# Pathways to efficiency, pathways to growth: Evidence from the UK Innovation Survey

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# ABSTRACT

Previous studies have suggested there is little correlation between efficiency – measured by sales per employee - and growth at firm level. Here, using data from successive waves of the UK innovation survey we consider two questions. First, do different types of innovation have different effects on efficiency and growth? Our analysis suggests that product or service innovation has a significant positive relationship to employment growth but a significant negative effect on efficiency growth two years after innovation is measured. Organisational innovation has a positive efficiency growth effect due to a negative employment effect. Process innovation raises both efficiency and sales growth. Furthermore, these short-term product and process innovation effects prove robust across our sample sub-groups. Over the longer term four years after innovation is measured, however, these significant positive and negative effects are not sustained, and some sign patterns change.

Secondly, we consider whether the source of firms' R&D finance matters. Is there a difference between the effects on innovation of publicly-supported and wholly-privately-funded R&D? We find that firms receiving public R&D support are no more likely to undertake process or organisational innovation than those paying for all of their own R&D costs. Additionality is greater in terms of product or service innovation. Again, these results prove robust across a range of sectors and firm sizebands. Our results suggest the dynamics of the relationship between innovation and firm performance and the importance of a medium to long-term perspective in evaluating the value of innovation support schemes.

**Keywords:** Innovation, efficiency, growth, public-support

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# 1. INTRODUCTION

Market failures linked to asymmetric information, and firms' consequent inability to estimate and appropriate the full rents from innovation, are often used to justify public support for private innovation (Arrow 1962). When such support is available, the evidence suggests that it can have substantial additionality, increasing firms' investments in R&D and innovation and boosting levels of innovative output (Zuniga-Vicente, Alonso-Borrego et al. 2014; Becker 2015; Dimos and Pugh 2016). Innovation itself is, however, of little interest until it either generates value added for firms or consumers, and/or benefits for the environment or individuals' quality of life. Here, the evidence is more limited, results are more mixed, and studies are often limited to a specific intervention. For example, while US evidence suggests public R&D support may improve firms' survival prospects and their ability to attract follow-on venture capital funding (Zhao and Ziedonis 2014; Howell 2017), neither effect is evident in China (Wang, Li and Furman 2017). In terms of efficiency, a recent Korean study using a difference-in-difference approach identified positive effects from innovation (Cin et al. 2017). However, recent European evidence from Italy and Finland is more equivocal, identifying positive growth effects (in employment and assets) from public R&D support but providing little evidence of positive efficiency effects (Bayona-Saez et al. 2010; Karhunen and Huovari 2015). Positive business-growth effects from public R&D support are also evident in recent studies of the impact of UK Research Councils (Scandura 2016; Vanino et al. 2019).

The differential impacts of R&D and innovation support on firm survival, growth and efficiency are perhaps unsurprising. Previous studies have suggested the weak correlations between different performance metrics such as sales and employment growth (Chandler et al. 2009; Baum, Locke et al. 2001; Delmar et al. 2003), and growth in sales per employee. Moreover, it is clear from analyses of high-growth firms and population cohorts that high growth – on whatever metric – is rarely sustained and is therefore inherently unpredictable – the 'picking winners' problem (Coad et al. 2013; Anyadike-Danes and Hart 2018). Other studies have noted differences in the order in which firm performance metrics change as a firm grows. Coad et al. (2017) suggest that, for most firms, growth begins with employment, followed by increases in sales, profits and assets. Their analysis also suggests that high growth firms – perhaps those more likely to be innovating – exhibit a different pattern in which sales and profits growth precede that of employment. These findings lead Kiviluoto (2013, p. 572) to conclude that 'determining what exactly characterizes the success of a firm is a multifaceted task ... As success can take different forms and shapes, one could assume that only one measure cannot possibly represent the preferred outcome of all possible choices made within the firm'.

Innovation itself can also take a number of forms relating to firms' products or services, business processes, operating routines and organisational structures. Each might be expected to have differential impacts on the different dimensions of firm performance (Roper et al. 2008; Roper and Arvanitis 2012). For example, Exposito and Sanchis-Llopis (2018) report recent evidence of the impact of product/service, process and organisational innovation on the financial and operational performance of Spanish manufacturing SMEs. Based on cross-sectional survey data for 1424 SMEs they find: a positive correlation between product innovation, sales growth and costs; few significant process effects on sales growth or costs; and, a negative association between organisational innovation and costs. They conclude: 'the strength of the innovation–performance relationship depends on the type of innovation and on the performance dimension considered … our findings confirm that the impact of innovation initiatives on business performance should be analysed from a multi-dimensional approach' (Exposito and Sanchis-Llopis 2018, p. 925).

We extend the analysis of Exposito and Sanchis-Llopis (2018) in three directions. First, as we have panel data, we are able to consider the causal influence of different types of innovation – product/service, process and organisational – on different dimensions of firm performance. Second, we are able to identify separately those situations in which innovation is wholly funded by the firm and where there is an element of public funding. Together these attributes of our data allow us to map the causal mechanisms from public R&D support, through innovation of different types to firm efficiency and growth. Third, due to the scale of our database we are able to estimate robust sub-sample results for firms of different sizes and separately for firms in manufacturing and services. Our results confirm the differential –

and not always positive – impact of 'innovation' on the different measures of firm performance.

The remainder of the paper is organised as follows. Section 2 outlines our conceptual perspective linking R&D investments, innovation and business performance. Section 3 develops related hypotheses and Section 4 discusses data and our econometric approach. Section 5 presents the key empirical results and robustness tests and Section 6 provides a summary and discussion. Supporting material and sub-sample estimates are included in appendices.

# 2. CONCEPTUAL FRAMEWORK

## 2.1 Innovation

Innovation - the market introduction of new products and processes - can be radical or incremental; it can relate to products, processes or services. Radical innovation may lead to disruptive changes in the structure of a market, create new markets or displace existing products or services (Schumpeter 1942). Incremental innovation - the improvement of an existing product, process or service – may also be commercially significant but is unlikely to have important effects on market structure (Tidd et al. 1997).

Innovative firms may create new or improved products or processes, may develop new methods of commercialisation, or might formulate new models of organisation (Diamond 1997). An innovating firm's introduction of a new product, process or service represents the end of a process of knowledge sourcing (for example, research and development – R&D – activities) and transformation (i.e. turning knowledge into an innovation) and the beginning of a process of exploitation by the firm in an attempt to improve performance and generate value added (Roper et al. 2008). Taken together, this process of knowledge sourcing, transformation and exploitation by the innovating firm is what has become known as the Innovation Value Chain (IVC) (Roper et al. 2008).

The IVC can be seen as including three inter-related activities. The first of these encompasses firms' knowledge-sourcing. Roper et al. (2008) identify five different types of knowledge-sourcing activity: intramural R&D (Shelanski and Klein 1995), customer linkages (Joshi and Sharma 2004), supplier and external-consultant linkages (Horn 2005), competitor and joint-venture linkages (Link et al. 2005) and university/public-research-centre linkages (Roper et al. 2004). In practice, knowledge-sourcing activities do not occur in isolation – some complement each other, while others are substitutes. Firms' knowledge-sourcing strategies will also depend on the strength of their existing knowledge base and absorptive capacity. The second activity in the IVC involves the transformation of knowledge into marketable innovation outputs, with the success of any transformation depending upon firm characteristics, resources and capabilities (Griliches 1992; Love and Roper 1999). The third activity in the IVC relates to exploitation with implications for business performance (Roper et al. 2008; Geroski et al. 1993).

Here, we are primarily concerned with firms' knowledge transformation and exploitation activities and how these relate to firm performance. The following section outlines the processes by which knowledge obtained through R&D can impact on firms' innovation output.

## 2.2 From R&D to innovation

R&D is often viewed as being a contributor to innovation through a process of discovery and invention (Ray and Bhaduri 2001). However, the translation of R&D investments into new knowledge is complex and may be influenced by firm characteristics, internal resources, and the market environment (Griliches 1992; Roper et al. 2008; Love and Roper 1999). Consistent with a resource-based or capabilities perspective (Foss 2004), firms' internal resources are expected to contribute positively to the efficiency with which firms capitalise on their R&D investments (Crépon et al. 1998; Lööf and Heshmati 2001 and 2002). In addition to generating new knowledge, R&D investment can also enhance a firm's absorptive capacity, i.e. its ability to assess, assimilate and exploit existing information (Cohen and Levinthal 1989; Griffith et al. 2000 and 2003)[1].

To allow for both attributes of R&D, Cohen and Levinthal (1989) develop a theoretical model which suggests that firms' stock of knowledge relates both to the firm's own investment in R&D plus a fraction of the knowledge available in the public domain. Public domain knowledge includes potential spillovers from other firms' R&D activities as well as extra-industry knowledge generated by universities etc. The degree to which knowledge spills over between firms will, however, depend both on firms' knowledge protection practices and the nature of the technology involved. For example, where new knowledge builds upon previous knowledge firms' absorptive capacity may be greater. Alternatively, when advances in knowledge are rapid and unrelated to previous developments firms may find it more difficult to appropriate external information.

The 'two faces' of R&D (Cohen and Levinthal 1989) provide firms with the incentive to invest in R&D activity. However, whether or not a firm is able to successfully exploit available knowledge and improve performance depends upon its ability to appropriate innovation returns[2]. The appropriability problem (Arrow 1962) arises because firms are unable to completely stop other firms from accessing their knowledge or imitating their innovations, and as a consequence of this, firms fail to appropriate all of the returns from their R&D investments (Ceccagnoli and Rothaermel 2008)[3]. Firms are faced with a risk of imitation by both existing competitors and new competitors (Hurmelinna-Laukkanen 2009): a fast second entrant or even a slow third may outperform the innovator (Teece 2012). A firm therefore faces a key strategic challenge: it somehow needs to capture returns from its R&D activity,

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[1] Tilton (1971) found that firms in the semi-conductor industry invested in R&D in order to gain a technical capability which allowed them to keep up-to-date with the latest developments. In addition, this capability helped firms to assimilate any new technologies developed elsewhere.
[2] The appropriability problem (Arrow 1962) is a feature of innovative activity which distinguishes it from other strategic investments made by firms (Geroski 1995).
[3] In this sense, technological knowledge produced through firms' R&D activities is both non-rivalrous and not (completely) excludable. So as the private rate of return to R&D is below the social rate of return, firms' R&D investment may be lower than what is socially optimal.

and its ability to do so may determine its performance and continued survival (Ceccagnoli and Rothaermel 2008).

### 2.3 Public funding for R&D

Empirical evidence provided by Griliches (1979, 1998) supports the theoretical suggestion that the private rate of return to firms' R&D is typically below the social rate of return. This, or more strategic objectives linked to a desire to build capacity in specific sectors, technologies or localities (Vanino et al. 2019), provide the justification for public R&D support. In either case, it is expected that public support will incentivise firms to increase or begin R&D activity which will increase firms' innovation capabilities and outputs and result in an improvement in business performance over the longer term (Becker 2019). It is then envisaged that this increased volume of R&D and innovation activity will generate positive externalities moving the economy towards the social optimum (Becker 2015).

Vanino et al. (2019) identify four mechanisms through which public R&D support may lead to increased innovative activity and economic performance. First, firms that receive public support for R&D experience increased liquidity and financial slack. The financial support effectively reduces the riskiness of some innovations and increases the likelihood that more risky innovations will take place (Zona 2012). However, by effectively shielding recipient firms from risk, firm managers are insulated from market realities, potentially encouraging inertia or poor resource allocation towards highly risky projects (Nohria and Gulati 1996). Hence, slack resources may also have negative effects. Together, these effects suggest an inverted U-shaped relationship between slack and innovation – too little slack hinders innovation, while too much may reduce firms' incentives to innovate. This may result in over-subsidised innovation and firms that are grant dependent (Kilponen and Santavirta 2007).

Second, public support for private R&D introduces a form of cost sharing which effectively reduces both the amount of investment firms are required to make and the associated risk. A firm's decision to innovate is positively related to post-innovation returns and negatively related to the risks it perceives to be associated with the investment (Calantone et al. 2010;

Mechlin and Berg 1980). These perceived risks relate to the technologies involved in the project (where development projects fail to achieve the desired technological or performance outcomes, for example) and the commercial viability of the project in terms of any expected sales and profitability (where there is uncertain demand, for example) (Keizer and Halman 2007; Roper et al. 2008; Cabrales et al. 2008). Both types of risk are interrelated, and this may lead firms to seek public support in order to undertake those projects with a higher risk-reward ratio. In addition, if subsidy rates are high, firms may seek public support for their riskier projects leading to negative selection bias (Vanino et al. 2019).

Third, when market failures exist, public support for R&D and innovation may take on a market-making role and address particular social or economic challenges (Mazzucato 2016). There may be a particular role for public-sector market-making where technologies are emergent and markets uncertain (Van Alphen et al. 2009) or where there are wider social benefits from an innovation (Zehavi and Breznitz 2017). Fourth, public support for R&D and innovation can have an enabling or bridging role, helping firms to access otherwise unavailable new or pre-existing knowledge. Public support in the form of innovation vouchers, for example, encourages firms to approach knowledge providers. Such vouchers also encourage knowledge providers to work with new partners (OECD 2010). Further support in the form of subsidies, for example, may support R&D collaboration, further enhancing the creation of new knowledge.

### 2.4 From innovation to business performance

Numerous theoretical contributions (see for example, Romer 1986, 1990; Grossman and Helpman 1991; Aghion and Howitt 1998) predict that R&D and innovation will have a positive impact on firm growth and efficiency. The innovation-to-efficiency and innovation-to-growth linkages are explained through both endogenous growth theory (Romer 1990) and Schumpeterian arguments related to entrepreneurial entry and competition i.e. ‘creative destruction’ (Schumpeter 1942).

Endogenous growth theorists propose that improvements in technology are the driving force which lies behind continual, rising standards of living. They suggest that technological progress requires an intentional investment of resources by profit-seeking firms or entrepreneurs (Grossman and Helpman 1994), and that such industrial innovation is the engine of growth (Romer 1990; Aghion and Howitt 1992; Grossman and Helpman 1994). The Schumpeterian 'creative-destruction' viewpoint suggests that opportunistic, entrepreneurial firms that invest in new technologies and the commercialisation of new products/services produce innovations which allow them to achieve a position of market leadership. Subsequently, these entrepreneurial 'creators' reap first-mover benefits (Roper and Hewitt-Dundas 2017). It is the incumbent firms that experience the associated 'destruction' as the entrepreneurial creation undermines or eliminates the value of incumbents' assets or technologies. Entrepreneurial 'first-movers' have an opportunity to become the market leader, gain a competitive advantage and achieve an improved performance in terms of efficiency and growth. Firms adopting a first-mover strategy become dominant in their product class or market and gain superior performance over time (Cohen and Levinthal 1990; Roberts and Amit, 2003). First-mover advantage encourages firms to engage in innovative activity, increases the likelihood that firms will be aware of latest developments, absorb new and related knowledge and benefit from innovative activities in the long run (Damanpour 2017).

