Birmingham, Coventry, Leicester, Nottingham, Bristol, and Glasgow.

[22] The weights used are available in the CIS datasets, rather than the ARD, as the latter is merged into the CIS data.

(non-manufacturing data) and the measures of absorptive capacity (mainly non-manufacturing) differ significantly.[23]

Concerning the three key variables we shall be modeling, Table 2 shows that on average some 46% of establishments in manufacturing were engaged in R&D, 41% produced an innovation (product and/or process), and 51% exported in the three year period covered by each CIS; in non-manufacturing, the comparable figures were 29%, 27% and 25%.[24]

(Table 3 about here)

Information on both the exporting, innovation and R&D activities of establishments is presented in Table 3. As can be seen, over 22% of manufacturers engaged jointly in exporting, producing an innovation and spending on R&D; while only 7.5 % undertook all three activities in the non-manufacturing sector. Conversely, just over 31% in manufacturing did none of these activities (over 55% in non-manufacturing). In manufacturing this leaves nearly half of the establishments engaging in either one or two of the other activities (in non-manufacturing some 37% of establishments did one or two out of the three activities covered). This suggests that while there are relationships between these variables, they may not be quite as strong as expected, and they are likely to involve various feedback relationships that cannot be predicted using the information in Table 3. In particular, and irrespective of the (two-) way relationship between R&D and exporting or innovation and exporting, there does not seem to be any clear evidence that R&D and innovation are interchangeable in any model explaining exporting; e.g., and especially in manufacturing, nearly 9% exported and undertook R&D but did not innovate, compared to just over 4% who exported and innovated but did no R&D. It seems, at least in manufacturing, there is some initial evidence that R&D (through the 'second face' of R&D effect) may help firms to overcome barriers to exporting that are not necessarily linked to producing innovations.

It would also seem that, especially in manufacturing, exporting is somewhat less dependent on innovation and R&D than is innovation on R&D and exporting, or R&D on innovation and exporting; since 14% of manufacturers (8.5% in non-manufacturing) exported without the need for the other two activities, while only 5.1% of innovators did no R&D and

[23] The differences for the agglomeration variable are presumably reflecting the loss of establishments located in less 'populated' rural areas, which are less likely to have consecutive observations in the pooled CIS dataset. Note the AC indices were calculated using all the CIS data in a particular wave; non-manufacturing establishments had much lower values – which bunch more around the mean (of zero) – when compared to manufacturing.

[24] These large differences in the proportion of establishments engaged in the activities studied here explains why we have chosen to model the manufacturing and non-manufacturing sectors separately.

did not export (6.5% in non-manufacturing), and 5.7% engaged in R&D but not exporting nor producing an innovation (8.1% in non-manufacturing).

In all there are possibly a number of different relationships between whether an establishment exports, does R&D, and produces an innovation, all of which will be conditional on other variables that intervene in determining how and when establishments break down barriers to entry into these activities. Thus, we now set out the modelling strategy used to try to disentangle these relationships that are so important in determining and influencing long-run productivity.

3.2 Modelling strategy

We have three (0/1) dichotomous variables that we wish to model taking account of the potential simultaneous relationships between them; thus we follow the approach of Maddala (1983) and instrument each endogenous variable using the reduced-form of each equation to guide us towards choosing appropriate instruments. The structural equations in our system were set out above in equation (1). For convenience we repeat them here:

$$\begin{aligned} EXP_{it} &= f(INN_{it}, R\&D_{it}, X_{it}^{1}) + u_{it}^{1} \qquad & u_{it}^{1} &\sim N(0,1) \\ R\&D_{it} &= f(INN_{it}, EXP_{it}, X_{it}^{2}) + u_{it}^{2} \qquad & u_{it}^{2} &\sim N(0,1) \qquad (1') \\ INN_{it} &= f(EXP_{it}, R\&D_{it}, X_{it}^{3}) + u_{it}^{3} \qquad & u_{it}^{3} &\sim N(0,1) \end{aligned}$$

where EXP_{it} refers to whether establishment i exports in time t;[25] $R\&D_{it}$ refers to whether it spends on research and development; and INN_{it} is whether it introduces a product and/or process innovation during t. The X_{it} are vectors of other (exogenous) variables (including lagged values of the dependent variables) that determine the various outcomes for establishment i in time t, and it is assumed that each X_{it} have some elements that are exclusive – i.e., $X_{it}^{1} \notin X_{it}^{2} \notin X_{it}^{3}$, and there exist variables (labelled Z_{it}^{n} where n = 1, 2, 3, such that $Z_{it}^{n} \in X_{it}^{n}$ but $Z_{it}^{1} \neq Z_{it}^{2} \neq Z_{it}^{3}$) that identify each equation and which can be used as instruments if a single-equation approach is used to estimate (1′). Clearly if the covariance is non-zero between u_{it}^{n} and the right-hand-side variables EXP_{it}, $R\&D_{it}$ and INN_{it} in (1′), then these are

[25] Note, with respect to the dependent variables in equation (1), time t refers to the following 3-year periods: 2002-2004, 2004-2006 and 2006-2008. In contrast t refers to 2004, 2006 and 2008 with regard to (most of) the variables in X (the exceptions are the variables measuring absorptive capacity and barriers to innovation which cover the same period as the dependent variables).

endogenous; and since no system approach is available for estimation we use a single-equation IV approach. That is, we replace equation (1′) with:

$$
\begin{aligned}
EXP_{it} &= f(\hat{INN}_{it}, \hat{R\&D}_{it}, X^1_{it}) + u^{1\prime}_{it} \qquad & u^{1\prime}_{it} \sim N(0,1) \\
R\&D_{it} &= f(\hat{INN}_{it}, \hat{EXP}_{it}, X^2_{it}) + u^{2\prime}_{it} \qquad & u^{2\prime}_{it} \sim N(0,1) \\
INN_{it} &= f(\hat{EXP}_{it}, \hat{R\&D}_{it}, X^3_{it}) + u^{3\prime}_{it} \qquad & u^{3\prime}_{it} \sim N(0,1)
\end{aligned} \tag{2}
$$

where:

$$
\hat{EXP}_{it} = f(Z^1_{it}, W_{it}); \qquad \hat{R\&D}_{it} = f(Z^2_{it}, W_{it}); \qquad \hat{INN}_{it} = f(Z^3_{it}, W_{it}) \tag{3}
$$

and $W_{it} = X^1_{it} \cup X^2_{it} \cup X^3_{it}$. Essentially, equation (3) is the reduced-form counterpart of equation (1′), after substituting out the right-hand-side endogenous variables. Note, the variables comprising Z^1_{it} will differ depending on whether we are instrumenting EXP_{it} in the second or third equation in (2); this is also the case for the variables included in Z^2_{it}, Z^3_{it} when INN_{it} and $R\&D_{it}$ are instrumented. In short, the membership of Z^n_{it} depends on which endogenous variable is being instrumented, and which endogenous variable comprises the left-hand-side variable in (2).