In addition, through process innovation, the transformation of knowledge into new processes enables firms to optimise elements of their operations. For example, computer-aided manufacturing (CAM) allows firms to use computer software to control machine tools and related machinery in manufacturing processes. The adoption of such process technologies may influence a firm's innovation capabilities (Santamaría et al. 2009; Raymond et al. 2009) and generate economies of scope for the firm (Bourke and Roper 2016). New processes may allow firms to adopt more flexible production systems which may also allow firms to adopt more complex innovation strategies with potentially higher returns (Hewitt-Dundas 2004). New processes may pave the way for more radical innovations as entrepreneurs seek to establish a position of market or technological leadership (disruptive, Schumpeterian innovation) (Anthony et al. 2008; Hang et al. 2010). Process innovations may also lead to efficiency advantages which may reduce the cost of innovations and increase any associated returns. As a result, firms may be more likely to innovate or increase their innovative activity (Levin and Reiss 1984; Calantone et al. 2010). The improvements in product quality and reliability which result from process innovation may therefore have a positive effect on innovation returns and reduce the commercial uncertainty of an innovation (Astebro and Michela 2005): higher returns and reduced uncertainty increase firms' incentive to innovate (Bourke and Roper 2016).

In addition to technology-based product and process innovations, firms introduce innovations to adapt to environmental change and to maintain and improve performance. Firms innovate in response to environmental changes, to renew business portfolios and to serve customers or clients more effectively (Damanpour and Gopalakrishnan 1998; Roberts and Amit, 2003). These innovations enable a firm to survive and thrive (Damanpour 2017). Here, we term innovation of this type 'organisational innovation' – innovations which are a means of organisational adaptation and progression. Organisational change is the introduction of activities which are different from those currently in use (Burke 2002) – new behaviours and methods of operation, for example.  Firms are motivated to engage in organisational innovation by both internal and external factors. External factors include competitors, deregulation, isomorphism, resource scarcity and customer demands, and internal factors include high aspirations and a wish to increase the extent and quality of products and services. In this sense, organisational innovations are 'instruments of organisational change' for effective performance (Damanpour 2017). Organisational innovations comprise of innovations which are technical in nature (directly related to the primary work activity of the firm and produce changes mainly in its operating systems – lean production and quality management, for example) and those which are managerial/administrative (indirectly related to the firm's primary work activity and affect mainly its management systems – the integration or de-integration of departments, for example). The influence of organisational innovation on performance is less predictable than that of product and process innovation. Given the need for firms to adapt and progress in line with rapidly changing economies, however, organisational innovation is expected to be positively related to firm performance when combined with more technological innovations

(Damanpour 2017). Nevertheless, those firms that engage in organisational innovation are perceived to be more innovative and rated more highly in terms of management quality than other firms within their industry (Staw and Epstein 2000).

## 3. HYPOTHESES

Hall (2011) provides an overview of early research on the link between indicators of product innovation and productivity and notes the cross-sectional nature of the majority of early papers. Her review identifies evidence of a consistent positive relationship between innovation and productivity across a range of countries when product innovation is measured using the percentage of sales. When in other studies product innovation is measured using a dummy variable, links to productivity are less consistent but again positive in the majority of cases. More recent studies provide mixed evidence, albeit with a tendency for a positive link in cross-sections between product innovation and sales per employee. Doran and O'Leary (2011), for example, find a positive relationship between innovative sales per employee and efficiency (turnover per employee) for a group of Irish firms. Similarly, Dai and Cheng (2018) examine the relationship between product innovation and different elements of efficiency in Chinese manufacturing firms and find, overall, a positive relationship. However, their analysis suggests that the positive product innovation-productivity relationship may be driven by improvements in margins rather than physical efficiency changes. Relationships between product innovation and physical efficiency are either negative or insignificant, perhaps suggesting the type of disruption effects envisaged in Roper et al. (2008) following the introduction of a new product. For Taiwanese firms, Lin et al. (2016) also find a positive relationship between product innovation and efficiency but only when product change is accompanied by related process innovation. Trans-national studies also provide support for a positive link between product innovation and sales per employee growth. Morris (2018) in a cross-country study find a consistent and positive link between product innovation and a range of efficiency measures although the strength of the link varies significantly between estimation methods and between manufacturing and services (Morris, 2018). Crowley and McCann (2018) using data on a range of transition economies in Europe find a similar positive link between product innovation and sales per employee across both the manufacturing and service sectors.

Evidence of a negative or insignificant relationship between product innovation and sales per employee also comes from a number of studies. Roper et al. (2008) find a negative effect from product innovation on sales per employee in Irish manufacturing firms but positive impacts on sales and employment growth. Crowley and McCann (2015) in a cross-sectional study for Irish firms also find a negative relationship between product innovation and sales per employee for Irish firms perhaps reflecting the suggestion by Mohnen and Hall (2013) that efficiency may fall for a period of time after a new product introduction. Other studies find an insignificant relationship between product innovation and efficiency for Swiss manufacturing firms (Roper and Arvanitis 2012) and new technology-based firms in the UK (Ganotakis and Love 2012).

Evidence of the relationship between product innovation and business growth is less extensive and, in some cases, conditional on other firm and market characteristics. Lentz and Mortensen (2008) using panel data on Danish firms find a positive relationship between innovation and efficiency and a positive association between efficiency and subsequent growth. Corsino and Gabriele (2011) also find a positive relationship between product innovation and growth in the dynamic business environment of the integrated circuit sector. Ganotakis and Love (2012) find consistent evidence of positive product innovation effects on the employment and sales growth of new technology-based firms in the UK. Similarly, Cucculelli and Ermini (2013) find a positive relationship between product innovation and growth in a sample of Italian firms although this relationship is conditional on the risk appetite of the firm's owner-manager. The balance of evidence suggests our first hypothesis:

***Hypothesis 1: Product/service innovation***

H1a: Product or service innovation will have a positive effect on growth in efficiency (sales per employee).

H1b: Product or service innovation will have a positive effect on sales and employment growth.

Hall (2011) also reviews early work on the link between process innovation and productivity and identifies an inconsistent pattern both in terms of sign and significance. This ambiguity in the links between process innovation and sales per employee continues through more recent studies. Crowley and McCann (2015) in a cross-sectional study for Irish firms find significant evidence of a strong positive link between process innovation and growth in sales per employee. This positive result is also evident in trans-national studies by Morris (2018) and Crowley and McCann (2018), although in Morris (2018) this effect is weaker in manufacturing and in the context of panel data estimation[4]. For Taiwanese firms Lin et al. (2016) also find a positive relationship between process innovation and growth in sales per employee but only when process change is accompanied by related product innovation. Ganotakis and Love (2012) find negative links between process innovation and sales growth and insignificant efficiency effects for new technology-based firms in the UK. For Irish manufacturing firms Roper, Du et al. (2008) also find a positive effect from process innovation on sales and employment growth but no significant sales per employee effect. Roper and Arvanitis (2012), however, find a negative effect from measures of process innovation on productivity in Irish manufacturing companies and largely insignificant negative effects in Switzerland. On balance we suggest that:

***Hypothesis 2: Process innovation***

H2a: Process innovation will have a positive effect on growth in efficiency (sales per employee).

H2b: Process innovation will have a positive effect on sales and employment growth.

[4] Neither study considers the impact of product or process innovation on firm growth.

There is strong and positive evidence of the relationship between management practices and productivity: better or more intensively managed firms tend to have higher productivity (Bender et al. 2018; Bloom and van Reenen, 2006). However, relatively few studies have considered the relationship between organisational innovation (i.e. changes in management practices) and firm performance. Crowley and McCann (2015) in a cross-sectional study of Irish firms, find that organisational innovation (and product innovation) have a negative effect on the sales per employee of Irish firms. This potential disruption effect is also evident where firms adopt new quality improvement processes and advanced manufacturing technologies (Bourke and Roper 2016; Bourke and Roper 2017). Organisational change can however play a complementary role to green innovation in firms' products or services, offsetting potentially negative implications for efficiency (Hottenrott, Rexhauser et al. 2016), a similar complementarity to that noted by Lin et al. (2016) between product and process change. This suggests:

***Hypothesis 3: Organisational innovation***

H3a: Organisational innovation will have a negative effect on growth in efficiency (sales per employee).

H3b: Organisational innovation will have a negative effect on sales and employment growth.

As indicated earlier there is significant evidence that public support for firms' R&D has positive crowding-in effects or input additionality, increasing the scale of firms' R&D investments (Zuniga-Vicente et al. 2014). We expect this to lead to increased levels of innovative output – output additionality. Here, however, there is less direct evidence on the relative efficiency with which publicly-funded R&D and wholly-privately funded R&D translate into innovation (Beck, Lopes-Bento et al. 2016). And, where evidence does exist, results are again somewhat contradictory. Hottenrott and Lopes-Bento (2014), for example, find positive effects on innovative sales in Flemish companies from both privately funded and publicly funded R&D, the latter effect being marginally larger. Both effects increase in significance where projects involve international collaboration. Using data for German firms, however, Czarnitzki and Hussinger (2018) provide some evidence that the effect of privately funded R&D on firms' patenting activity is marginally stronger than that of the increment to R&D activity stimulated by public support. They conclude: 'We find that both the privately financed R&D and the publicly induced R&D spending show a positive impact on patent outcome and patent quality' (Czarnitzki and Hussinger 2018, pp. 1336-7). Also using data on German firms, and focussing on measures of product innovation, Czarnitzki and Lopes-Bento (2014, p. 404) conclude that 'keeping innovation investment constant allows us to indirectly conclude that the granted research projects have a similar efficiency as purely privately funded projects'. Using Swiss data Beck, Lopes-Bento et al. (2016) find a positive link between privately funded R&D for both radical and incremental innovation but publicly funded R&D only links to sales of more radical innovations (see also Hottenrott et al. 2017).

Differences in the efficiency of publicly funded and wholly-privately funded R&D may be linked both to firms' previous experiences and the nature of the innovation being undertaken. There is clear evidence, for example, that firms which have received public subsidies in the past are more likely to do so in the future (Aschhoff 2010). Learning from prior innovation projects may increase the efficiency of firms' current innovation projects, suggesting that publicly-funded R&D may Euro-for-Euro be more efficient in producing innovation (Love et al. 2014). Public agencies may also prioritise supporting projects in firms with a track record of successful innovation – picking winners – increasing the average impact of subsidies on innovative outputs. On the other hand, firms may be more likely to seek public subsidies for innovation where projects are risky and uncertain (Aschhoff 2010) or where there are significant financial constraints. Delays or the costs of obtaining public funding may also impact negatively on firms' innovation, particularly where firms face financial constraints. Other issues may arise from the government side if, for example, the government favours more radical or novel projects which are more likely to fail (Hottenrott and Lopes-Bento 2014). Given the limited and rather mixed empirical evidence, and the lack of definitive conceptual arguments we suggest:

***Hypothesis 4:***

*H4a: Publicly-funded R&D will have a similar effect on product/service innovation as wholly privately-funded R&D.*

*H4b: Publicly-funded R&D will have a similar effects on process innovation as wholly privately-funded R&D.*

*H4c: Publicly-funded R&D will have similar effects on organisational innovation as wholly privately-funded R&D.*

## 4. DATA AND METHODS

Data from five waves of the UK Innovation Survey (UKIS) – UKIS 4 to 8 – is used to undertake an analysis of the links between R&D, innovation of different types and business performance (namely, efficiency growth measured by sales per employee, turnover growth and employment growth). The UKIS is based upon a core questionnaire developed by the European Commission (Eurostat) and Member States, and forms part of a wider survey covering European countries – the European Union Community Innovation Survey.[5]

Conducted every two years by means of a postal questionnaire and follow-up telephone interviews, the UKIS is the main source of innovation data in the UK. Used widely by innovation researchers (see for example, Laursen and Salter 2005; Love et al. 2010; Hall and Sena 2017), the survey provides an insight into the objectives of firms' innovation activity and firms' external innovation connections.  Questions relating to firm size and structure, customer base, firm product and process innovation activity, the sources of innovation,

[5] The background and motivation for the innovation survey can be found in the Organisation for Economic Co-operation and Development's (OECD) Oslo manual (OECD 2005), along with a description of the type of questions and definitions used.  In the UK, the Office for National Statistics (ONS) – the UK official government statistical office – manages the administration and data collection for the UKIS.

perceived barriers to innovation, the levels of public support and basic economic information about the firm are included.

The sampling frame for the UKIS is taken from the Inter-departmental Business Register (IDBR), a UK-Government compiled register of all UK businesses based on tax and payroll records. The survey is statistically representative of the 12 regions of the UK, most industrial sectors and firms of all sizes, although firms with fewer than 10 employees are excluded. The waves of data included in the statistical analysis here achieved a response rate ranging between 50 per cent in 2010 (UKIS 7) and 58 per cent in 2004 (UKIS 4).

There are many advantages to using the UKIS to undertake a causal analysis of this type. First, it is a large-scale survey allowing both national and sub-sample estimates to be obtained. Second, the survey provides details of R&D investment, innovation of different types and performance indicators (efficiency –measured by sales per employee – and sales growth), allowing for consistent reporting units, and third, the survey provides a number of variables which can be used as control factors in the empirical analysis. Although each wave of data includes around 14,000 firms, the introduction of a dynamic element into our analysis means that only those firms that respond to two consecutive waves of the survey are used, significantly reducing the sample size.

## 4.1 Model variables

Variable definitions are given in Annex 1, and correlation coefficients are presented in Annex 2. Table 1 provides descriptive statistics – the number of observations, the mean and the standard deviation – for the variables included in the empirical analysis. Annex 3.1 to Annex 3.3 provide descriptive statistics for the different sub-groups of firms used in our analysis.

### *4.1.1 Dependent variables*

Three baseline models are estimated, each with a different performance indicator as the dependent variable i.e. efficiency or sales per employee growth, turnover growth and employment growth. First, to calculate *efficiency growth*, efficiency – measured as firms' turnover per employee at the end of the survey period – is calculated using firms' responses to two survey questions which ask firms to report their total turnover for the final year of the survey period and their average number of employees during the same period. *Efficiency growth* is then calculated using firms' efficiency at the end of two consecutive survey periods. On average, efficiency growth across firms in the estimation sample is 2.3 per cent (Table 1). Second, *turnover growth* is calculated using the firm's estimate of its total turnover at the end of two consecutive survey periods. Across all firms in the estimation sample, average annual turnover growth is 5.2 per cent (Table 1). Third, *employment growth* is calculated using firms' average number of employees during two consecutive survey periods. Average employment growth across all firms is 2.5 per cent (Table 1).

#### *4.1.2 Independent variables*

The analysis considers how three different types of innovation – product/service, process and organisational – are related to the three performance indicators. First, the UKIS asks firms whether they introduced any new or significantly improved[6] goods or services during the survey period[7]. Based upon firms' responses, a binary variable is constructed to represent *product/service innovators*. The variable takes on the value of 1 if the firm introduced a new or significantly improved good or service and 0 if they did not. The descriptive statistics in Table 1 show that some 23 per cent of firms in the estimation sample engage in product/service innovation. Second, the survey asks firms whether they introduced any new or significantly improved methods for the production or supply of goods and services i.e. processes, during the survey period. Based upon firms' responses, a binary variable is constructed to represent *process innovators*. The variable takes on the value of 1 if the firm introduced a new or significantly improved process and 0 if they did not. Around 13 per cent of firms in the estimation sample engage in process innovation (Table 1). Third, the survey asks firms whether they made any major changes to business practices, the organisation of work responsibilities and decision making, the organisation of external

[6] An improvement in quality or distinct user benefits, for example.

relationships, or their marketing concepts or strategies during the survey period. Based upon firms' responses, a binary variable is constructed to represent *organisational innovators*. The variable takes on the value of 1 if the firm introduced a new or significantly improved form of organisation, business structure or practice aimed at raising internal efficiency or the effectiveness of approaching markets or customers, and 0 if they did not. Organisational innovation is carried out by 41 per cent of firms in the estimation sample (Table 1).

Adopting an IVC perspective, the analysis here suggests that R&D may influence innovation in the short term and that any performance effects may take longer to emerge. The three types of innovation are therefore treated as being endogenously determined in the empirical analysis and are allowed to vary according to firms' R&D activities. In addition, some UKIS surveys include indicators of whether innovating firms received public support for their R&D from regional or national agencies within the UK[8]. This allows for a comparison between the returns to R&D when firms' R&D and innovation is wholly supported by private funding and the returns to R&D when firms' R&D and innovation is partially supported by public funding.

Three R&D variables are constructed using firms' survey responses. First, the survey asks firms if they invested in internal R&D during the survey period (i.e. 'creative activities to increase knowledge for the development of new and improved goods and services and processes'). The survey also asks firms if they invested in external R&D during the survey period (i.e. 'creative activities carried out by other firms and public or private research organisations'). Based upon firms' responses, a binary variable is constructed to represent *R&D-active firms*. The variable takes on the value of 1 if the firm invested in either internal or external R&D during the survey period and 0 if they did not. Within the estimation sample, 21.7 per cent of firms are R&D active (Table 1).

[8] UKIS 5 (2004 to 2006) and UKIS 8 (2010 to 2012) do not include indicators of whether innovating firms received public support for their R&D activity, whereas UKIS 4 (2002 to 2004), UKIS 6 (2006 to 2008) and UKIS 7 (2008 to 2010) do.

Second, two further variables are constructed using firms' responses relating to R&D financial support. Firms are asked whether they received public financial support for their innovation activities from UK local or regional authorities and UK central government during the survey period. In the analysis here, a firm is assumed to have received support for its R&D activities if it received finance from either UK regional or UK national authorities. Using this information, R&D-active firms are partitioned into R&D-active firms that received public support during the survey period and R&D-active firms that did not receive public support for innovation during the survey period. Based upon this information, two further binary 0/1 variables are constructed: an *R&D-active firms with UK support* variable which takes on the value of 1 if the firm was R&D-active during the survey period and received UK support and 0 if the firm was R&D-active during the survey period and did not receive UK support, and an *R&D-active firms without support* variable which takes on the value of 1 if the firm was R&D-active during the survey period and did not receive UK support and 0 if the firm was R&D-active during the survey period and received UK support. The descriptive statistics in Table 1 show that 0.2 per cent of firms engage in publicly-supported R&D, while 21.5 per cent of firms engage in wholly-privately-funded R&D.

#### *4.1.3 Control variables*

In considering the relationship between R&D and innovation of different types, and innovation of different types and performance – in the form of efficiency growth, turnover growth and employment growth – a range of other factors (or control variables) which may influence firm innovation and performance are included in the empirical analysis.

- Firm size – measured by employment – is included to reflect the scale of a firm's resources. Larger firms, for example, may have the R&D resources and capabilities to promote innovation and drive efficiency and growth. Employment is commonly used in innovation studies (Cohen 1995) and is thought to influence a firm's propensity to innovate (Laursen et al. 2013).

- Skill levels – or the strength of firms' human resources – impact upon innovation (Leiponen 2005; Freel 2005; Hewitt-Dundas 2006) and are measured using the proportion of a firm's employees that hold a degree or higher qualification in (a) science or engineering subjects and (b) other subjects. Firms with a more highly-skilled workforce may be better able to harness the performance benefits of innovation and better incorporate R&D into the innovation process.

- Exporting and innovative activity has been linked through both competition and learning effects (Love and Roper 2015). A binary (0/1) variable is included indicating whether or not the firm exported during the three-year period.

- Other innovation-related investments are included. Following Becker et al. (2016), several variables reflecting firms' innovation related investments are included in the model. Binary (0/1) variables indicating whether or not acquisition of advanced machinery and equipment took place, whether or not training for innovative activities took place, whether the acquisition of knowledge from other businesses or organisations took place – such as the purchase or licensing of patents and non-patented inventions and know-how – whether investment into the market introduction of innovations took place and whether or not engagement in design activities took place are all included. Investment into design has been shown to impact upon innovation outputs (Love et al. 2011), and it is expected that the additional innovation investment variables included here may also have a positive impact upon a firm's innovation outputs and performance.

- Any government assistance a firm receives enhances its resource base, and the additional internal resources are expected to impact positively upon the firm's innovation outputs (Roper and Hewitt-Dundas 2005; Link et al. 2005). Two binary (0/1) variables indicating whether or not the firm received public support for innovation from (a) the UK and (b) the EU are included.

- The extent of a firm's interactive knowledge search has been used extensively in studies of the determinants of innovation (for example, Laursen and Salter 2006; Becker et al. 2016) and is measured by a variable indicating the extent or breadth of the firm's innovation co-operation. The UKIS asks firms if they co-operated on any innovation activity. Firms are asked specifically about co-operation which may have taken place with seven particular co-operation partners (for example, competitors or other businesses within the industry, universities or other higher education institutions and government or public research institutes). Following Laursen and Salter (2006) and Becker et al. (2016), firms' binary (0/1) responses for each of the seven co-operation partners are summed to create a count indicator having a minimum value of 0 and a maximum value of 7. This count indicator is included in the model to represent firms' breadth of innovation co-operation.

To control for any temporal effects on the dependent variables, wave dummies are included in each model. In addition, to allow for sectoral heterogeneity – different levels of innovation intensities across industries (Levin et al. 1987; Cohen et al. 2000) – sector dummies at the two-digit level are also included.

### 4.2 Estimation method

The estimation method adopts a value-chain perspective suggesting that R&D may influence innovation in the short term, but that any performance effects – in the form of efficiency growth, turnover growth and employment growth – may take some time to emerge. The analysis draws on firms in the pooled UKIS dataset that responded to two consecutive waves of the Survey (more than 9,700 firms) so that a causal analysis of the links which exist between R&D, innovation of different types, and efficiency growth, turnover growth and employment growth can be undertaken. Reflecting the temporal structure of the data our modelling strategy involves two sequential stages: first, the link between each of the R&D variables and the different types of innovation, and subsequently the link between innovation and our three performance variables. Equation (1) represents the link between efficiency growth in the current period ($PRODG_t$), the lagged innovation indicators ($IPROD_{t-1}$, $IPROC_{t-}$

$_{1}$, $IORG_{t-1}$) and a set of controls ($CV_t$). Essentially similar models are used for turnover growth and employment growth. Equations (2), (3) and (4) relate innovation in the previous period to firms' involvement in R&D in the previous period which is wholly-privately-funded ($RDPRIV_{t-1}$) or partially-publicly-funded ($RDPUB_{t-1}$) and a set of lagged controls ($CV_{t-1}$).[9] In addition to the models which include publicly-supported and wholly-privately-funded R&D, similar models which relate innovation in the previous period to the single lagged R&D engagement variable are also estimated for each performance indicator.

$$PRODG_t = \beta_o + \beta_1 IPROD_{t-1} + \beta_2 IPROC_{t-1} + \beta_3 IORG_{t-1} + \beta_4 CV_t + \varepsilon_{It} \quad (1)$$

$$IPROD_{t-1} = \delta_{10} + \delta_{11} RDPRIV_{t-1} + \delta_{12} RDPUB_{t-1} + \delta_{13} CV_{t-1} + \varepsilon_{2t} \quad (2)$$

$$IPROC_{t-1} = \delta_{20} + \delta_{21} RDPRIV_{t-1} + \delta_{22} RDPUB_{t-1} + \delta_{23} CV_{t-1} + \varepsilon_{3t} \quad (3)$$

$$IORG_{t-1} = \delta_{30} + \delta_{31} RDPRIV_{t-1} + \delta_{32} RDPUB_{t-1} + \delta_{33} CV_{t-1} + \varepsilon_{4t} \quad (4)$$

We use the Conditional Mixed Process (CMP) module within Stata to allow efficient estimation of three probit models for each of the innovation indicators and simultaneously the OLS efficiency growth (or turnover growth or employment growth) model (Roodman 2011). Efficiency growth (or turnover growth or employment growth) in wave t are related to innovation variables (and their determinants) in survey wave t-1 to reflect the time taken for innovation to influence business performance. The inclusion of lagged innovation and R&D measures significantly reduces the number of observations available for use in the estimations.[10]

[9] Given the lagged structure in equations (2), (3) and (4), UKIS 6 is excluded from our regression analysis due to the lack of public-support-for-R&D information in UKIS 5. However, data from UKIS 6 is used to construct the lagged variables for UKIS 7.
[10] Efficiency outliers (where turnover per employee is greater than £1m per annum) and R&D-expenditure outliers (where R&D expenditure as a proportion of total turnover is greater than 20 per cent) are excluded from the analysis.

Initially, a series of baseline models (all firms) are estimated to examine the link which exists between R&D engagement (each of the three forms defined above), innovation of different types and efficiency growth, turnover growth or employment growth. Following this, a series of sub-sample models are estimated to examine how the link differs in large firms, SMEs, manufacturing and service firms, and high-technology/knowledge-intensive and low-technology/less knowledge-intensive firms.

# 5. RESULTS

The results from our econometric estimates examining the links which exist between R&D (engagement, publicly-supported and wholly-privately-funded), innovation of different types and efficiency growth, turnover growth and employment growth are given in Table 2. Sub-sample estimates are reported in Annex 4. Part A of each table reports estimates of equation (1) illustrating the results for the efficiency growth and/or turnover growth and/or employment growth models. These models include the endogenous lagged product/service innovation, process innovation and organisational innovation terms as well the control variables discussed in Section 4.13 above. Parts B, C and D of each table report estimates of equations (2), (3) and (4) and relate to the probability of a firm undertaking each of the three different types of innovation – product/service, process and organisational – in the period prior to the measurement of efficiency growth, turnover growth or employment growth. Determinants in these models include the three R&D variables – R&D engaged firms, R&D-active firms receiving public support and R&D-active firms not receiving public support – as well as the control variables discussed in Section 4.13 above[11].

## 5.1 Estimation results

The results in Table 2 represent the average effects across all firms in the estimation sample. In the efficiency growth model, lagged process and lagged organisational innovation have

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[11] Note we also include wave dummies as well as industry dummy variables in each of the four equations but do not report these.

significant, positive effects (at the 1 per cent level) on efficiency growth. These results provide evidence in support of Hypothesis 2a and against Hypothesis 3a. In contrast, lagged product innovation has a significant, negative effect (at the 1 per cent level) on efficiency growth, providing evidence against Hypothesis 1a. Similar results are found in the turnover growth model. Both lagged process and organisational innovation have significant, positive effects (at the 1 per cent and 5 per cent level, respectively) on turnover growth. These results provide evidence in support of Hypothesis 2b and evidence against Hypothesis H3b. Lagged product innovation has a significant, negative effect (at the 1 per cent level) on turnover growth, leading to the rejection to Hypothesis 1b. The contrasting effects of product and process innovation on both efficiency growth and turnover growth suggest that new product/service introductions may be associated with a short-term disruption effect when new innovative products/services are first introduced (Mohnen and Hall 2013)[12]. Alternatively, the negative efficiency growth effect which we observe may be explained by a product life-cycle effect. In this event, newly introduced products are initially produced inefficiently with negative efficiency consequences (Roper et al. 2008). In our analysis organisational innovation leads to an increase in both efficiency growth and turnover growth (Table 2A), although the effect on turnover growth is less significant. Given any firm's limited managerial capacity, this may reflect a concentration of managerial attention on organisational change with less focus on effective service or product delivery. As Hortinha, Lages, and Lages (2011, p. 37), comment: 'the trade-off between customer orientation and technology orientation is of the utmost importance … resources are limited, and firms must make choices in their allocation'.

In addition to efficiency growth and turnover growth, Table 2A shows the effect on employment growth following an increase in the probability that a firm will undertake either product/service, process or organisational innovation. An increase in the probability that a firm will carry out product/service innovation leads to a significant, positive effect on employment growth, and this exacerbates the negative turnover-growth effect on efficiency

[12] Such short-term disruption effects have been noted in other studies of product change, see for example, Bourke and Roper (2017).

growth.[13] There is an insignificant effect on employment growth following an increase in process innovation, suggesting that the positive efficiency-growth effect is driven by the increase in turnover growth. As the probability of organisational innovation increases, there is a significant (at the 1 per cent level), negative effect on employment growth. As is the case for product/service innovation, employment changes reinforce the effect on efficiency growth; higher turnover growth and lower employment growth contribute to higher efficiency growth when organisational innovation increases. In summary, our results suggest that both significant turnover growth and employment growth effects arise following an increase in product and organisational innovation, whereas significant turnover growth effects occur when the probability of process innovation increases – employment changes are insignificant.

The three innovation models in the efficiency growth, turnover-growth and employment growth CMP estimations (Table 2, parts B, C and D) suggest that R&D engagement (and whether publicly-supported or wholly-privately supported) has the anticipated significant and positive effects (at the 1 per cent level) on the probability of innovation – regardless of innovation type. The marginal effects reported in Tables 3-5 suggest that R&D engagement leads to a 10.0-10.5 percentage point increase in the probability of product/service innovation compared with a 5.1-5.2 percentage point increase in the probability of process innovation and an 8.1-9.0 percentage point increase in the probability of organisational innovation. Notably, R&D engagement has its largest positive impact upon the probability of product/service innovation and its smallest positive impact upon the probability of process innovation. The impact on the probability of organisational innovation lies between the two.

When R&D-active firms are separated into those that receive public support and those that do not, as in equations (2)-(4) above, the effect of R&D on the probability of all three types

[13] This may reflect the personnel needed to introduce new innovations to market but, where firms receive public support, may also reflect administrative requirements imposed on firms related to job creation.

of innovation is positive and significant (at the 1 per cent level) for both groups in all three performance models (Table 2). The marginal effects (Tables 3-5) suggest that the impact of R&D on the probability of product/service innovation in publicly-supported firms is greater than that in unsupported firms (15 percentage points higher compared with 10 percentage points higher, respectively). The effect of R&D on the probability of process innovation is also greater when firms receive public support for their R&D, although the difference between supported and unsupported firms is not so pronounced – the probability of process innovation increases by some 7 percentage points when firms receive support compared with some 5 percentage points when they do not (Figure 1). Supported R&D also has a larger, positive effect upon the probability of organisational innovation than unsupported R&D, but as with process innovation, the difference is not as pronounced as it is with product innovation (R&D with support increases the probability of organisational innovation by some 12 percentage points compared with a 9 percentage point increase for unsupported R&D).

An essentially similar story emerges from the marginal effects for the turnover growth and employment growth models (Tables 4 and 5). These findings suggest that receipt of public support for R&D makes more difference to the probability of undertaking product/service innovation rather than process or organisational innovation (Figure 1). The results here lead us to reject Hypothesis 4a that publicly-funded R&D has a similar effect on product/service innovation as wholly privately-funded R&D. In addition, they suggest that we cannot reject Hypotheses 4b and 4c which state that publicly-funded R&D has similar effects on process innovation and organisational innovation as wholly privately-funded R&D.

In summary, R&D engagement may have an ambiguous effect on performance through its impacts on different types of innovation: it increases the probability of process innovation and organisational innovation contributing positively towards efficiency growth – increasing turnover growth and reducing employment growth (in the case of organisational innovation), and it increases the probability of product/service innovation, contributing negatively towards efficiency growth in the short term (reducing turnover growth and increasing employment growth). In addition, publicly-supported R&D leads to a greater increase in the probability of product/service innovation than wholly-private R&D, whereas public support for R&D has relatively little additional positive impact upon the probability of process innovation and organisational innovation (Figure 1).