Note, following Angrist and Kruger (2001), who show that using a *nonlinear* first stage to generate fitted values for the second stage does not result in consistent estimates unless the first stage model is exactly correct (Angrist and Kruger, *op. cit.*, p.80), we first estimate equation (3) using OLS regression and use these predicted values at stage 2 when estimating equation (2) using probit regressions.[26] A *stepwise* OLS approach was preferred when estimating (3) in order to limit the number of insignificant variables used to predict EXP_{it}, $R\&D_{it}$ and INN_{it}, and thus to increase the precision of our estimates.[27] The identification of the instruments was based on first our a priori expectations as to which variables were most likely to be valid (i.e., they should be consistent with – or at least not in opposition to – economic theory); and secondly, by confirming such expectations from estimating the reduced-form model, and searching for those variables that were uniquely significant in determining each dependent variable.

[26] We also tried using predicted values based on probit estimates of (3), and there was little difference in our results.
[27] Again, it made little difference, when estimating equation (2) using the predicted values in equation (3), whether we used the full-set of exogenous variables available in W, or just those that were significant at the 10% level.

(Table 4 about here)

Table 4 shows which variables act as instruments to predict the left-hand-side variables in (3), and which are then used in estimating equation (2); in manufacturing, we find that productivity, establishment size, absorptive capacity, barriers to innovation (e.g., the cost of finance), diversification and competition (as measured by the Herfindahl index), and ownership status play a key role in determining R&D and/or innovation but generally not exporting; while capital intensity, market size (as measured by agglomeration), operating in a number of regions, and industry/location effects are particularly important as instruments for exporting. This accords with what might be expected, and lends weight to believing the instruments are valid. The results for services are also broadly consistent with economic theory although not as clear-cut: the measures of absorptive capacity act as instruments for both R&D and innovation in the exporting equations, unsurprisingly many of the barriers to innovation act as instruments for innovation (although more supply-side barriers are more relevant as instruments in exporting), and industry effects are mostly important as instruments for exporting (while location effects in services are more applicable for R&D). In contrast with manufacturing, labour productivity is an instrument for exporting in both R&D and innovation equations, while diversification and capital intensity act more as instruments for R&D.

Instruments are only appropriate if they can be shown to strongly determine the endogenous variable, but have no direct impact on the outcome variable in the model estimated. Various tests have been developed for linear IV models based on continuous dependent variables, but not for use with the probit model. Thus we test whether our instruments are appropriate by including them as additional variables when estimating equation (3), and testing if they are jointly-insignificant.[28] If the null of joint insignificance is accepted, then we can be confident that the set of instruments used are not determining the outcome variable. This testing procedure is similar to undertaking a Sargen-Hansen test of over-identification in the standard IV (or 2SLS) approach. We report the χ^2-statistics obtained from this exclusion test in our tables of results (below). We also test to ensure we do not have weak instruments by testing that the Z_{it}^{n} used to estimate equation (3) are significant; noting (as mentioned above) that the membership of Z_{it}^{n} depends on which endogenous variable is

[28] For example, when estimating the equation for *EXP*, in equation (2), we add Z_{it}^{2}, Z_{it}^{3} to the equation and test the joint null that the parameter estimates for these variables are equal to zero. Note, we also ensure that no individual parameter estimate is significant, as additional insurance that we have the correct instrument set.

being instrumented and also which endogenous variable comprises the left-hand-side variable in (2). Thus for each equation in (2), there are two sets of tests of the null that each instrument set comprises variables that are jointly significant (one for each variable instrumented), and the results of these F-tests are also reported in the tables of results set out below.

Since we have essentially a panel dataset, comprising three CIS waves, there is also an issue of whether equation (2) should be estimated incorporating fixed-effects, μ_i. However, since we have only 3 cross-sections in our panel, and with a lagged dependent variable this reduces to two, there is essentially insufficient information on many of the establishments to estimate the fixed-effect intercept.[29]

Lastly, instead of using a simultaneous estimator several authors have used lagged values of (potentially) endogenous variables and omitted contemporaneous values to try to overcome any simultaneous bias. There are two main problems with this approach; firstly, if firms do make joint-decisions about whether to export, undertake R&D and innovate, the use of lagged variables will not capture the full extent of the relationships between these variables (indeed if there are more complicated dynamics in the model – such as product and innovation life-cycle effects which impact on the timing of R&D, innovation and exporting – then lagged variables may pick up no or even a wrongly signed impact). The second problem with using lagged variables is that they do not necessarily overcome the simultaneity issue; if firms have prior knowledge of their exporting, R&D and innovation prospects, they are likely to make current decisions on these variables in part based on expectations of the effects of undertaking complementary activities – all of which are expected to impact positively on productivity levels. To this extent lagged values are being (at least in part) determined by expected outcomes in time *t*, and given also that entry into all three activities usually involves significant sunk costs (and associated path-dependency effects), these activities need to be presumed to be endogenous to each other.

In summary, our estimation strategy is to first obtain predicted values of the right-hand-side endogenous variables by OLS estimation of equation (3), and then use these instrumented variables in a second-stage (probit) estimation of the structural models as set out in equation (2), also testing to ensure our instruments sets are valid. Finally, since the instrumented endogenous variables are generated regressors, we need to correct the standard

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[29] We tried introducing an intercept for every establishment, obtaining implausible results. Similar a fixed-effects logit estimator (available in STATA) had similar problems. This essentially results from a large number of establishments not changing their 'state' over the short period considered (e.g., they are always exporters), so no information is provided concerning the determination of the fixed-effect parameters. Thus there is an identification problem (the so-called mover-stayer problem) as discussed in Lechner *et al.* (2008).

errors in the second stage regression; in the two-variable probit simultaneous equations model, Maddala (1983) and Murphy and Topel (1985) provide the appropriate corrections needed to the second-stage variance-covariance matrix. In a three-equation model, such corrections become much more complicated, and therefore we tried the jackknife approach to obtaining standard errors in our model (which is a common approach when the underlying distribution of error term is non-normal).[30] This had almost no impact on the standard errors so the default robust standard errors are presented below.

(Table 5 about here)

4. Results

4.1 Manufacturing

The results for manufacturing are presented in Table 5. As shown in the table, the IV probit results for all three models cannot reject the null that the instruments do not determine the relevant dependent (outcome) variable; excluding these instruments is however strongly rejected in the stage 1 modelling of which variables belong to each instrument set. We thus take this as evidence that we have an appropriate instrument set.

The key results relate to the (contemporaneous and lagged) interactions between exporting, R&D and innovation. With exporting as the dependent variable, Table 5 shows that establishments involved in spending on R&D were just over 48% more likely to also export. This higher contemporaneous impact of R&D on exporting suggests that spending on R&D was not simply to boost the probability of innovating (Table 5 shows that the probability of innovating was 20% higher in establishments that undertook R&D), but it likely involved an additional impact of overall increasing the importance of the establishment's (intangible) knowledge assets, helping it to break down barriers to international markets. Interestingly, the impact of lagged R&D on the probability of exporting is negative, suggesting that establishments that spent on R&D in the previous period (e.g., during 2002-2004) were 14% less likely to export in the current period (e.g., 2004-2006); this may be indicating that while current R&D is used to help enter export markets in time *t*, as a firm gains exporting experience (and/or as any new products age) some firms revert to selling exclusively in the

[30] In practice, we were not able (using STATA 9.2) to use the more common technique of bootstrapping with replacement as we estimate weighted regression models; instead we tried a jackknife approach which uses sub-sets of the available observations.

home market and exploiting their now better technology and knowledge base in what is likely to be a less competitive (or at least easier to exploit) market.[31]

Table 5 shows that exporting increased the probability of engaging in R&D by 16%. Therefore, there is evidence that as a result of exporting, establishments will undertake R&D in order to internalise the knowledge that can be gained, and thus there is what can be termed an indirect 'learning-by-exporting' effect via R&D; but it is much smaller than the impact of R&D on overcoming barriers to exporting (for the reasons set out above). Establishments that exported in the current period were no more likely to innovate, and innovation had no separate (cet. par.) impact on exporting (we find no significant impacts in either direction). However, innovation and R&D are interrelated; establishments that undertook R&D in any three-year period were some 20% more likely to innovate, while those that innovated were over 25% more likely to also undertake R&D. Clearly, in manufacturing the relationships between these two variables are important but they show that when other factors are controlled for, neither is very strong; in particular, that spending on innovation inputs does not increase dramatically the likelihood of producing an innovation suggests that much R&D is either misdirected or inefficient, produces other effects, or that successful innovation is about much more, including large element of 'luck' or serendipity.

Other determinants of R&D, innovation and exporting are also included in Table 4; the sunk costs involved in overcoming entry barriers are important in all three equations as shown by the size and significance of the lagged values for R&D, innovation and exporting. Higher labour productivity increases the likelihood of undertaking R&D (a one standard deviation increase in productivity increases the probability of R&D by 4.9%); while higher capital intensity increases the likelihood of exporting (by 5.6% given a standard deviation increase in log capital intensity). Older establishments are (-2.9%) less likely to export; while higher industrial clustering increases the likelihood of exporting (by 4.7%) but decreases the probability of engaging in R&D (by -3.6%). There are economies-of-scope exploited in exporting (establishments operating in more than one industry were nearly 6% more likely to export); and US-owned establishments were some 11% less likely (cet. par.) to innovate. Having more graduates employed in the establishment had a positive impact on all three outcomes, especially for exporting where establishments with no graduates are some 23% less likely to export; however too many graduates reduced the likelihood of an innovation. Different measures of absorptive capacity had positive impacts on whether an establishment

[31] Other explanations are possible, but without a longer time-series it is difficult to test further the dynamic linkages between R&D and exporting.

undertook R&D and/or innovated, but for exporting these variables were insignificant. The importance of acquiring external knowledge was most influential (e.g., a standard deviation increase in this variable increased the likelihood of innovating by 17%), but more specialised, international knowledge was also important in the innovation equation. Firms stating that the high costs of innovation acted as a barrier were just over 13% more likely to undertake R&D;[32] for innovation the cost of finance acts as a barrier lowering the likelihood of new product and/or process innovations, while issues over availability of finance increases the probability of innovating by nearly 11%; lack of qualified personnel acted as a spur to overcoming barriers to R&D, while uncertain demand for innovative goods/services reduced the probability of innovating (excessive perceived economic risks increased the probability of innovating by nearly 6%). There were few industry effects impacting on the decision to undertake R&D and/or innovate, whereas a number of more traditional industries had lower propensities to engage in exporting vis-à-vis the benchmark industries (i.e., those not featuring in Table 4). Finally, we found a small number of location effects were important; for example, manufacturers in Bristol are (cet. par.) more likely to undertake R&D; those in London are just over 12% more likely to innovate; while being located in Scotland, Bristol, Cardiff or Coventry reduced the probability of exporting. This might suggest negative externalities are a feature in those locations, and/or firms in these areas are more likely to supply local firms perhaps because of stronger intra/inter-industry linkages (associated with clusters).

(Figure 1 around here)

4.2 Non-manufacturing

As in the case for manufacturing, the null that the instruments can be excluded from the outcome equation is not rejected; the null that these variables have no explanatory power for the endogenous variable instrumented is rejected in each case at better than the 1% significance level. They therefore satisfy the conditions to be valid instrumental variables.

[32] Note, respondents to the CIS survey are asked to state whether a factor was a constraint to their innovation activities in influencing a decision not to innovate. The positive impact suggests that this 'barrier' was overcome, with such firms intensifying their efforts to undertake R&D. In demand and supply terms, this would mean that while the cost of innovation might move a firm down its demand for R&D curve, there are outward shifts in the supply curve (associated with a higher 'taste' for innovation) that more than fully compensate any 'pure' price/cost effects. Similar results of this type (i.e., positive relationships between such 'barriers' and undertaking innovation-related activities) are fairly common when using CIS (and similar) datasets (see, for example, Masso and Vahter, 2008; Frenz and Ietto-Gillies, 2009 and Smit et al., 2010).

As in manufacturing, the lag of the dependent variable has a positive and significant coefficient in each model which suggests that sunk costs are important. In the R&D model, only exporting has a positive and statistically significant impact; exporting leads to an increase in the probability of performing R&D of 15%. This is slightly smaller than the corresponding impact for manufacturing (see Figure 1), but the major difference is that in non-manufacturing innovation has no impact in determining R&D. Performing R&D increases the probability of innovation by 25%. However, unlike in manufacturing, there is no bi-directional relationship between R&D and innovation as innovation is not a significant determinant of performing R&D. Another difference when compared to manufacturing is the size of the impact on exporting of undertaking R&D; it is much smaller (a 14% increase in the probability of exporting compared to 48% in manufacturing). As with manufacturing, exporting is not found to be a significant determinant of innovation performance.

In terms of the control variables, having lower levels of human capital (as proxied by the 'no graduates' variable) lowered the probability of undertaking R&D while having higher levels of three types of absorptive capacity and facing high costs of innovation (see footnote 14) increased the probability of undertaking R&D. These results were also obtained for manufacturing. The results differ from manufacturing in that a higher capital intensity increased the probability of performing R&D and smaller establishments (with between 10-19 employees) were less likely to invest in R&D. Furthermore, establishments that are part of multi-industry enterprises, and establishments operating in a market dominated by established business, had a lower probability of engaging in R&D. Labour productivity, industry agglomeration and a lack of qualified personnel are significant determinants of R&D in manufacturing but not in non-manufacturing. There were also differences in the significance of the industry and region dummies across the two sectors.

In the innovation model, the absorptive capacity variables all had a significant and positive impact and a number of barriers to innovation were also significant. This was also the case for manufacturing. The results differ from manufacturing in that age, being situated in close proximity to other firms from the same industry and a lack of market information had a negative impact on the probability of innovation. US-owned establishments, establishments with over 75% of graduates and establishments with uncertain demand for innovative goods/services were less likely to innovate in manufacturing but not in non-manufacturing. In addition, being situated in London had a positive impact on the probability of innovating while being located in Manchester had a negative impact in manufacturing whereas none of the spatial dummies were significant in non-manufacturing.