## 5.2 Robustness test – R&D intensity

As a robustness test, we explore the influence of R&D intensity (measured as R&D expenditure as a percentage of sales) rather than our earlier R&D dummy variable on each type of innovation. Some sub-sample differences are evident but our key results prove consistent across different time periods and R&D indicators.

In addition to an R&D engagement indicator, the UK Innovation Survey provides an estimate of firms' R&D expenditure. Using firms' sales turnover at the end of the period, an R&D 'intensity' variable is created (defined as R&D expenditure as a percentage of sales turnover at the end of the survey period). As with the R&D engagement indicator, this R&D intensity variable is partitioned into two variables – R&D intensity for those firms receiving public support and R&D intensity for those firms not receiving public support.

The relationship between the R&D intensity indicators and the three different innovations is again examined using the CMP module within Stata (see Section 4.2 above). On average, the impact of R&D intensity on the probability of a firm carrying out product/service innovation is significant, positive and similar across publicly supported and unsupported firms, whereas the effect is significant and positive and larger for supported firms when the binary indicator for R&D engagement is considered (Tables 2 and 3).

On average, the impact of R&D intensity on the probability of a firm carrying out process innovation is insignificant for those firms receiving and those not receiving public support – differing from the results obtained using the R&D engagement variables (Tables 2 and 3). Across all firms, the average impact of R&D intensity on the probability of a firm carrying out organisational innovation is also insignificant for firms receiving public support. The effect is positive and significant for those firms not receiving support in the efficiency-growth and turnover-growth models. However, the effect is insignificant for firms not receiving support in the employment growth model.

In summary, compared to the R&D engagement results (Table 2 and Table A4.2), R&D intensity – supported and unsupported – has a similar impact upon the probability of product/service innovation, whereas effects on the probability of process and organisational innovation differ to those in the R&D engagement models.

We report two robustness tests related to the two key questions we address. First, we explore whether the effects we observe between innovation and the three performance indicators across subsequent survey waves are also consistent when we compare impacts across two survey waves, i.e. over a 4-year rather than 2-year time lag.

### 5.3 Longer-term effects

To test the continuity of our results we explore whether the effects we observe between innovation and the three performance indicators across subsequent survey waves are also consistent when we compare impacts across two survey waves, i.e. over a 4-year rather than 2-year time lag. Here, sample sizes are smaller and results generally less robust due to the requirement for firms in our unbalanced panel to have responded to three consecutive survey waves.

To investigate whether the effects of the different innovations upon efficiency growth, turnover growth and employment growth change over time, the models are re-estimated with a two-wave (rather than a one-wave) time lag for the different innovations and their determinants. The sign and significance of the different innovation effects on the performance measures for a 2-year lag and a 4-year lag are given in Table 6.

The significant, negative effect on productivity growth following an increase in the probability of product/service innovation is overturned after four years, with the effect becoming positive, although statistically insignificant in the longer term. The effect on turnover growth is also positive, but insignificant, in the longer term, compared with negative and strongly significant in the shorter term. The positive employment-growth effect persists after four years, although the significance level is lower. The effect of an increase in process innovation on productivity growth is reversed after four years becoming negative but insignificant. The effect of an increase in the probability of process innovation on turnover growth remains positive but becomes insignificant in the longer term. The weaker effect of process innovation on turnover growth combined with the stronger, positive effect on employment growth leads to a fall in productivity growth. Following an increase in organisational innovation, the significant, positive effect on productivity growth after two years remains positive after four years but becomes insignificant. The effect on turnover growth is reversed becoming negative and insignificant, and the strongly significant, negative effect on employment growth is still present after four years.

In summary,

- The significant, negative effects on efficiency growth and turnover growth from product/service innovation are reversed but become weaker in the longer term.
- The significant, positive effects on efficiency growth and turnover growth from process innovation are reversed in the longer term for efficiency growth and are far weaker in the case of turnover growth.
- The significant, positive effects on efficiency growth and turnover growth from organisational innovation are reversed in the longer term for turnover growth and are far weaker in the case of efficiency growth.
- The short-term effects on employment growth persist in the longer term.

## 6. DISCUSSION AND CONCLUSIONS

Using data from consecutive observations on the same firms in the UK Innovation Survey we examine the links between publicly-supported and wholly-privately-funded R&D and innovation and its subsequent links to growth and efficiency. Two groups of results emerge. First, we find a less straightforward relationship between innovation and firm growth and efficiency than we anticipated. Moreover, the effects of 'innovation' on firm performance two years later sometimes differ between growth and efficiency. The key linkages are:

- Product or service innovation has a positive relationship to employment growth but a negative effect on sales growth and efficiency growth after two years. These effects are short-term becoming weakly positive four years beyond the date at which innovation is measured (Table 6). The positive employment growth effect is consistent with earlier studies (Lentz and Mortensen 2008; Ganatakis and Love 2012; Cucculelli and Ermini 2013). The negative effect on efficiency is also consistent with some other evidence which find either negative or insignificant efficiency effects (Roper et al. 2008; Crowley and McCann 2015). It has been suggested that this type of negative efficiency effect may reflect low efficiency after the introduction of new products or services, i.e. a product/service life-cycle effect. Another possible explanation relates to the timing of employment and sales increases following the introduction of new innovations. Coad et al. (2017), for example, suggests that employment growth often precedes that in sales as firms grow. It is interesting to note, however, that process innovation and organisational innovation lead to both efficiency and sales growth benefits in the shorter term, with these effects all but disappearing after four years.

- Organisational innovation has a positive sales-growth effect, a negative employment-growth effect and a net-positive efficiency effect (Table 6). These effects persist for efficiency growth and employment growth but are far weaker four years after innovation is measured. The positive efficiency effect runs contrary to other limited evidence which has suggested a negative relationship with efficiency (Crowley and McCann 2015). Instead, our findings are more suggestive of recent research suggesting positive linkages between high performance work practices, work organisation and efficiency (Awano et al. 2017).

- Process innovation has a positive effect on both efficiency growth and turnover growth in the short term. This result reflects the findings of recent trans-national studies (Morris 2018; Crowley and McCann 2018). Employment growth effects are insignificant initially but positive and significant four years after innovation is measured.

The differential effects of each type of innovation on growth and efficiency inevitably reflect the diverse nature of the innovation itself and the strategic and market requirements for achieving either scale or operational efficiency (Chandler et al. 2009; Baum, Locke et al. 2001; Delmar et al. 2003).

In strategic terms, our results suggest the importance for firms of having a clear view of what they are trying to achieve through their innovation investments: in the short term, firms prioritising jobs growth should focus on product innovation; those seeking efficiency improvement should focus on organisational or process change. Firms also need to be aware that before generating longer-term performance benefits, innovation can cause short-term disruption effects leading to a fall in both growth and efficiency. This type of short-term disruption effect has been noted elsewhere in the adoption of quality improvement mechanisms (Bourke and Roper 2017) and aspects of process innovation (Bourke and Roper 2016).

Our results suggest the strongly dynamic nature of the relationship between innovation and aspects of business performance. Short-term disruption effects are significant with the potential for longer-term gains in terms of growth and productivity, four or more years after innovation is measured[14]. This suggests the necessity of a medium to long-term perspective in any evaluation of innovation policy as measuring effects after two years would provide a misleading picture of potential longer-term gains.

Our second group of results relate to the impact of R&D on the probability of innovation and the differential impacts of wholly-privately-funded and publicly-supported R&D. Here, the limitations of the UK Innovation Survey mean that we do not know the scale of any public support received by firms only whether firms actually received public support, i.e. a binary

[14] Here, the measured impacts of innovation after four years are largely insignificant due perhaps to the relatively small sample of firms for which data on both innovation and public support is available. In other analyses following a similar modelling approach but based on a less restricted and larger data set, effects often prove positive and significant four years after innovation is measured.

measure. Our focal question therefore relates to the extensive margin: How does the probability of innovation change when firms are engaged in either wholly-privately-funded or publicly-supported R&D? The results clearly emphasise the importance of R&D to all types of innovation (Figure 1). There is, however, no significant difference between the effects of wholly-privately-funded or publicly-supported R&D on process or organisational innovation. In other words, firms receiving public R&D support are no more likely to innovate in terms of processes or organisational change than those paying for all of their own R&D costs. Additionality is stronger for public support for product/service innovation, and here there is a clear and significant difference between publicly and wholly-privately funded R&D. This effect is largely attributable to the effect on manufacturing firms (Figure 2).

Results differ somewhat when we consider R&D intensity with and without public support rather than the binary variables. Here, we find no significant difference between publicly-supported and wholly-privately supported R&D for product/service innovation and weaker and often insignificant effects for process and organisational change. The implication is perhaps that it is the presence rather than the scale of public support for R&D and innovation that is more important at the extensive margin, i.e. in increasing the proportion of innovating firms. Other factors aside from R&D also prove important in shaping firms' ability to innovate. For product/service innovation, collaboration, exporting and a range of intangible investments including design and training also prove significant across all sizes and sectors (Table A4.1). For process and organisational innovation exporting and design investment are less important, but training and capital investment remain significant.

Two important caveats apply to our results. First, at this point we are unable to allow for firms' use of R&D tax credits. This is potentially significant due both the scale of the tax incentive but also because of the sharp growth in recent years – the number of claims grew by 22 per cent between 2014-15 and 2015-16 with similar growth in previous years (HMRC 2018, p. 6). The second caveat relates to the limitations of the UK Innovation Survey itself and the lack of any quantitative data on the value of the innovation and R&D support which firms receive. Instead, we have a simple binary indicator reflecting whether or not firms received public support. This limits our ability to develop robust quantifications of either input or output additionality.

## Table 1: Sample descriptives

| Variable | No. Obs. | Mean | Std. Dev. |
|---|---|---|---|
| | | | |
| **Efficiency growth (%)** | 9,220 | 0.023 | 0.678 |
| **Turnover growth (%)** | 9,302 | 0.052 | 0.617 |
| **Employment growth (%)** | 9,342 | 0.025 | 0.476 |
| **Product/service innovator (0/1)** | 9,712 | 0.228 | 0.420 |
| **Process innovator (0/1)** | 9,723 | 0.129 | 0.335 |
| **Organisational innovator (0/1)** | 9,729 | 0.414 | 0.493 |
| **R&D firm (0/1)** | 9,729 | 0.217 | 0.412 |
| **R&D firm receiving public support (0/1)** | 9,729 | 0.002 | 0.048 |
| **R&D firm with not receiving support (0/1)** | 9,729 | 0.215 | 0.411 |
| **Employment (log)** | 9,729 | 3.502 | 1.070 |
| **Science graduates (%)** | 8,090 | 5.918 | 14.740 |
| **Other graduates (%)** | 8,622 | 10.736 | 21.292 |
| **Exporting firm (0/1)** | 9,729 | 0.311 | 0.463 |
| **Innovation partners (0 to 7)** | 9,729 | 0.496 | 1.266 |
| **Innovation partners (squared) (0 to 49)** | 9,729 | 1.849 | 6.616 |
| **UK innovation support (0/1)** | 9,729 | 0.004 | 0.059 |
| **EU innovation support (0/1)** | 9,729 | 0.001 | 0.028 |
| **Design-engaged firm (0/1)** | 9,698 | 0.148 | 0.355 |
| **Training-engaged firm (0/1)** | 9,723 | 0.268 | 0.443 |
| **Acquisition of existing knowledge (0/1)** | 9,729 | 0.086 | 0.280 |
| **Market introduction of innovation (0/1)** | 9,729 | 0.305 | 0.460 |
| **Acquisition of advanced machinery (0/1)** | 9,729 | 0.530 | 0.499 |