The coefficients on the control variables in the exporting model differ considerably from those obtained for manufacturing. In both sectors, being situated near other establishments from the same industry had a positive impact on the probability of exporting while having no graduates reduced the probability of exporting. The following variables had a significant impact in non-manufacturing but not in manufacturing: labour productivity (a positive impact); diversification (negative); having 20-75% graduates (negative); absorptive capacity for international co-operation (positive); four barriers to innovation; the Greater South East dummy (positive) and the East Midlands dummy (positive). By comparison, the following had a significant effect in manufacturing but not in non-manufacturing: capital intensity (positive); age (negative); being part of a multi-plant enterprise (positive) and five spatial dummies.

5. Summary and conclusions

This study considers the determinants of whether a firm exports, undertakes R&D and/or innovates, and the contemporaneous links between these variables (e.g., undertaking R&D and/or innovating are likely to both impact on the firm's decision to export or not, and in turn to be influenced by the experience of exporting). The major motivation for studying these relationships is that such activities underpin our understanding of productivity differences between firms; and being able to explain more fully the reasons why there is significant heterogeneity across firms should provide policy-makers with better tools for improving aggregate productivity levels.

Despite the growing number of papers that have begun to look at whether there are links between R&D/innovation and exporting, most studies only consider causality in one direction (the most popular being whether undertaking R&D/innovation results in firms having a higher probability of exporting), and invariably they do not allow for *contemporaneous* links between exporting and R&D/innovation. Moreover, and as far as we know, no study looks at the relationships between all three variables (and yet our discussion in section 2.1 shows that there are theoretical reasons why all three activities are linked). This was accomplished here using probit regressions of whether a firm engages in exporting, R&D, and innovation, in which the dichotomous endogenous variables were instrumented using other (exogenous) variables in the dataset.

This study used three waves of the UK Community Innovation Survey (CIS) carried out in 2005, 2007 and 2009; giving a nationally representative account of the innovation activities of the reporting enterprises for the period covering 2002-2008. The analysis was conducted for both the manufacturing and service sectors. Concentrating on the results showing the (contemporaneous) relationships between exporting, R&D, and innovation, we found that in both manufacturing and services being involved in exporting increased the probability that an establishment was engaged in spending on R&D (although innovating in the current period had a larger impact on whether current R&D spending occurred in manufacturing), with the strength of such 'learning-by-exporting' being similar across sectors. However, spending on R&D in manufacturing had a much larger impact on the probability of exporting (about three times larger); this suggests that spending on R&D was not simply to boost the probability of producing new goods and services (in manufacturing the probability of innovating was 20% higher in establishments that undertook R&D), but it likely involved an additional ('second face' of R&D) impact of improving the establishment's (intangible) knowledge assets, helping it to break down barriers to international markets. In non-manufacturing, spending on R&D increased both the probability of innovating (by 25%) and the probability of exporting (by 14%), but the latter effect is relatively much smaller than for manufacturing establishments. Thus, there are significant differences across the two sectors in the extent to which firms need to engage in R&D to become more productive and thus break down the barriers to exporting. We also found that exporting had no direct (contemporaneous) impact on whether innovation occurred in either sector (neither did we find that the lag of exporting impacted on innovation, suggesting that establishments involved in exporting do not experience any short-run requirement to develop new products or processes).

Lastly, while innovation and R&D are interrelated in manufacturing (there are similar causal links in both directions across both sectors), the relationships between these two variables are not as strong as might have (a priori) been expected; in particular, in both manufacturing and non-manufacturing, spending on R&D does not increase dramatically the likelihood of producing an innovation, suggesting that much R&D is either misdirected or inefficient, produces other effects, or that successful innovation is about much more (including a large element of 'luck' or serendipity, especially in manufacturing).

Turning to policy, the results obtained show that (with the exception of the impact of R&D on exporting in manufacturing), many of the links between exporting, R&D and innovation were not particularly strong, suggesting that pursuing policies to boost R&D will not on its own significantly increase the number of innovative British firms, while helping more firms to sell abroad only has a marginal impact on encouraging them to become involved in R&D. And yet, as was stated in the introduction (and also covered in the literature review), we know that establishments that engage in any combination of the three activities covered here tend to head firm-level productivity league tables. This therefore points to both the complexity of the underlying processes that determine establishment level productivity, and thus the need to recognise that there are no quick and simple policies that will increase the 'extensive' margins of activity in these areas. However, at the same time, we have established that exporting, R&D and innovation are clearly interconnected in the current period, and therefore policy needs to recognise such linkages and ensure that it takes advantage of them when devising and implementing productivity-enhancing policies at the micro-level. This is especially true for R&D in the manufacturing sector.

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Table 1: Variable definitions used in CIS-ARD merged dataset for 2004-2008

Variable	Definitions	Source*
R&D	Whether the establishment undertook R&D (coded 1) or not	CIS
Innovation	Whether the establishment introduced either/both product/process (coded 1) innovations or not	CIS
Exporting	Whether the establishment sold goods and services outside the UK (coded 1) or not	CIS
Labour productivity	Establishment turnover per employee	CIS
Capital Intensity	Capital to employment ratio	ARD
Size	Number of employees in the establishment, broken down into 5 size-bands, i.e. 0-9, 10-19, 20-49, 50-199 and 200+	CIS
Age	Age of establishment in years	ARD
Industry agglomeration	% of industry output (at 5-digit SIC level) located in travel-to-work area in which establishment is located	ARD
Diversification	% of 5-digit industries (from over 650) located in travel-to-work area in which establishment is located	ARD
Multi-region enterprise	Whether the establishment belongs to an enterprise with establishments in more than one region (coded 1) or not	ARD
Multi-industry enterprise	Whether the establishment belongs to an enterprise with establishments in more than one industry (coded 1) or not	ARD
Herfindahl	Herfindahl index of industry concentration (5-digit level)	ARD
Single-plant enterprise	Whether the establishment was a single-plant enterprise (coded 1) or not	ARD
US-owned	Whether the establishment was owned by a US enterprise (coded 1) or not	ARD
Other foreign-owned	Whether the establishment was foreign-owned by a non-US enterprise (coded 1) or not	ARD
Size of graduates workforce	Proportion of employees educated to degree level or above in the establishment, broken down into 5 bands, i.e. no graduates, 0-5% graduates, 5-20% graduates, 20-75% graduates, and 75%+ graduates	CIS
Absorptive capacity (5 factors, see text for details)	AC for external knowledge	CIS
	AC for corporate strategy and management techniques	CIS
	AC for national co-operation	CIS
	AC for international co-operation	CIS
	AC for global specialised knowledge	CIS
Barriers to innovation† (10 aspects)	Excessive perceived economic risks	CIS
	High costs of innovation	CIS
	Cost of finance	CIS
	Availability of finance	CIS
	Lack of qualified personnel	CIS
	Lack of information on technology	CIS
	Lack of information on markets	CIS
	Market dominated by established businesses	CIS
	Uncertain demand for innovative goods/services	CIS
	Impact of UK/EU regulations	CIS
Industry	Whether the establishment was located in a particular industry 2-digit SIC (coded 1) or not	CIS
GO regions	Whether the establishment was located in a particular GB region (coded 1) or not	CIS
Greater South East	Whether establishment belongs to enterprise operating in Greater South East region (coded 1) or not	CIS
Cities	Whether the establishment was located in a major GB city (coded 1) or not (defined by NUTS3 code)	CIS
Weight	Population weights based on the ratio between population employment and sample employment	CIS

* CIS refers to the CIS4/5/6 datasets covering 2002-2004, 2004-2006, and 2006-2008 respectively; the ARD data covered 2004, 2006, and 2007 matched to CIS4/5/6, respectively (note 2008 ARD data was not available)

† Each dummy variable is coded 1 if the barrier is of medium-to-high importance

Table 2: Weighted mean values for variables in CIS-ARD merged dataset for 2004-2008

Variable	Manufacturing		Non-manufacturing	
	All*	Model†	All	Model
R&D	0.464	0.472	0.295	0.275
Innovation	0.412	0.404	0.275	0.239
Exporting	0.513	0.551	0.252	0.256
Labour productivity	4.315	4.400	4.170	4.174
Capital intensity	9.421	9.643	8.910	9.121
20-49 employees	0.303	0.282	0.365	0.342
50-199 employees	0.357	0.370	0.334	0.359
200+ employees	0.224	0.248	0.159	0.175
ln Age	2.095	2.271	2.179	2.433
ln Industry agglomeration	-0.386	-0.333	-0.051	-0.204
ln Diversification	2.202	2.093	2.463	2.280
Multi-region enterprise	0.188	0.201	0.133	0.139
Multi-industry enterprise	0.294	0.319	0.192	0.194
ln Herfindahl	-2.288	-2.637	-2.097	-2.504
Single-plant enterprise	0.648	0.620	0.684	0.657
US-owned	0.029	0.027	0.010	0.009
Other foreign-owned	0.056	0.060	0.031	0.023
No graduates	0.469	0.447	0.505	0.511
5-20% graduates	0.227	0.235	0.157	0.155
20-75% graduates	0.084	0.085	0.138	0.134
75%+ graduates	0.031	0.030	0.080	0.059
Excessive perceived economic risks	0.396	0.390	0.284	0.271
High costs of innovation	0.425	0.424	0.292	0.278
Cost of finance	0.357	0.356	0.276	0.257
Availability of finance	0.288	0.283	0.236	0.223
Lack of qualified personnel	0.176	0.173	0.125	0.118
Lack of information on technology	0.198	0.192	0.130	0.116
Lack of information on markets	0.291	0.273	0.219	0.212
Market dominated by established businesses	0.337	0.337	0.219	0.208
Uncertain demand for innovative goods/services	0.283	0.278	0.227	0.205
Impact of UK/EU regulations	0.233	0.212	0.211	0.190
AC for external knowledge	0.256	0.332	0.003	0.001
AC for corporate strategy and management techniques	0.079	0.125	0.009	-0.014
AC for national co-operation	0.120	0.125	0.013	-0.018
AC for international co-operation	0.073	0.094	0.011	-0.002
AC for global specialised knowledge	0.058	0.161	-0.005	-0.049
Greater South East	0.391	0.395	0.457	0.432
N	11067	3595	22083	6861

* All observations in CIS4/5/6 (excluding Northern Ireland and missing data)

† Observations included when estimating equations (2) and (3) (i.e., only establishments with at least two consecutive observations over time are included).

Table 3: Percentage of establishments undertaking R&D, exporting and innovating in CIS-ARD merged dataset for 2004-2008

Innovate:	no		yes	
Export:	no	yes	no	yes
(1) Manufacturing				
Undertake R&D:				
no	31.5	14.0	5.1	4.2
yes	5.7	8.7	8.1	22.5
(2) Non-manufacturing				
Undertake R&D:				
no	55.4	8.5	6.5	2.3
yes	8.1	3.2	8.5	7.5

Notes: Data are weighted and cells sum to 100% for each sector. The percentages are based on all observations in CIS4/5/6 (excluding Northern Ireland only).

Table 4: Instrumental Variables

	Manufacturing						Services					
Dependent variable in 2nd stage	R&D		INN		EXP		R&D		INN		EXP	
Instrumented variable in 1st stage	INN	EXP	R&D	EXP	R&D	INN	INN	EXP	R&D	EXP	R&D	INN
R&D$_{it-1}$			✓						✓		✓	
Innovation$_{it-1}$	✓					✓	✓					✓
Exporting$_{it-1}$		✓		✓				✓	✓	✓		
ln Labour productivity$_{it}$			✓		✓			✓		✓		
ln Capital Intensity$_{it}$		✓		✓					✓		✓	
20-49 employees$_{it}$	✓					✓						
50-199 employees$_{it}$	✓					✓						
ln Industry agglomeration$_{it}$				✓			✓	✓				
ln Diversification$_{it}$			✓		✓			✓		✓		
ln Herfindahl index$_{it}$			✓		✓							
ln Age$_{it}$							✓					✓
Multi-region enterprise$_{it}$		✓		✓								
Multi-industry enterprise$_{it}$									✓		✓	
Single plant enterprise$_{it}$	✓					✓						
US-owned$_{it}$	✓					✓						
Other foreign-owned$_{it}$	✓					✓			✓		✓	
No graduates$_{it}$			✓	✓					✓	✓		
5-20% graduates$_{it}$		✓		✓								
20-75% graduates$_{it}$								✓		✓		
75%+ graduates$_{it}$	✓				✓	✓		✓		✓		
AC external knowledge$_{it}$					✓	✓					✓	✓
AC national co-operation$_{it}$					✓	✓					✓	✓
AC corporate strategy and management techniques$_{it}$					✓	✓					✓	✓
AC international co-operation$_{it}$	✓					✓		✓				
AC global specialised knowledge$_{it}$	✓					✓					✓	✓
Cost of finance$_{it}$	✓					✓	✓					✓
Availability of finance$_{it}$	✓					✓	✓					✓
Lack of information on technology$_{it}$								✓		✓		
Lack of market information$_{it}$							✓	✓				
Lack of qualified personnel$_{it}$			✓		✓			✓		✓		
Excessive perceived economic risks$_{it}$	✓					✓	✓					
High costs of innovation$_{it}$			✓	✓					✓		✓	
Market dominated by established businesses$_{it}$									✓		✓	
Greater south-east$_{it}$.	✓					✓		✓		✓		
East Midlands$_{it}$.								✓		✓		
North-east$_{it}$		✓		✓								
South-west$_{it}$									✓		✓	
Wales$_{it}$									✓		✓	
West Midlands$_{it}$		✓		✓								
Yorkshire/Humberside$_{it}$			✓	✓								
Bristol$_{it}$			✓	✓								
Cardiff$_{it}$		✓		✓					✓		✓	
Coventry$_{it}$.		✓		✓								
Liverpool$_{it}$.							✓					✓
London$_{it}$									✓		✓	
Tyneside$_{it}$.									✓		✓	
Food & drink$_{it}$		✓		✓								
Textiles$_{it}$		✓		✓								
Wood products$_{it}$		✓		✓								

Table 4: Instrumental Variables (cont.)