**Source:** UK Innovation Surveys 4 to 8

## Table 2: Modelling the link between R&D engagement, innovation and performance: all firms

| | Efficiency growth | | Turnover growth | | Employment growth | |
|---|---|---|---|---|---|---|
| | All R&D | Publicly supported and other R&D | All R&D | Publicly supported and other R&D | All R&D | Publicly supported and other R&D |
| **A. Efficiency growth, turnover growth and employment growth models** | | | | | | |
| Product/service innovator (lag) | -0.553*** | -0.552*** | -0.488*** | -0.490*** | 0.292** | 0.280** |
| | (0.105) | (0.106) | (0.133) | (0.131) | (0.131) | (0.121) |
| Process innovator (lag) | 0.340*** | 0.344*** | 0.348*** | 0.353*** | 0.230 | 0.247* |
| | (0.103) | (0.103) | (0.081) | (0.080) | (0.177) | (0.149) |
| Organisational innovator (lag) | 0.435*** | 0.434*** | 0.237** | 0.238** | -0.513*** | -0.511*** |
| | (0.107) | (0.107) | (0.097) | (0.096) | (0.052) | (0.053) |
| Employment (log) | -0.087*** | -0.087*** | 0.072*** | 0.072*** | 0.180*** | 0.180*** |
| | (0.016) | (0.016) | (0.012) | (0.011) | (0.018) | (0.018) |
| Science graduates (%) | -0.000 | -0.000 | 0.001 | 0.001 | 0.001 | 0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Other graduates (%) | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.050* | 0.050* | 0.040* | 0.040* | -0.016 | -0.016 |
| | (0.026) | (0.026) | (0.023) | (0.023) | (0.019) | (0.019) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.471*** | | 0.454*** | | 0.487*** | |
| | (0.055) | | (0.055) | | (0.060) | |
| R&D with UK support (0/1) | | 0.686*** | | 0.689*** | | 0.728*** |
| | | (0.104) | | (0.106) | | (0.108) |
| R&D without UK support (0/1) | | 0.456*** | | 0.435*** | | 0.469*** |
| | | (0.057) | | (0.056) | | (0.061) |
| Employment (log) | -0.046*** | -0.045** | 0.040** | 0.041** | -0.075** | -0.071* |
| | (0.017) | (0.017) | (0.020) | (0.019) | (0.037) | (0.036) |
| Science graduates (%) | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Other graduates (%) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002* | 0.002* |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.165*** | 0.164*** | 0.141*** | 0.140*** | 0.140** | 0.139** |
| | (0.053) | (0.053) | (0.051) | (0.051) | (0.056) | (0.056) |
| Innovation partners (0 to 7) | 0.489*** | 0.494*** | 0.483*** | 0.487*** | 0.499*** | 0.504*** |
| | (0.043) | (0.043) | (0.045) | (0.046) | (0.046) | (0.046) |
| Innovation partners (squared) (0 to 49) | -0.065*** | -0.065*** | -0.064*** | -0.064*** | -0.065*** | -0.066*** |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.008) | (0.008) |
| UK innovation support (0/1) | 0.249*** | | 0.254*** | | 0.247*** | |
| | (0.074) | | (0.075) | | (0.075) | |
| EU innovation support (0/1) | -0.086 | 0.030 | -0.033 | 0.080 | -0.015 | 0.088 |
| | (0.207) | (0.221) | (0.211) | (0.221) | (0.221) | (0.237) |
| Design-engaged firm (0/1) | 0.251*** | 0.252*** | 0.246*** | 0.247*** | 0.242*** | 0.243*** |
| | (0.063) | (0.063) | (0.061) | (0.061) | (0.068) | (0.068) |
| Training-engaged firm (0/1) | 0.236*** | 0.239*** | 0.197*** | 0.201*** | 0.231*** | 0.234*** |
| | (0.056) | (0.056) | (0.055) | (0.054) | (0.061) | (0.061) |
| Acquisition of existing knowledge (0/1) | 0.037 | 0.039 | 0.044 | 0.047 | 0.022 | 0.023 |
| | (0.071) | (0.071) | (0.069) | (0.069) | (0.077) | (0.077) |
| Market introduction of innovation (0/1) | 0.655*** | 0.656*** | 0.629*** | 0.629*** | 0.709*** | 0.709*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.058) | (0.058) | (0.058) | (0.058) | (0.057) | (0.057) |
| Acquisition of advanced machinery (0/1) | 0.336*** | 0.342*** | 0.320*** | 0.326*** | 0.329*** | 0.333*** |
| | (0.052) | (0.052) | (0.051) | (0.051) | (0.059) | (0.058) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.286*** | | 0.280*** | | 0.277*** | |
| | (0.062) | | (0.061) | | (0.060) | |
| R&D with UK support (0/1) | | 0.376*** | | 0.375*** | | 0.342*** |
| | | (0.098) | | (0.097) | | (0.097) |
| R&D without UK support (0/1) | | 0.291*** | | 0.284*** | | 0.283*** |
| | | (0.063) | | (0.062) | | (0.061) |
| Employment (log) | 0.064*** | 0.064*** | 0.027 | 0.027 | -0.047 | -0.052 |
| | (0.021) | (0.021) | (0.018) | (0.018) | (0.058) | (0.050) |
| Science graduates (%) | 0.002 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Other graduates (%) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Exporting firm (0/1) | -0.059 | -0.055 | -0.058 | -0.053 | -0.033 | -0.026 |
| | (0.060) | (0.059) | (0.059) | (0.059) | (0.061) | (0.060) |
| Innovation partners (0 to 7) | 0.357*** | 0.365*** | 0.350*** | 0.358*** | 0.325*** | 0.332*** |
| | (0.043) | (0.043) | (0.042) | (0.042) | (0.045) | (0.044) |
| Innovation partners (squared) (0 to 49) | -0.043*** | -0.043*** | -0.042*** | -0.042*** | -0.038*** | -0.038*** |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| UK innovation support (0/1) | 0.312*** | | 0.314*** | | 0.300*** | |
| | (0.078) | | (0.077) | | (0.082) | |
| EU innovation support (0/1) | 0.022 | 0.235 | 0.038 | 0.249 | 0.008 | 0.223 |
| | (0.193) | (0.198) | (0.197) | (0.203) | (0.187) | (0.187) |
| Design-engaged firm (0/1) | 0.166** | 0.171** | 0.159** | 0.165** | 0.145** | 0.149** |
| | (0.067) | (0.067) | (0.067) | (0.067) | (0.071) | (0.068) |
| Training-engaged firm (0/1) | 0.269*** | 0.272*** | 0.287*** | 0.290*** | 0.301*** | 0.305*** |
| | (0.059) | (0.059) | (0.057) | (0.057) | (0.057) | (0.056) |
| Acquisition of existing knowledge (0/1) | 0.018 | 0.019 | 0.026 | 0.028 | 0.050 | 0.053 |
| | (0.074) | (0.074) | (0.074) | (0.074) | (0.070) | (0.070) |
| Market introduction of innovation (0/1) | 0.232*** | 0.235*** | 0.255*** | 0.258*** | 0.256*** | 0.260*** |
| | (0.061) | (0.061) | (0.062) | (0.061) | (0.062) | (0.062) |
| Acquisition of advanced machinery (0/1) | 0.699*** | 0.705*** | 0.706*** | 0.712*** | 0.734*** | 0.740*** |
| | (0.053) | (0.053) | (0.053) | (0.053) | (0.053) | (0.052) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.323*** | | 0.333*** | | 0.294*** | |
| | (0.057) | | (0.059) | | (0.054) | |
| R&D with UK support (0/1) | | 0.421*** | | 0.432*** | | 0.426*** |
| | | (0.102) | | (0.107) | | (0.102) |
| R&D without UK support (0/1) | | 0.322*** | | 0.332*** | | 0.290*** |
| | | (0.059) | | (0.061) | | (0.055) |
| Employment (log) | 0.141*** | 0.142*** | 0.082*** | 0.083*** | 0.266*** | 0.265*** |
| | (0.020) | (0.020) | (0.016) | (0.016) | (0.031) | (0.031) |
| Science graduates (%) | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Other graduates (%) | 0.003** | 0.003** | 0.003** | 0.003** | 0.003** | 0.003** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.064 | 0.064 | 0.068 | 0.068 | 0.051 | 0.050 |
| | (0.051) | (0.051) | (0.052) | (0.052) | (0.047) | (0.047) |
| Innovation partners (0 to 7) | 0.288*** | 0.295*** | 0.287*** | 0.294*** | 0.290*** | 0.296*** |
| | (0.044) | (0.044) | (0.045) | (0.045) | (0.040) | (0.040) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Innovation partners (squared) (0 to 49) | -0.035*** | -0.036*** | -0.035*** | -0.035*** | -0.037*** | -0.037*** |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.007) | (0.007) |
| UK innovation support (0/1) | 0.219*** | | 0.228*** | | 0.241*** | |
| | (0.082) | | (0.085) | | (0.076) | |
| EU innovation support (0/1) | 0.158 | 0.309 | 0.155 | 0.313 | 0.205 | 0.360* |
| | (0.210) | (0.209) | (0.220) | (0.218) | (0.208) | (0.198) |
| Design-engaged firm (0/1) | 0.029 | 0.033 | 0.044 | 0.048 | 0.079 | 0.083 |
| | (0.067) | (0.067) | (0.070) | (0.070) | (0.060) | (0.060) |
| Training-engaged firm (0/1) | 0.158*** | 0.160*** | 0.181*** | 0.183*** | 0.139*** | 0.144*** |
| | (0.055) | (0.055) | (0.057) | (0.056) | (0.053) | (0.052) |
| Acquisition of existing knowledge (0/1) | 0.156* | 0.157* | 0.170** | 0.171** | 0.165** | 0.167** |
| | (0.083) | (0.083) | (0.084) | (0.084) | (0.073) | (0.073) |
| Market introduction of innovation (0/1) | 0.670*** | 0.672*** | 0.681*** | 0.682*** | 0.599*** | 0.598*** |
| | (0.058) | (0.058) | (0.058) | (0.058) | (0.054) | (0.053) |
| Acquisition of advanced machinery (0/1) | 0.566*** | 0.570*** | 0.589*** | 0.593*** | 0.498*** | 0.505*** |
| | (0.051) | (0.051) | (0.049) | (0.049) | (0.054) | (0.053) |
| | | | | | | |
| Number of observations | 9729.000 | 9729.000 | 9732.000 | 9732.000 | 9732.000 | 9732.000 |
| Chi-squared | 4482.423 | 4509.763 | 4619.832 | 4644.173 | 5088.806 | 5081.478 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| bic | 3.89e+05 | 3.90e+05 | 3.77e+05 | 3.77e+05 | 3.32e+05 | 3.33e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table 3: The effect of R&D engagement on the probability of innovation – efficiency growth models (marginal effects)

| | Product/service innovation | | | Process innovation | | | Organisational innovation | | |
|---|---|---|---|---|---|---|---|---|---|
| | R&D | R&D with support | R&D without support | R&D | R&D with support | R&D without support | R&D | R&D with support | R&D without support |
| All firms (N=7622) | 0.103*** | 0.150*** | 0.100*** | 0.052*** | 0.068*** | 0.053*** | 0.088*** | 0.115*** | 0.088*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.03) | (0.02) |
| Manufacturing firms (N=2263) | 0.176*** | 0.285*** | 0.163*** | 0.048 | 0.111*** | 0.041* | 0.125*** | 0.142*** | 0.124*** |
| | (0.06) | (0.03) | (0.02) | (0.30) | (0.03) | (0.02) | (0.02) | (0.04) | (0.02) |
| Service firms (N=5359) | 0.079*** | 0.089*** | 0.079*** | 0.051*** | 0.046** | 0.054*** | 0.077*** | 0.111** | 0.076*** |
| | (0.01) | (0.03) | (0.02) | (0.01) | (0.02) | (0.01) | (0.02) | (0.05) | (0.02) |
| SMEs (N=5493) | 0.101*** | 0.147*** | 0.097*** | 0.054*** | 0.064*** | 0.055*** | 0.095*** | 0.119*** | 0.095*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.03) | (0.02) |
| Larger firms (N=2129) | 0.115** | 0.165** | 0.114** | 0.078 | 0.196 | 0.071 | 0.03 | 0.05 | 0.03 |
| | (0.06) | (0.07) | (0.05) | (0.54) | (0.86) | (0.32) | (0.03) | (0.06) | (0.03) |
| High-technology/knowledge-intensive firms (N=3013) | 0.122*** | 0.183*** | 0.118*** | 0.041* | 0.05 | 0.043** | 0.056** | 0.083** | 0.057** |
| | (0.02) | (0.03) | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) | (0.04) | (0.02) |
| Low-technology/less knowledge-intensive firms (N=4609) | 0.094*** | 0.135*** | 0.091*** | 0.057*** | 0.077*** | 0.057*** | 0.108*** | 0.139*** | 0.106*** |
| | (0.02) | (0.03) | (0.02) | (0.01) | (0.02) | (0.01) | (0.02) | (0.04) | (0.02) |

**Notes:** Marginal effects are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table 4: The effect of R&D engagement on the probability of innovation – turnover growth models (marginal effects)

| | Product/service innovation | | | Process innovation | | | Organisational innovation | | |
|---|---|---|---|---|---|---|---|---|---|
| | R&D | R&D with support | R&D without support | R&D | R&D with support | R&D without support | R&D | R&D with support | R&D without support |
| All firms (N=7622) | 0.100*** | 0.152*** | 0.096*** | 0.051*** | 0.068*** | 0.052*** | 0.090*** | 0.117*** | 0.090*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.03) | (0.02) |
| Manufacturing firms (N=2263) | 0.174 | 0.277*** | 0.160*** | 0.046** | 0.103*** | 0.043* | 0.128*** | 0.165*** | 0.135*** |
| | (0.15) | (0.03) | (0.02) | (0.02) | (0.03) | (0.02) | (0.01) | (0.05) | (0.03) |
| Service firms (N=5359) | 0.076*** | 0.092*** | 0.076*** | 0.052*** | 0.051** | 0.055*** | 0.078*** | 0.121** | 0.077*** |
| | (0.01) | (0.03) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.05) | (0.02) |
| SMEs (N=5493) | 0.099*** | 0.152*** | 0.095*** | 0.053*** | 0.064*** | 0.055*** | 0.094*** | 0.119*** | 0.094*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.03) | (0.02) |
| Larger firms (N=2129) | 0.132*** | 0.168*** | 0.131*** | 0.069*** | 0.187*** | 0.062*** | 0.013 | 0.026 | 0.012 |
| | (0.04) | (0.04) | (0.03) | (0.00) | (0.05) | (0.02) | (0.03) | (0.05) | (0.03) |
| High-technology/knowledge-intensive firms (N=3013) | 0.125*** | 0.196*** | 0.119*** | 0.037* | 0.046 | 0.040* | 0.056** | 0.090** | 0.057** |
| | (0.02) | (0.03) | (0.02) | (0.02) | (0.03) | (0.02) | (0.03) | (0.04) | (0.03) |
| Low-technology/less knowledge-intensive firms (N=4609) | 0.093*** | 0.137*** | 0.089*** | 0.058*** | 0.078*** | 0.058*** | 0.110*** | 0.144*** | 0.109*** |
| | (0.01) | (0.03) | (0.02) | (0.01) | (0.02) | (0.01) | (0.02) | (0.04) | (0.02) |

**Notes:** Marginal effects are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table 5: The effect of R&D engagement on the probability of innovation – employment growth models (marginal effects)

| | Product/service innovation | | | Process innovation | | | Organisational innovation | | |
|---|---|---|---|---|---|---|---|---|---|
| | **R&D** | **R&D with support** | **R&D without support** | **R&D** | **R&D with support** | **R&D without support** | **R&D** | **R&D with support** | **R&D without support** |
| **All firms (N=7622)** | 0.105*** | 0.157*** | 0.101*** | 0.051*** | 0.063*** | 0.052*** | 0.081*** | 0.117*** | 0.080*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.02) | (0.03) | (0.02) |
| **Manufacturing firms (N=2263)** | 0.181*** | 0.271*** | 0.157*** | 0.055** | 0.113*** | 0.047** | 0.146*** | 0.166*** | 0.141*** |
| | (0.02) | (0.03) | (0.02) | (0.02) | (0.04) | (0.02) | (0.02) | (0.03) | (0.02) |
| **Service firms (N=5359)** | 0.083*** | 0.103*** | 0.082*** | 0.050*** | 0.049** | 0.053*** | 0.064*** | 0.111** | 0.061*** |
| | (0.02) | (0.03) | (0.02) | (0.01) | (0.02) | (0.01) | (0.02) | (0.04) | (0.02) |
| **SMEs (N=5493)** | 0.103*** | 0.154*** | 0.099*** | 0.051*** | 0.056*** | 0.053*** | 0.093*** | 0.123*** | 0.092*** |
| | (0.01) | (0.02) | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) | (0.03) | (0.02) |
| **Larger firms (N=2129)** | 0.119*** | 0.157 | 0.117 | 0.065*** | 0.185*** | 0.058** | 0.009 | 0.021 | 0.009 |
| | (0.05) | (0.21) | (0.16) | (0.02) | (0.07) | (0.03) | (0.02) | (0.04) | (0.02) |
| **High-technology/knowledge-intensive firms (N=3013)** | 0.126*** | 0.197*** | 0.120*** | 0.046** | 0.05 | 0.049** | 0.045** | 0.076** | 0.046** |
| | (0.02) | (0.03) | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) | (0.04) | (0.02) |
| **Low-technology/less knowledge-intensive firms (N=4609)** | 0.094*** | 0.141*** | 0.091*** | 0.055*** | 0.068*** | 0.055*** | 0.101*** | 0.138*** | 0.099*** |
| | (0.02) | (0.03) | (0.02) | (0.01) | (0.02) | (0.01) | (0.02) | (0.04) | (0.02) |