	Manufacturing						Services					
Dependent variable in 2nd stage	R&D		INN		EXP		R&D		INN		EXP	
Instrumented variable in 1st stage	INN	EXP	R&D	EXP	R&D	INN	INN	EXP	R&D	EXP	R&D	INN
Rubber & plastics$_{it}$			✓		✓							
Paper$_{it}$	✓	✓		✓								
Publishing & printing$_{it}$		✓		✓								
Non-metallic metals$_{it}$		✓		✓								
Fabricated metals$_{it}$		✓		✓								
Basic metals$_{it}$	✓					✓						
Furniture & manuf nes$_{it}$.			✓		✓							
Sale/repair motors$_{it}$							✓					✓
Wholesale trade$_{it}$									✓		✓	
Retail$_{it}$								✓		✓		
Transport$_{it}$								✓		✓		
Hotels and restaurants$_{it}$										✓		
Transport$_{it}$										✓		
Financial$_{it}$											✓	✓
Real estate$_{it}$								✓		✓		
Computing$_{it}$									✓		✓	
R&D$_{it}$							✓					✓
Other business$_{it}$								✓		✓		
Film etc services$_{it}$									✓		✓	

Table 5: Weighted structural probit models of GB establishments, 2004-2008 (manufacturing, MAN, and non-manufacturing, NMAN)

Dependent variable:	R&D		Innovation		Exporting	
Estimation method:	MAN	NMAN	MAN	NMAN	MAN	NMAN
	(1)	(1a)	(2)	(2a)	(3)	(3a)
$R\&D_{it}$	n.a	n.a	0.197***	0.249***	0.484***	0.139***
			(0.076)	(0.065)	(0.087)	(0.047)
$Innovation_{it}$	0.255**		n.a	n.a	–	
	(0.110)					
$Exporting_{it}$	0.164***	0.149***	–	–	n.a	n.a
	(0.046)	(0.035)				
$R\&D_{it-1}$	0.286***	0.209***	–	–	-0.135***	–
	(0.026)	(0.023)			(0.042)	
$Innovation_{it-1}$	–	–	0.239***	0.173***	–	–
			(0.025)	(0.023)		
$Exporting_{it-1}$	–	–	–		0.573***	0.535***
					(0.021)	(0.024)
ln Labour $productivity_{it}$	0.062***	–	–		–	0.027***
	(0.020)					(0.008)
ln Capital $intensity_{it}$	–	0.017**	–		0.046***	
		(0.007)			(0.014)	
10-19 $employees_{it}$		-0.038*				
		(0.020)				
ln Age_{it}	–		–	-0.026**	-0.055*	
				(0.012)	(0.031)	
ln Industry $agglomeration_{it}$	-0.016**		–	-0.007*	0.021***	0.032***
	(0.007)			(0.004)	(0.008)	(0.011)
ln $Diversification_{it}$						-0.036**
						(0.015)
Multi-industry $enterprise_{it}$	–	-0.054***	–		0.057**	
		(0.019)			(0.028)	
US-$owned_{it}$	–		-0.109**		–	
			(0.054)			
No $graduates_{it}$	-0.089***	-0.059***	–		-0.228***	-0.111***
	(0.029)	(0.020)			(0.034)	(0.021)
5-20% $graduates_{it}$	–		–		-0.076**	
					(0.034)	
20-75% $graduates_{it}$						0.075**
						(0.034)
75%+ $graduates_{it}$	–		-0.125**		–	0.137***
			(0.052)			(0.039)
AC external $knowledge_{it}$	0.096***	0.122***	0.172***	0.116***	–	
	(0.025)	(0.011)	(0.018)	(0.013)		
AC national co-$operation_{it}$	0.056***	0.061***	0.061***	0.039***	–	
	(0.017)	(0.009)	(0.014)	(0.011)		
AC corporate strategy and management techniques $_{it}$	0.057***	0.049***	0.049***	0.025**	–	
	(0.014)	(0.011)	(0.015)	(0.011)		
AC international co-$operation_{it}$	–	–	0.024**	0.018**	–	0.014**
			(0.012)	(0.008)		(0.006)
AC global specialised $knowledge_{it}$	–	–	0.027**	0.029***	–	
			(0.011)	(0.009)		
High costs of $innovation_{it}$	0.135***	0.152***	–		–	
	(0.027)	(0.025)				
Cost of $finance_{it}$	–		-0.088**	0.086***	–	
			(0.036)	(0.031)		

Availability of finance$_{it}$	–		0.109*** (0.040)	-0.073*** (0.023)	–	
Uncertain demand for innovative goods/services$_{it}$	–		–		–	
Lack of information on technology$_{it}$						-0.088*** (0.025)
Lack of market information$_{it}$				-0.048** (0.021)		0.066* (0.038)
Lack of qualified personnel$_{it}$	0.089*** (0.031)		–		–	0.063** (0.029)
Excessive perceived economic risks$_{it}$	–		–	0.048** (0.022)	–	-0.043* (0.023)
Market dominated by established businesses$_{it}$	-0.042* (0.022)	-0.042* (0.022)	–		–	
Food & drink$_{it}$	–		–		-0.213*** (0.045)	
Textiles$_{it}$	–		–			
Wood products$_{it}$	–		–		-0.245*** (0.073)	
Paper$_{it}$	–		–		-0.131* (0.078)	
Publishing & printing$_{it}$	–		–		-0.179*** (0.048)	
Non-metallic minerals$_{it}$	–		–		-0.183*** (0.057)	
Fabricated metals$_{it}$	–		–		-0.102*** (0.037)	
Sale/repair motors$_{it}$	–	–	-0.114*** (0.026)	-0.113*** (0.028)	–	–
Retail$_{it}$	–	–	–	–	-0.070*** (0.021)	-0.067*** (0.021)
Hotels and restaurants$_{it}$	-0.059** (0.026)	-0.055** (0.026)	–	–	–	–
Financial$_{it}$	0.244** (0.109)	0.256** (0.106)	0.194* (0.106)	0.170 (0.105)	–	–
Real estate$_{it}$	–	–	–	–	-0.178*** (0.014)	-0.178*** (0.014)
Computing$_{it}$	0.103** (0.040)	0.108*** (0.040)	–	–	–	–
R&D$_{it}$	–	–	-0.124*** (0.029)	-0.120*** (0.032)	–	–
Other business$_{it}$	–	–	–	–	-0.062*** (0.021)	-0.060*** (0.021)
Film etc services$_{it}$	0.215** (0.091)	0.221** (0.090)	–	–	–	–
Greater South East$_{it}$		0.091*** (0.034)				
East Midlands$_{it}$		0.123*** (0.048)				
Scotland$_{it}$	–		–		-0.121*** (0.046)	
South East$_{it}$						
Wales$_{it}$						
West Midlands$_{it}$	–		–		0.069*	

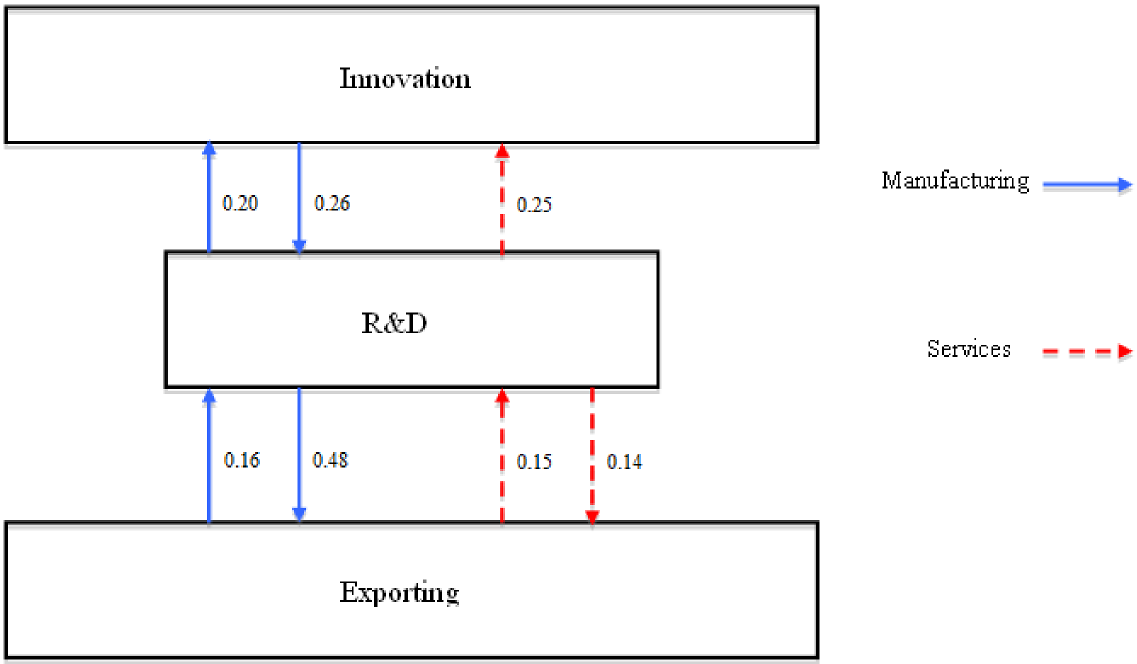
					(0.040)	
$Yorkshire/Humberside_{it}$	-0.091** (0.046)		−		0.133*** (0.041)	
$Bristol_{it}$	0.268** (0.115)		−		-0.290*** (0.087)	
$Cardiff_{it}$	−	-0.098** (0.045)	−		-0.359*** (0.068)	
$Coventry_{it}$	−		−		-0.303** (0.129)	
$Edinburgh_{it}$						
$London_{it}$	−	0.060 (0.037)	−		−	
$Manchester_{it}$	−		−		−	
$Tyneside_{it}$		0.191*** (0.072)				
Observations	3595	6861	3595	6861	3595	6861
Pseudo- R^2	0.334	0.330	0.309	0.377	0.423	0.374
χ^2-test of excluded instruments[c]	27.50	18.91	22.45	22.07	25.35	19.11
F-test of excluded instruments in 1st	14.82***	14.83***	37.81***	18.41***	54.07***	72.23***
stage regressions[d]	93.58***	96.24***	128.4***	115.5***	94.37***	117.5***

Notes: Coefficients are marginal effects ($\partial\hat{p} / \partial x$). Models are based on equation (2). Data used is pooled CIS-ARD data covering 2004-2008.

*/**/*** denotes significance at the 10%/5%/1% levels. − denotes not significant at 10% level.

‡ see text for explanation.

Figure 1: Contemporaneous relationships between exporting, innovation and R&D



Source: parameter estimates reported in Table 5

Appendix

Table A.1: Structure matrix of factor loadings: correlations between variables and rotated common factors, CIS4*

Input Variables	**Factor 1** Business management & network	**Factor 2** External knowledge	**Factor 3** National co-operation	**Factor 4** International co-operation	**Factor 5** Global specialised knowledge	**Kaiser-Meyer-Olkin Measures**†
Sources of knowledge/info for innovation						
Suppliers	0.033	***0.809***	-0.001	-0.015	-0.090	0.933
Clients/customers	0.042	***0.835***	0.012	0.008	-0.138	0.883
Competitors/other businesses	0.020	***0.822***	-0.008	-0.002	-0.082	0.904
Consultants/labs/R&D institutes	0.112	***0.477***	0.080	0.055	***0.341***	0.942
Universities and other HEIs	0.047	***0.299***	0.061	0.093	***0.644***	0.851
Government/research organisations	0.042	***0.343***	0.096	0.012	***0.638***	0.874
Conferences/trade fairs/exhibitions	0.040	***0.712***	-0.029	0.051	0.078	0.950
Scientific journals and trade/technical publications	-0.020	***0.732***	-0.000	0.028	0.185	0.931
Professional/industry associations	-0.003	***0.751***	0.027	-0.033	0.192	0.918
Technical/industry standards	0.032	***0.743***	0.016	0.001	0.148	0.935
Co-operation partners on innovation activities (national/international)						
Suppliers (national)	0.013	0.067	***0.815***	0.017	-0.122	0.891
Suppliers (international)	0.011	0.150	0.137	***0.608***	-0.257	0.900
Clients/customers (national)	0.016	0.083	***0.813***	0.047	-0.157	0.872
Clients/customers (international)	0.055	0.087	0.181	***0.605***	-0.192	0.901
Competitors (national)	-0.021	0.024	***0.831***	-0.100	-0.076	0.900
Competitors (international)	0.006	0.075	0.092	***0.624***	-0.212	0.889
Consultants/labs/R&D institutes (national)	0.022	-0.023	***0.774***	0.044	0.070	0.917
Consultants/labs/R&D institutes (international)	-0.006	0.006	-0.051	***0.751***	0.015	0.874
Universities, HEIs (national)	0.039	-0.115	***0.661***	0.132	0.304	0.872
Universities, HEIs (international)	0.010	-0.110	-0.046	***0.670***	0.283	0.832
Government/research organisations (national)	0.011	-0.105	***0.756***	0.001	0.267	0.876
Government/research organisations (international)	0.016	-0.111	-0.066	***0.634***	0.253	0.803
Areas of changes of business structure and HRM practices						
Corporate strategies	***0.822***	-0.043	-0.010	0.002	-0.010	0.878
Management techniques	***0.705***	-0.022	0.020	-0.063	0.092	0.930
Organisational structures	***0.817***	-0.016	-0.033	0.015	-0.027	0.878
Marketing concepts/strategies	***0.697***	0.096	0.023	0.007	-0.068	0.929
No. of observations						16,445
LR test: independent vs. saturated: $\chi^2(325)$						2.0e+05
Overall KMO						0.900

Notes: *Factors extracted using principal-component method (5 factors retained) in conjunction with weighting, then rotated using oblique oblimin technique. †Kaiser-Meyer-Olkin measure of sampling adequacy is employed to assess the value of input variables. Historically, the following labels are given to different ranges of KMO values: 0.9-1 Marvellous, 0.8-0.89 Meritorious, 0.7-0.79 Middling, 0.6-0.69 Mediocre, 0.5-0.59 Miserable, 0-0.49 Unacceptable.