**Notes:** Marginal effects are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

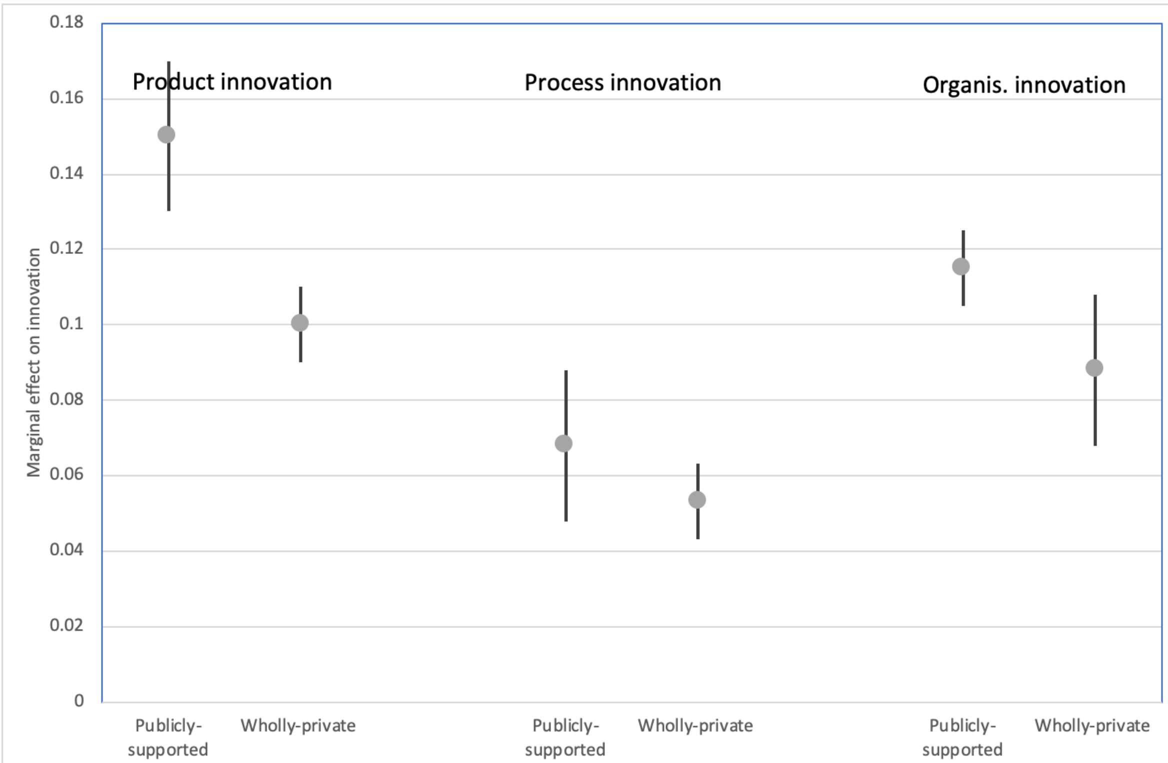
**Table 6: Direction of change in efficiency growth, turnover growth and employment growth following an increase in the probability to innovate – all firms**

| | Innovation type | Efficiency growth | Turnover growth | Employment growth |
|---|---|---|---|---|
| **One wave lag** | | | | |
| | **Product** | - *** | - *** | + ** |
| | **Process** | + *** | + *** | + |
| | **Organisational** | + *** | + ** | - *** |
| | | | | |
| **Two wave lag** | | | | |
| | **Product** | + | + | + * |
| | **Process** | - | + | + *** |
| | **Organisational** | + | - | - *** |

**Notes:** * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

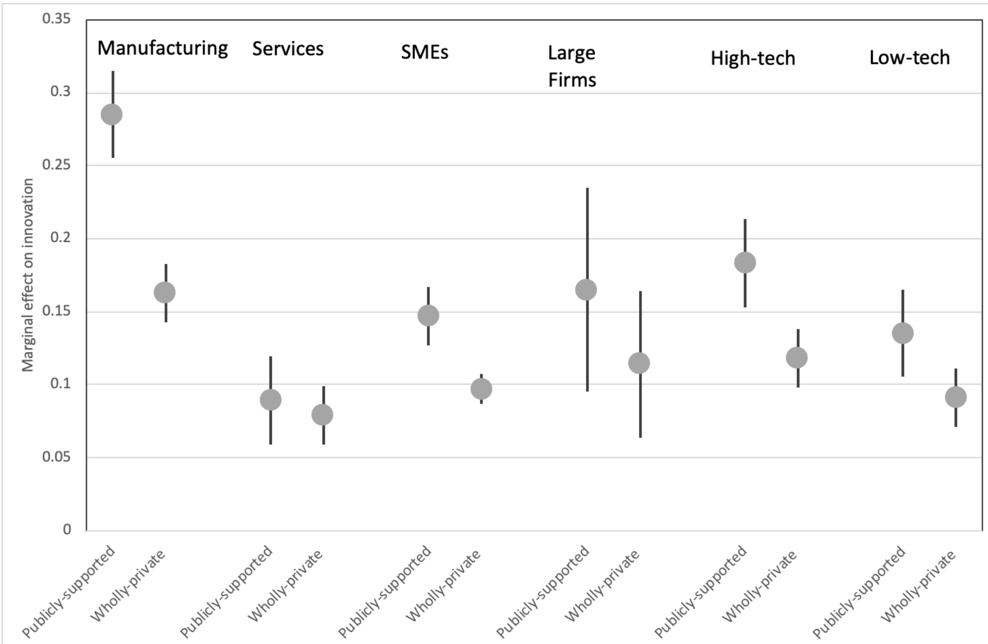
**Figure 1: Marginal effects of R&D funding on innovation: all firms**



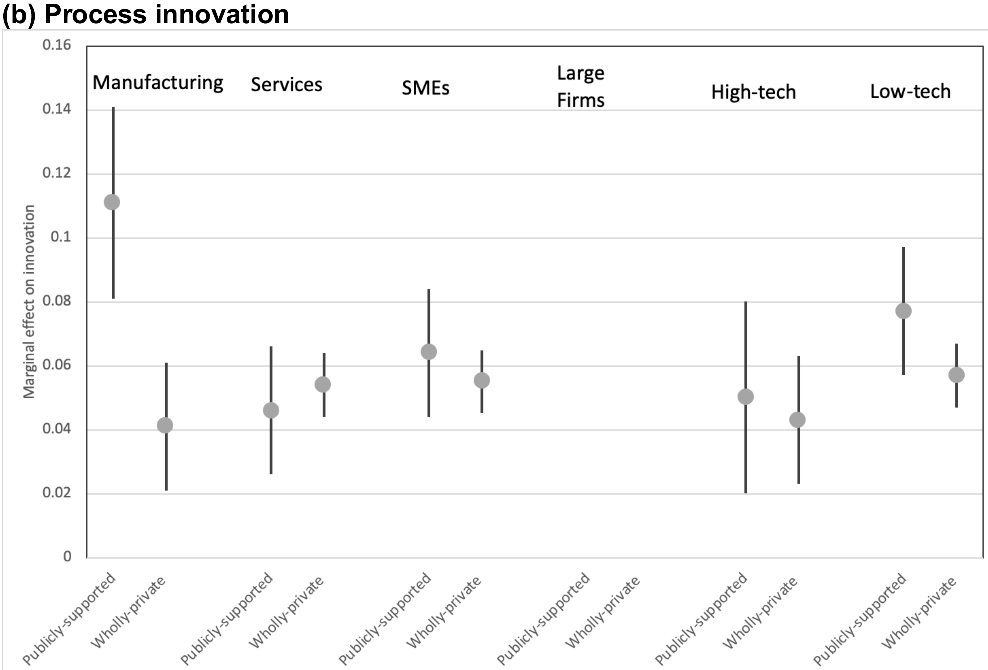

**Source:** UK Innovation Surveys 4 to 8. See Table 3.

**Figure 2: Impact of R&D on product and process innovation: by firm sub-group**

**(a) Product and service innovation**




**(b) Process innovation**




**Source:** UK Innovation Surveys 4 to 8. See Table 3. Note insignificant effects dropped for large firms from (b).

## Annex 1: Variable definitions

| Variable | Definition |
|---|---|
| | |
| **Efficiency growth (%)** | Efficiency (sales turnover per employee) growth between 2 consecutive waves of data (end of period) |
| **Turnover growth (%)** | Sales turnover growth between 2 consecutive waves of data (end of period) |
| **Employment growth (%)** | Employment growth between 2 consecutive waves of data (end of period) |
| **Product/service innovator (0/1)** | Firms introducing a new or improved product or service |
| **Process innovator (0/1)** | Firms introducing a new or improved process. |
| **Organisational innovator (0/1)** | Firms introducing an innovation in strategy, marketing or work organisation |
| **R&D firm (0/1)** | Firms undertaking R&D (in-house or external) |
| **R&D firm receiving public support (0/1)** | Firms undertaking publicly-supported R&D (in-house or external) |
| **R&D firm with not receiving support (0/1)** | Firms undertaking wholly-private R&D (in-house or external). |
| **Employment (log)** | Employment at the end of the survey period |
| **Science graduates (%)** | Proportion of the workforce that are science or engineering graduates |
| **Other graduates (%)** | Proportion of the workforce that are graduates in subjects other than science or engineering |
| **Exporting firm (0/1)** | Firms that are exporting |
| **Innovation partners (0 to 7)** | Number of innovation partners |
| **Innovation partners (squared) (0 to 49)** | Number of innovation partners squared |
| **UK innovation support (0/1)** | Firms receiving public financial support for innovation activities from UK local or national authorities |
| **EU innovation support (0/1)** | Firms receiving public financial support for innovation activities from EU institutions or programmes |
| **Design-engaged firm (0/1)** | Firms investing in design |
| **Training-engaged firm (0/1)** | Firms investing in training related to innovation |
| **Acquisition of existing knowledge (0/1)** | Firms investing in external knowledge acquisition related to innovation |
| **Market introduction of innovation (0/1)** | Firms investing in the acquisition of market intelligence related to innovation |
| **Acquisition of advanced machinery (0/1)** | Firms investing in the acquisition of machinery related to innovation |

**Source:** UK Innovation Surveys 4 to 8

## Annex 2: Correlation matrix, N=7,350

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Efficiency growth (%) | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| (2) Turnover growth (%) | 0.71 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| (3) Employment growth (%) | -0.54 | 0.21 | 1.00 | | | | | | | | | | | | | | | | | | | |
| (4) Product/service innovator (0/1) | 0.04 | 0.05 | 0.01 | 1.00 | | | | | | | | | | | | | | | | | | |
| (5) Process innovator (0/1) | 0.02 | 0.03 | 0.01 | 0.42 | 1.00 | | | | | | | | | | | | | | | | | |
| (6) Organisational innovator (0/1) | 0.02 | 0.03 | 0.02 | 0.28 | 0.25 | 1.00 | | | | | | | | | | | | | | | | |
| (7) R&D firm (0/1) | 0.03 | 0.05 | 0.01 | 0.50 | 0.36 | 0.27 | 1.00 | | | | | | | | | | | | | | | |
| (8) R&D firm receiving public support (0/1) | 0.01 | -0.01 | -0.02 | 0.14 | 0.11 | 0.06 | 0.17 | 1.00 | | | | | | | | | | | | | | |
| (9) R&D firm with not receiving support (0/1) | 0.03 | 0.05 | 0.01 | 0.47 | 0.33 | 0.26 | 0.97 | -0.07 | 1.00 | | | | | | | | | | | | | |
| (10) Employment (log) | -0.06 | 0.08 | 0.19 | 0.08 | 0.10 | 0.13 | 0.13 | 0.07 | 0.11 | 1.00 | | | | | | | | | | | | |
| (11) Science graduates (%) | 0.00 | 0.01 | 0.01 | 0.17 | 0.12 | 0.13 | 0.23 | 0.08 | 0.22 | 0.01 | 1.00 | | | | | | | | | | | |
| (12) Other graduates (%) | 0.00 | 0.01 | 0.02 | 0.06 | 0.04 | 0.08 | 0.08 | 0.00 | 0.08 | 0.05 | 0.15 | 1.00 | | | | | | | | | | |
| (13) Exporting firm (0/1) | 0.04 | 0.03 | -0.02 | 0.27 | 0.21 | 0.11 | 0.35 | 0.08 | 0.34 | 0.09 | 0.24 | 0.10 | 1.00 | | | | | | | | | |
| (14) Innovation partners (0 to 7) | 0.03 | 0.03 | 0.00 | 0.41 | 0.39 | 0.29 | 0.41 | 0.21 | 0.36 | 0.16 | 0.21 | 0.06 | 0.22 | 1.00 | | | | | | | | |
| (15) Innovation partners (squared) | 0.01 | 0.02 | 0.01 | 0.33 | 0.30 | 0.22 | 0.33 | 0.20 | 0.29 | 0.14 | 0.19 | 0.05 | 0.18 | 0.94 | 1.00 | | | | | | | |
| (16) UK innovation support (0/1) | 0.00 | -0.01 | -0.02 | 0.12 | 0.10 | 0.06 | 0.12 | 0.85 | -0.08 | 0.09 | 0.08 | 0.00 | 0.07 | 0.19 | 0.18 | 1.00 | | | | | | |
| (17) EU innovation support (0/1) | 0.00 | -0.01 | -0.01 | 0.06 | 0.04 | 0.02 | 0.08 | 0.31 | 0.00 | 0.01 | 0.08 | 0.02 | 0.05 | 0.10 | 0.10 | 0.30 | 1.00 | | | | | |
| (18) Design-engaged firm (0/1) | 0.00 | 0.02 | 0.01 | 0.40 | 0.32 | 0.25 | 0.52 | 0.10 | 0.51 | 0.10 | 0.17 | 0.06 | 0.27 | 0.37 | 0.32 | 0.08 | 0.06 | 1.00 | | | | |
| (19) Training-engaged firm (0/1) | 0.01 | 0.03 | 0.03 | 0.36 | 0.30 | 0.28 | 0.41 | 0.07 | 0.40 | 0.08 | 0.15 | 0.10 | 0.17 | 0.30 | 0.26 | 0.06 | 0.03 | 0.39 | 1.00 | | | |
| (20) Acquisition of existing knowledge (0/1) | 0.01 | 0.02 | 0.01 | 0.26 | 0.23 | 0.17 | 0.33 | 0.09 | 0.31 | 0.08 | 0.09 | 0.07 | 0.14 | 0.28 | 0.27 | 0.08 | 0.04 | 0.34 | 0.35 | 1.00 | | |
| (21) Market introduction of innovation (0/1) | 0.03 | 0.03 | 0.00 | 0.46 | 0.32 | 0.39 | 0.51 | 0.09 | 0.49 | 0.09 | 0.14 | 0.09 | 0.24 | 0.34 | 0.28 | 0.08 | 0.04 | 0.48 | 0.46 | 0.29 | 1.00 | |
| (22) Acquisition of advanced machinery (0/1) | -0.01 | 0.05 | 0.07 | 0.28 | 0.27 | 0.33 | 0.30 | 0.05 | 0.29 | 0.02 | 0.10 | 0.04 | 0.14 | 0.23 | 0.18 | 0.05 | 0.02 | 0.28 | 0.41 | 0.25 | 0.35 | 1.00 |