Table A.2: Structure matrix of factor loadings: correlations between variables and rotated common factors, CIS5*

Input Variables	**Factor 1** Business management & network	**Factor 2** External knowledge	**Factor 3** National co-operation	**Factor 4** International co-operation	**Factor 5** Global specialised knowledge	**Kaiser-Meyer-Olkin Measures**†
Sources of knowledge/info for innovation						
Suppliers	0.349	***0.808***	0.173	0.051	0.175	0.940
Clients/customers	0.400	***0.840***	0.189	0.068	0.170	0.883
Competitors/other businesses	0.382	***0.835***	0.164	0.071	0.226	0.910
Consultants/labs/R&D institutes	0.370	***0.581***	0.218	0.139	***0.579***	0.939
Universities and other HEIs	0.277	***0.440***	0.191	0.185	***0.814***	0.854
Government/research organisations	0.280	***0.471***	0.178	0.124	***0.814***	0.874
Conferences/trade fairs/exhibitions	0.367	***0.723***	0.199	0.099	0.363	0.957
Scientific journals and trade/technical publications	0.296	***0.736***	0.167	0.106	*0.473*	0.935
Professional/industry associations	0.315	***0.779***	0.177	0.060	*0.462*	0.926
Technical/industry standards	0.347	***0.779***	0.190	0.057	*0.410*	0.939
Co-operation partners on innovation activities (national/international)						
Suppliers (national)	0.207	0.248	***0.781***	0.212	-0.022	0.882
Suppliers (international)	0.128	0.181	0.402	***0.569***	-0.045	0.885
Clients/customers (national)	0.223	0.251	***0.819***	0.287	0.034	0.874
Clients/customers (international)	0.126	0.170	0.408	***0.616***	0.035	0.887
Competitors (national)	0.177	0.160	***0.752***	0.232	0.065	0.902
Competitors (international)	0.086	0.079	0.340	***0.661***	0.050	0.895
Consultants/labs/R&D institutes (national)	0.213	0.136	***0.753***	0.353	0.204	0.910
Consultants/labs/R&D institutes (international)	0.107	0.065	0.213	***0.734***	0.051	0.881
Universities, HEIs (national)	0.162	0.071	***0.691***	0.414	0.397	0.866
Universities, HEIs (international)	0.091	-0.008	0.243	***0.756***	0.189	0.830
Government/research organisations (national)	0.156	0.050	***0.718***	0.328	0.347	0.868
Government/research organisations (international)	0.063	0.005	0.191	***0.771***	0.148	0.805
Areas of changes of business structure and HRM practices						
Corporate strategies	***0.795***	0.292	0.174	0.102	0.099	0.885
Management techniques	***0.699***	0.250	0.144	0.066	0.208	0.926
Organisational structures	***0.806***	0.343	0.186	0.087	0.159	0.896
Marketing concepts/strategies	***0.759***	0.362	0.170	0.105	0.094	0.915
No. of observations						14872
LR test: independent vs. saturated: $\chi^2(325)$						1.8e+05
Overall KMO						0.900

Notes: *Factors extracted using principal-component method (5 factors retained) in conjunction with weighting, then rotated using oblique oblimin technique. †Kaiser-Meyer-Olkin measure of sampling adequacy is employed to assess the value of input variables. Historically, the following labels are given to different ranges of KMO values: 0.9-1 Marvellous, 0.8-0.89 Meritorious, 0.7-0.79 Middling, 0.6-0.69 Mediocre, 0.5-0.59 Miserable, 0-0.49 Unacceptable.

Table A.3: Structure matrix of factor loadings: correlations between variables and rotated common factors, CIS6*

Input Variables	**Factor 1** Business management & network	**Factor 2** External knowledge	**Factor 3** National co-operation	**Factor 4** International co-operation	**Factor 5** Global specialised knowledge	**Kaiser-Meyer-Olkin Measures†**
Sources of knowledge/info for innovation						
Suppliers	0.100	***0.753***	-0.054	0.001	-0.079	0.960
Clients/customers	0.171	***0.720***	-0.032	0.007	-0.063	0.935
Competitors/other businesses	0.141	***0.748***	-0.026	0.027	-0.037	0.956
Consultants/labs/R&D institutes	0.041	***0.746***	0.105	0.022	***0.509***	0.960
Universities and other HEIs	-0.012	***0.748***	0.206	0.024	***0.405***	0.905
Government/research organisations	-0.015	***0.777***	0.192	0.003	***0.370***	0.928
Conferences/trade fairs/exhibitions	0.009	***0.864***	-0.048	0.048	0.103	0.972
Scientific journals and trade/technical publications	-0.022	***0.909***	-0.018	0.008	0.039	0.968
Professional/industry associations	0.042	***0.840***	-0.002	0.014	0.074	0.965
Technical/industry standards	0.034	***0.849***	-0.006	-0.003	0.030	0.969
Co-operation partners on innovation activities (national/international)						
Suppliers (national)	0.090	0.197	***0.401***	-0.035	-0.065	0.947
Suppliers (international)	-0.029	0.181	-0.041	***0.548***	-0.352	0.905
Clients/customers (national)	0.105	0.323	***0.362***	-0.045	-0.322	0.956
Clients/customers (international)	0.023	0.156	0.017	***0.565***	0.211	0.900
Competitors (national)	-0.015	0.027	***0.655***	0.018	0.022	0.941
Competitors (international)	0.022	-0.004	0.067	***0.770***	0.119	0.906
Consultants/labs/R&D institutes (national)	0.039	0.005	***0.744***	0.018	-0.025	0.914
Consultants/labs/R&D institutes (international)	-0.022	0.020	0.013	***0.858***	-0.163	0.894
Universities, HEIs (national)	0.060	0.021	***0.798***	0.037	0.298	0.852
Universities, HEIs (international)	0.027	-0.044	-0.003	***0.879***	0.267	0.800
Government/research organisations (national)	0.026	-0.018	***0.830***	0.030	0.209	0.879
Government/research organisations (international)	-0.002	-0.048	-0.020	***0.880***	0.316	0.824
Areas of changes of business structure and HRM practices						
Corporate strategies	***0.834***	-0.038	0.012	0.013	-0.067	0.941
Management techniques	***0.739***	0.007	-0.027	0.007	-0.109	0.961
Organisational structures	***0.777***	-0.002	0.022	0.015	-0.016	0.959
Marketing concepts/strategies	***0.732***	0.043	0.007	-0.020	0.062	0.954
No. of observations						12220
LR test: independent vs. saturated: $\chi^2(325)$						2.2e+05
Overall KMO						0.935

Notes: *Factors extracted using principal-component method (5 factors retained) in conjunction with weighting, then rotated using oblique oblimin technique. †Kaiser-Meyer-Olkin measure of sampling adequacy is employed to assess the value of input variables. Historically, the following labels are given to different ranges of KMO values: 0.9-1 Marvellous, 0.8-0.89 Meritorious, 0.7-0.79 Middling, 0.6-0.69 Mediocre, 0.5-0.59 Miserable, 0-0.49 Unacceptable.