**Source:** UK Innovation Surveys 4 to 8

## Annex 3.1: Sample descriptives: Manufacturing and services firms

| Variable | Manufacturing firms | | | Service firms | | |
|---|---|---|---|---|---|---|
| | No. Obs. | Mean | Std. Dev. | No. Obs. | Mean | Std. Dev. |
| | | | | | | |
| Efficiency growth (%) | 2,623 | 0.071 | 0.476 | 6,597 | 0.010 | 0.724 |
| Turnover growth (%) | 2,637 | 0.077 | 0.472 | 6,665 | 0.045 | 0.653 |
| Employment growth (%) | 2,654 | 0.004 | 0.308 | 6,688 | 0.030 | 0.514 |
| Product/service innovator (0/1) | 2,733 | 0.372 | 0.483 | 6,979 | 0.188 | 0.391 |
| Process innovator (0/1) | 2,734 | 0.230 | 0.421 | 6,989 | 0.101 | 0.301 |
| Organisational innovator (0/1) | 2,734 | 0.461 | 0.498 | 6,995 | 0.401 | 0.490 |
| R&D firm (0/1) | 2,734 | 0.396 | 0.489 | 6,995 | 0.168 | 0.374 |
| R&D firm receiving public support (0/1) | 2,734 | 0.007 | 0.080 | 6,995 | 0.001 | 0.034 |
| R&D firm with not receiving support (0/1) | 2,734 | 0.390 | 0.488 | 6,995 | 0.167 | 0.373 |
| Employment (log) | 2,734 | 3.682 | 1.023 | 6,995 | 3.453 | 1.078 |
| Science graduates (%) | 2,410 | 5.320 | 10.594 | 5,680 | 6.097 | 15.765 |
| Other graduates (%) | 2,441 | 6.587 | 15.593 | 6,181 | 11.894 | 22.492 |
| Exporting firm (0/1) | 2,734 | 0.593 | 0.491 | 6,995 | 0.234 | 0.423 |
| Innovation partners (0 to 7) | 2,734 | 0.809 | 1.558 | 6,995 | 0.410 | 1.158 |
| Innovation partners (squared) (0 to 49) | 2,734 | 3.080 | 8.300 | 6,995 | 1.510 | 6.026 |
| UK innovation support (0/1) | 2,734 | 0.008 | 0.089 | 6,995 | 0.002 | 0.048 |
| EU innovation support (0/1) | 2,734 | 0.002 | 0.042 | 6,995 | 0.001 | 0.023 |
| Design-engaged firm (0/1) | 2,720 | 0.287 | 0.452 | 6,978 | 0.110 | 0.313 |
| Training-engaged firm (0/1) | 2,729 | 0.317 | 0.465 | 6,994 | 0.255 | 0.436 |
| Acquisition of existing knowledge (0/1) | 2,734 | 0.116 | 0.320 | 6,995 | 0.078 | 0.268 |
| Market introduction of innovation (0/1) | 2,734 | 0.421 | 0.494 | 6,995 | 0.272 | 0.445 |
| Acquisition of advanced machinery (0/1) | 2,734 | 0.612 | 0.487 | 6,995 | 0.508 | 0.500 |

**Source:** UK Innovation Surveys 4 to 8

## Annex 3.2: Sample descriptives: SMEs and larger firms

| Variable | SMEs | | | Larger firms | | |
|---|---|---|---|---|---|---|
| | No. Obs. | Mean | Std. Dev. | No. Obs. | Mean | Std. Dev. |
| | | | | | | |
| Efficiency growth (%) | 6,761 | 0.032 | 0.639 | 2,459 | -0.123 | 1.130 |
| Turnover growth (%) | 6,818 | 0.048 | 0.598 | 2,484 | 0.118 | 0.873 |
| Employment growth (%) | 6,868 | 0.012 | 0.435 | 2,474 | 0.240 | 0.905 |
| Product/service innovator (0/1) | 7,158 | 0.224 | 0.417 | 2,554 | 0.300 | 0.458 |
| Process innovator (0/1) | 7,167 | 0.124 | 0.329 | 2,556 | 0.217 | 0.412 |
| Organisational innovator (0/1) | 7,172 | 0.408 | 0.491 | 2,557 | 0.528 | 0.499 |
| R&D firm (0/1) | 7,172 | 0.210 | 0.407 | 2,557 | 0.341 | 0.474 |
| R&D firm receiving public support (0/1) | 7,172 | 0.001 | 0.036 | 2,557 | 0.020 | 0.140 |
| R&D firm with not receiving support (0/1) | 7,172 | 0.209 | 0.406 | 2,557 | 0.321 | 0.467 |
| Employment (log) | 7,172 | 3.337 | 0.819 | 2,557 | 6.354 | 0.848 |
| Science graduates (%) | 5,880 | 5.881 | 14.828 | 2,210 | 6.508 | 13.238 |
| Other graduates (%) | 6,294 | 10.700 | 21.388 | 2,328 | 11.322 | 19.640 |
| Exporting firm (0/1) | 7,172 | 0.306 | 0.461 | 2,557 | 0.406 | 0.491 |
| Innovation partners (0 to 7) | 7,172 | 0.470 | 1.227 | 2,557 | 0.951 | 1.747 |
| Innovation partners (squared) (0 to 49) | 7,172 | 1.727 | 6.351 | 2,557 | 3.956 | 9.909 |
| UK innovation support (0/1) | 7,172 | 0.002 | 0.045 | 2,557 | 0.029 | 0.167 |
| EU innovation support (0/1) | 7,172 | 0.001 | 0.026 | 2,557 | 0.003 | 0.053 |
| Design-engaged firm (0/1) | 7,152 | 0.144 | 0.351 | 2,546 | 0.226 | 0.419 |
| Training-engaged firm (0/1) | 7,167 | 0.264 | 0.441 | 2,556 | 0.344 | 0.475 |
| Acquisition of existing knowledge (0/1) | 7,172 | 0.083 | 0.275 | 2,557 | 0.147 | 0.354 |
| Market introduction of innovation (0/1) | 7,172 | 0.299 | 0.458 | 2,557 | 0.393 | 0.488 |
| Acquisition of advanced machinery (0/1) | 7,172 | 0.529 | 0.499 | 2,557 | 0.557 | 0.497 |

**Source:** UK Innovation Surveys 4 to 8

## Annex 3.3: Sample descriptives: High-technology/knowledge-intensive and other firms

| Variable | High-technology/knowledge-intensive firms | | | Low-technology/less knowledge-intensive firms | | |
|---|---|---|---|---|---|---|
| | No. Obs. | Mean | Std. Dev. | No. Obs. | Mean | Std. Dev. |
| | | | | | | |
| Efficiency growth (%) | 3,677 | 0.028 | 0.807 | 5,543 | 0.021 | 0.610 |
| Turnover growth (%) | 3,715 | 0.072 | 0.699 | 5,587 | 0.043 | 0.576 |
| Employment growth (%) | 3,720 | 0.039 | 0.587 | 5,622 | 0.018 | 0.416 |
| Product/service innovator (0/1) | 3,858 | 0.291 | 0.454 | 5,854 | 0.200 | 0.400 |
| Process innovator (0/1) | 3,864 | 0.174 | 0.379 | 5,859 | 0.109 | 0.311 |
| Organisational innovator (0/1) | 3,865 | 0.496 | 0.500 | 5,864 | 0.378 | 0.485 |
| R&D firm (0/1) | 3,865 | 0.316 | 0.465 | 5,864 | 0.173 | 0.378 |
| R&D firm receiving public support (0/1) | 3,865 | 0.005 | 0.071 | 5,864 | 0.001 | 0.033 |
| R&D firm with not receiving support (0/1) | 3,865 | 0.311 | 0.463 | 5,864 | 0.172 | 0.378 |
| Employment (log) | 3,865 | 3.662 | 1.163 | 5,864 | 3.431 | 1.018 |
| Science graduates (%) | 3,216 | 12.421 | 21.783 | 4,874 | 3.054 | 8.781 |
| Other graduates (%) | 3,428 | 18.506 | 25.687 | 5,194 | 7.206 | 17.879 |
| Exporting firm (0/1) | 3,865 | 0.398 | 0.490 | 5,864 | 0.273 | 0.445 |
| Innovation partners (0 to 7) | 3,865 | 0.675 | 1.454 | 5,864 | 0.417 | 1.164 |
| Innovation partners (squared) (0 to 49) | 3,865 | 2.572 | 7.707 | 5,864 | 1.528 | 6.039 |
| UK innovation support (0/1) | 3,865 | 0.007 | 0.081 | 5,864 | 0.002 | 0.047 |
| EU innovation support (0/1) | 3,865 | 0.002 | 0.043 | 5,864 | 0.000 | 0.018 |
| Design-engaged firm (0/1) | 3,857 | 0.198 | 0.398 | 5,841 | 0.126 | 0.332 |
| Training-engaged firm (0/1) | 3,863 | 0.335 | 0.472 | 5,860 | 0.238 | 0.426 |
| Acquisition of existing knowledge (0/1) | 3,865 | 0.100 | 0.300 | 5,864 | 0.080 | 0.271 |
| Market introduction of innovation (0/1) | 3,865 | 0.371 | 0.483 | 5,864 | 0.275 | 0.446 |
| Acquisition of advanced machinery (0/1) | 3,865 | 0.593 | 0.491 | 5,864 | 0.502 | 0.500 |

**Source:** UK Innovation Surveys 4 to 8

## Annex 4: Sub-sample estimates

Detailed estimation results for the sub-sample groups – manufacturing firms, service firms, SMEs, larger firms, high-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms are reported in Tables A4.1 to A4.6. First, firms in the estimation sample are separated into manufacturing and service firms using their three-digit Standard Industrial Classification (SIC) code. Second, firms in the estimation sample are separated according to their size: SMEs are defined here as those firms with less than 250 employees, and larger firms are defined as those firms with 250 or more employees. Third, firms are divided into high-technology and low-technology groups. Manufacturing firms are separated into high-technology and low-technology firms according to the OECD (2011) classification. The OECD uses expenditure on R&D to determine the technological input of each manufacturing industry. Both direct and indirect expenditure on R&D are considered, including the purchase of machinery, equipment and intermediary inputs (Hatzichronoglou 1997). Service firms are separated into knowledge-intensive firms and less knowledge-intensive firms according to the OECD's proposal for knowledge-intensive services (Eurostat 2007).

Estimation results in Tables A4.1 and A4.2 show the links which exist between R&D engagement (Table A4.1), publicly-supported and wholly-privately-funded R&D (Table A4.2), innovation of different types and efficiency growth across the different sub-groups of firms. As is the case in the efficiency-growth baseline models, the results suggest that an increase in the probability of product/service innovation has a negative effect on firm efficiency growth. Coefficients are negative and significant (at the 1 per cent level) in five of the six sub-groups (Table A4.1). This effect is insignificant in manufacturing firms. An increase in the probability of a firm engaging in process innovation has a positive, significant effect on firm efficiency growth in four of the six sub-groups – this coefficient is insignificant in the manufacturing and high-technology/knowledge-intensive sub-groups (Table A4.1). Compared with the whole-sample results, the significance level is lower for larger firms.

In line with the baseline results, an increase in the probability of a firm carrying out organisational innovation has a positive, significant effect on firm efficiency growth in four of the six sub-groups, although the significance level is lower for high-tech/knowledge-intensive firms – the effect is insignificant in manufacturing and larger firms (Table A4.1).

The results in Table A4.1 suggest that R&D engagement has a positive, significant effect (at the 1 per cent level) on the probability of product/service innovation across all groups of firms in the efficiency growth models. Distinguishing between R&D-active firms receiving public support and R&D-active firms receiving no public support (Table A4.2) reveals manufacturing firms as the sub-group which benefits most from public support for R&D activities: public support for R&D in manufacturing firms leads to a 28.5 percentage point increase in the probability of product/service innovation compared with a 16.3 per cent increase when no public support for R&D is received (Table 3 and Figure 2a). R&D engagement has a positive, significant effect on the probability of process innovation across all sub-groups of firms (Table A4.1 and Figure 2b). In four of the sub-groups (manufacturing firms, SMEs, larger firms and low-technology/less knowledge-intensive firms), publicly-supported R&D leads to a greater increase in the probability of process innovation than wholly-private R&D (Table A4.2). The marginal effects in Table 3 suggest that this effect is most pronounced in manufacturing firms where publicly-supported R&D increases the probability of process innovation by 11.1 percentage points compared with a 4.1 percentage-point increase in firms undertaking wholly-private R&D. Consistent with the whole-sample estimation results, the effect of R&D engagement on the probability of organisational innovation is positive and significant across five sub-sample groups – the effect is insignificant in larger firms, although positive (Table A4.1). Examining publicly-supported R&D and wholly-private R&D separately (Table A4.2) suggests that public support for R&D leads to a larger effect on the probability of organisational innovation than wholly- privately-funded R&D – the coefficients are significant in all but larger firms. The greatest difference is in service firms; the marginal effects in Table 3 suggest that publicly-supported R&D leads to an 11.1 percentage-point increase in the probability of organisational innovation compared with a 7.6 percentage-point increase in service firms undertaking wholly-private R&D.

Models linking R&D, innovation of different types and turnover growth across the different sub-groups of firms are reported in Tables A4.3 and A4.4. In the baseline models (Table 2), an increase in the probability of a firm engaging in product/service innovation leads to a fall in turnover growth. The results in Table A4.3 suggest that this result is inconsistent across sub-groups. Service firms, SMEs and low-technology/less knowledge-intensive firms are consistent with the whole-sample results so that product/service innovation leads to a significant, negative effect on firms' turnover growth (at the 1 per cent level). The effects in manufacturing firms and high-technology/knowledge-intensive firms are insignificant. In large firms, however, an increase in product/service innovation leads to a significant, positive effect on firms' turnover growth (at the 1 per cent level). The effects on turnover growth of process innovation are also mixed. In keeping with the baseline results (Table 2), the effect on turnover growth in service firms, SMEs and low-technology/less knowledge-intensive firms is positive and significant at the 1 per cent level. As is also the case for product innovation, the effect on manufacturing firms and high-technology/knowledge-intensive firms is insignificant. In larger firms, however, an increase in the probability of process innovation leads to a statistically significant fall in turnover growth. In the baseline models, there is a significant, positive effect on turnover growth following an increase in the probability of organisational innovation. SMEs, service firms and low-technology/less knowledge-intensive firms experience a similar positive effect on turnover growth, whereas the effect in larger firms is negative and significant. In manufacturing firms and high-technology/knowledge-intensive firms, turnover-growth effects are insignificant.

Overall, the relationships between our R&D indicators and innovation in the turnover-growth models are broadly consistent with those in the efficiency-growth models (Table A4.4). R&D engagement has a positive, significant effect (at the 1 per cent level) on the probability of product/service innovation across all groups of firms in the turnover-growth models. Manufacturing firms benefit most from public support for R&D activities in terms of the positive effect on the probability of product/service innovation: a result consistent with the efficiency-growth models in Table A4.2 (see also Table 4 and Figure 2).

R&D engagement has a positive, significant effect on the probability of process innovation across all sub-groups of firms (Table A4.3). In SMEs, large firms, manufacturing firms and low-technology/less knowledge-intensive firms, publicly-supported R&D leads to a greater increase in the probability of process innovation than wholly-private R&D (Figure 2). In larger firms, publicly-supported R&D increases the probability of process innovation by 18.7 percentage points compared with 6.2 percentage points in firms undertaking wholly-private R&D (Table 4). In line with the baseline results, R&D engagement has a significant, positive effect on the probability of organisational innovation across five of the six sub-sample groups – R&D engagement as an insignificant effect on the probability of organisational innovation in larger firms (Table A4.3). The results in Table A4.4 suggest that publicly-supported R&D has a positive, significant effect on the probability of organisational innovation in all sub-groups apart from larger firms (Figure 2). Publicly-supported R&D (unsupported R&D) leads to a 16.5 (13.5) percentage-point increase in the probability of organisational innovation in manufacturing firms, a 12.1 (7.7) percentage-point increase in service firms, an 11.9 (9.4) percentage-point increase in SMEs, a 9.0 (5.7) percentage point increase in high-technology/knowledge-intensive firms and a 14.4 (10.9) percentage point increase in low-technology/less knowledge-intensive firms (Table 4).

Estimation results in Tables A4.5 and A4.6 show the links which exist between R&D engagement (Table A4.5), publicly-supported and wholly-privately-funded R&D (Table A4.6), innovation of different types and employment growth across the different sub-groups of firms. In line with the employment-growth baseline models (Table 2), the results suggest that an increase in the probability of product/service innovation has a significant, positive effect on firm employment growth in three (Table A4.5) or four (Table A4.6) of the sub groups of firms (the effect is insignificant in high-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms). An increase in the probability of a firm engaging in process innovation has an insignificant effect in the whole-sample baseline models. In the sub-sample models, however, an increase in the probability of process innovation leads to higher employment growth in SMEs, high-technology/knowledge-intensive firms and low-technology/less knowledge-intensive firms (Tables A4.5 and Tables A4.6). In accordance with the baseline model results, an increase in the probability of a firm carrying out organisational innovation has a significant (at the 1 per cent level), negative effect on firm employment growth in all sub groups of firms.

The results in Table A4.5 suggest that R&D engagement has a significant, positive effect (at the 1 per cent level) on the probability of product/service innovation across all sub groups of firms in the employment-growth models. Distinguishing between R&D-active firms receiving public support and R&D-active firms receiving no public support (Table A4.6) reveals that public support for R&D is beneficial to all groups of firms, with SMEs, manufacturing firms and high-technology/knowledge-intensive firms benefitting most of all (as illustrated by the marginal effects given in Table 5). In line with the baseline whole-sample results, R&D engagement has a positive, significant effect on the probability of process innovation across all sub-groups of firms (Table A4.5 and Figure 2b). In four of the sub-groups (manufacturing firms, SMEs, larger firms and low-technology/less knowledge-intensive firms), publicly-supported R&D leads to a greater increase in the probability of process innovation than wholly-private R&D (Table A4.6). The marginal effects in Table 5 suggest that this effect is most pronounced in manufacturing and large firms where publicly-supported R&D increases the probability of process innovation by 11.3 percentage points and 18.5 percentage points respectively. The effect of R&D engagement on the probability of organisational innovation in the employment-growth models is positive and significant across five sub-sample groups – the effect is insignificant in larger firms, although positive (Table A4.5). Examining publicly-supported R&D and wholly-private R&D separately (Table A4.6) suggests that public support for R&D leads to a stronger effect on the probability of organisational innovation than wholly-privately-funded R&D – again, the coefficients are significant in all but larger firms. The marginal effects in Table 5 suggest that public support for R&D may lead to as much as a further 5.0 percentage point increase in organisational innovation compared with wholly-private R&D (service firms), although statistically, the standard errors across sub groups suggest that there may be no significant difference between the organisational-innovation effects following publicly-supported R&D and those following wholly-private R&D.

## Table A4.1: Modelling the link between R&D engagement, innovation and efficiency growth: sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Efficiency growth model** | | | | | | |
| Product/service innovator (lag) | 0.007 | -0.623*** | -0.581*** | -1.258*** | -0.555*** | -0.529*** |
| | (0.130) | (0.131) | (0.089) | (0.215) | (0.202) | (0.106) |
| Process innovator (lag) | 0.079 | 0.395*** | 0.348*** | 0.837** | 0.415 | 0.466*** |
| | (0.089) | (0.131) | (0.114) | (0.341) | (0.280) | (0.089) |
| Organisational innovator (lag) | 0.035 | 0.453*** | 0.460*** | 0.561 | 0.519* | 0.242*** |
| | (0.109) | (0.130) | (0.104) | (0.648) | (0.273) | (0.080) |
| Employment (log) | -0.017 | -0.101*** | -0.099*** | -0.045 | -0.124*** | -0.058*** |
| | (0.013) | (0.020) | (0.021) | (0.045) | (0.028) | (0.019) |
| Science graduates (%) | 0.002 | -0.001 | -0.000 | -0.001 | -0.001 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.003) | (0.001) | (0.002) |
| Other graduates (%) | -0.001 | 0.000 | 0.001 | -0.005*** | 0.000 | -0.000 |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.051* | 0.028 | 0.042 | 0.167** | 0.069 | 0.042 |
| | (0.029) | (0.034) | (0.027) | (0.075) | (0.042) | (0.034) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.749*** | 0.376*** | 0.464*** | 0.456*** | 0.536*** | 0.442*** |
| | (0.086) | (0.070) | (0.057) | (0.106) | (0.082) | (0.072) |
| Employment (log) | -0.005 | -0.052** | -0.047** | -0.185*** | -0.047 | -0.038* |
| | (0.036) | (0.020) | (0.022) | (0.049) | (0.033) | (0.021) |
| Science graduates (%) | 0.002 | 0.003 | 0.002 | 0.006** | 0.002 | 0.005 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.000 | 0.003* | 0.002 | 0.003 | 0.002 | 0.003 |
| | (0.004) | (0.001) | (0.001) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.139 | 0.148** | 0.168*** | 0.180** | 0.091 | 0.190*** |
| | (0.085) | (0.067) | (0.055) | (0.087) | (0.080) | (0.068) |
| Innovation partners (0 to 7) | 0.457*** | 0.500*** | 0.491*** | 0.402*** | 0.465*** | 0.504*** |
| | (0.070) | (0.053) | (0.045) | (0.059) | (0.065) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.057*** | -0.067*** | -0.066*** | -0.040*** | -0.061*** | -0.066*** |
| | (0.012) | (0.009) | (0.007) | (0.009) | (0.011) | (0.009) |
| UK innovation support (0/1) | 0.433*** | 0.134 | 0.251*** | 0.248** | 0.278** | 0.221** |
| | (0.098) | (0.106) | (0.078) | (0.100) | (0.115) | (0.089) |
| EU innovation support (0/1) | -0.374 | 0.114 | -0.100 | -0.065 | -0.432 | 0.157 |
| | (0.311) | (0.281) | (0.219) | (0.243) | (0.266) | (0.264) |
| Design-engaged firm (0/1) | 0.336*** | 0.223*** | 0.236*** | 0.214** | 0.238*** | 0.264*** |
| | (0.095) | (0.081) | (0.064) | (0.107) | (0.092) | (0.084) |
| Training-engaged firm (0/1) | 0.098 | 0.280*** | 0.236*** | 0.224** | 0.134 | 0.306*** |
| | (0.086) | (0.069) | (0.057) | (0.102) | (0.082) | (0.073) |
| Acquisition of existing knowledge (0/1) | 0.005 | 0.056 | 0.079 | -0.181* | 0.196* | -0.092 |
| | (0.116) | (0.087) | (0.075) | (0.106) | (0.106) | (0.093) |
| Market introduction of innovation (0/1) | 0.698*** | 0.675*** | 0.647*** | 0.551*** | 0.665*** | 0.629*** |
| | (0.100) | (0.068) | (0.060) | (0.123) | (0.084) | (0.076) |
| Acquisition of advanced machinery (0/1) | 0.368*** | 0.321*** | 0.354*** | 0.233** | 0.464*** | 0.266*** |
| | (0.084) | (0.064) | (0.053) | (0.112) | (0.077) | (0.069) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.187** | 0.319*** | 0.302*** | 0.355*** | 0.173* | 0.364*** |
| | (0.088) | (0.079) | (0.066) | (0.091) | (0.092) | (0.079) |
| Employment (log) | 0.067** | 0.055** | 0.058* | 0.057 | 0.066 | 0.072*** |
| | (0.031) | (0.026) | (0.032) | (0.042) | (0.041) | (0.028) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Science graduates (%) | -0.002 | 0.003 | 0.002 | 0.005 | 0.002 | 0.004 |
| | (0.004) | (0.002) | (0.002) | (0.004) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.002 | 0.002 | 0.004* | 0.002 | 0.000 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.007 | -0.084 | -0.048 | -0.069 | 0.009 | -0.086 |
| | (0.084) | (0.080) | (0.064) | (0.086) | (0.088) | (0.075) |
| Innovation partners (0 to 7) | 0.333*** | 0.369*** | 0.335*** | 0.579*** | 0.348*** | 0.361*** |
| | (0.062) | (0.055) | (0.047) | (0.054) | (0.060) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.031*** | -0.047*** | -0.040*** | -0.073*** | -0.043*** | -0.042*** |
| | (0.010) | (0.009) | (0.008) | (0.009) | (0.010) | (0.009) |
| UK innovation support (0/1) | 0.370*** | 0.269** | 0.299*** | 0.523*** | 0.196* | 0.381*** |
| | (0.097) | (0.119) | (0.083) | (0.119) | (0.116) | (0.102) |
| EU innovation support (0/1) | -0.078 | 0.128 | 0.049 | -0.396 | -0.014 | 0.077 |
| | (0.232) | (0.295) | (0.205) | (0.254) | (0.235) | (0.282) |
| Design-engaged firm (0/1) | 0.133 | 0.207** | 0.157** | 0.326*** | 0.282*** | 0.081 |
| | (0.093) | (0.088) | (0.073) | (0.091) | (0.092) | (0.089) |
| Training-engaged firm (0/1) | 0.309*** | 0.259*** | 0.259*** | 0.343*** | 0.370*** | 0.181** |
| | (0.082) | (0.076) | (0.064) | (0.083) | (0.082) | (0.078) |
| Acquisition of existing knowledge (0/1) | -0.102 | 0.077 | 0.019 | -0.068 | 0.162 | -0.084 |
| | (0.106) | (0.094) | (0.080) | (0.099) | (0.099) | (0.102) |
| Market introduction of innovation (0/1) | 0.051 | 0.307*** | 0.261*** | 0.002 | 0.094 | 0.361*** |
| | (0.092) | (0.076) | (0.066) | (0.086) | (0.087) | (0.079) |
| Acquisition of advanced machinery (0/1) | 0.754*** | 0.672*** | 0.719*** | 0.364*** | 0.590*** | 0.758*** |
| | (0.086) | (0.066) | (0.058) | (0.084) | (0.080) | (0.070) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.420*** | 0.291*** | 0.354*** | 0.093 | 0.192** | 0.415*** |
| | (0.081) | (0.075) | (0.061) | (0.104) | (0.081) | (0.079) |
| Employment (log) | 0.106*** | 0.144*** | 0.171*** | 0.084 | 0.143*** | 0.123*** |
| | (0.032) | (0.024) | (0.029) | (0.071) | (0.037) | (0.023) |
| Science graduates (%) | 0.000 | 0.003 | 0.002 | 0.003 | 0.004** | -0.003 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.001 | 0.003** | 0.002 | 0.005* | 0.001 | 0.006** |
| | (0.003) | (0.002) | (0.001) | (0.003) | (0.001) | (0.003) |
| Exporting firm (0/1) | -0.057 | 0.121* | 0.062 | 0.042 | 0.082 | 0.047 |
| | (0.075) | (0.065) | (0.054) | (0.081) | (0.076) | (0.068) |
| Innovation partners (0 to 7) | 0.294*** | 0.287*** | 0.277*** | 0.416*** | 0.189*** | 0.359*** |
| | (0.065) | (0.056) | (0.047) | (0.073) | (0.060) | (0.061) |
| Innovation partners (squared) (0 to 49) | -0.041*** | -0.031*** | -0.034*** | -0.044*** | -0.018* | -0.046*** |
| | (0.011) | (0.010) | (0.008) | (0.011) | (0.010) | (0.011) |
| UK innovation support (0/1) | 0.262*** | 0.174 | 0.212** | 0.125 | 0.227* | 0.193 |
| | (0.098) | (0.131) | (0.088) | (0.135) | (0.117) | (0.117) |
| EU innovation support (0/1) | -0.074 | 0.347 | 0.190 | -0.142 | -0.263 | 0.557* |
| | (0.275) | (0.298) | (0.224) | (0.305) | (0.257) | (0.307) |
| Design-engaged firm (0/1) | 0.055 | 0.062 | 0.037 | -0.055 | 0.089 | 0.025 |
| | (0.090) | (0.091) | (0.071) | (0.117) | (0.090) | (0.091) |
| Training-engaged firm (0/1) | 0.160** | 0.159** | 0.159*** | 0.173* | 0.138* | 0.182** |
| | (0.081) | (0.070) | (0.059) | (0.099) | (0.079) | (0.076) |
| Acquisition of existing knowledge (0/1) | 0.105 | 0.206* | 0.174* | -0.196 | 0.368*** | 0.015 |
| | (0.106) | (0.106) | (0.090) | (0.120) | (0.102) | (0.119) |
| Market introduction of innovation (0/1) | 0.467*** | 0.737*** | 0.680*** | 0.577*** | 0.544*** | 0.761*** |
| | (0.090) | (0.071) | (0.062) | (0.111) | (0.081) | (0.077) |
| Acquisition of advanced machinery (0/1) | 0.584*** | 0.560*** | 0.571*** | 0.340*** | 0.630*** | 0.531*** |
| | (0.076) | (0.061) | (0.054) | (0.098) | (0.084) | (0.063) |
| | | | | | | |
| Number of observations | 2734.000 | 6994.000 | 7172.000 | 2557.000 | 3865.000 | 5864.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Chi-squared | 22748.729 | 24168.519 | 4143.662 | 1679.161 | 1948.668 | 3050.906 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| bic | 86299.944 | 2.98e+05 | 3.56e+05 | 29071.603 | 1.38e+05 | 2.47e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table A4.2: Modelling the link between UK-supported and unsupported R&D engagement, innovation and efficiency growth: sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Efficiency growth model** | | | | | | |
| Product/service innovator (lag) | -0.014 | -0.629*** | -0.580*** | -1.258*** | -0.546*** | -0.529*** |
| | (0.151) | (0.128) | (0.089) | (0.214) | (0.212) | (0.106) |
| Process innovator (lag) | 0.086 | 0.402*** | 0.359*** | 0.825** | 0.422 | 0.468*** |
| | (0.102) | (0.132) | (0.113) | (0.344) | (0.281) | (0.089) |
| Organisational innovator (lag) | 0.051 | 0.458*** | 0.456*** | 0.576 | 0.514* | 0.241*** |
| | (0.115) | (0.128) | (0.104) | (0.646) | (0.280) | (0.080) |
| Employment (log) | -0.017 | -0.102*** | -0.099*** | -0.045 | -0.124*** | -0.058*** |
| | (0.014) | (0.020) | (0.021) | (0.045) | (0.028) | (0.019) |
| Science graduates (%) | 0.002 | -0.001 | -0.000 | -0.001 | -0.001 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.003) | (0.001) | (0.002) |
| Other graduates (%) | -0.001 | 0.000 | 0.001 | -0.005*** | 0.000 | -0.000 |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.052* | 0.028 | 0.041 | 0.166** | 0.069 | 0.042 |
| | (0.030) | (0.034) | (0.027) | (0.075) | (0.042) | (0.034) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 1.201*** | 0.422*** | 0.675*** | 0.649*** | 0.802*** | 0.633*** |
| | (0.127) | (0.143) | (0.108) | (0.144) | (0.152) | (0.133) |
| R&D without UK support (0/1) | 0.691*** | 0.378*** | 0.449*** | 0.448*** | 0.518*** | 0.428*** |
| | (0.088) | (0.071) | (0.058) | (0.107) | (0.083) | (0.074) |
| Employment (log) | -0.005 | -0.052** | -0.045** | -0.185*** | -0.045 | -0.037* |
| | (0.036) | (0.020) | (0.022) | (0.048) | (0.033) | (0.021) |
| Science graduates (%) | 0.003 | 0.003 | 0.003 | 0.006** | 0.002 | 0.005 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.001 | 0.003* | 0.001 | 0.003 | 0.002 | 0.003 |
| | (0.004) | (0.001) | (0.001) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.143* | 0.149** | 0.168*** | 0.180** | 0.090 | 0.189*** |
| | (0.084) | (0.067) | (0.055) | (0.087) | (0.080) | (0.068) |
| Innovation partners (0 to 7) | 0.467*** | 0.503*** | 0.496*** | 0.405*** | 0.469*** | 0.508*** |
| | (0.070) | (0.053) | (0.046) | (0.059) | (0.066) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.059*** | -0.067*** | -0.067*** | -0.040*** | -0.062*** | -0.066*** |
| | (0.012) | (0.009) | (0.007) | (0.009) | (0.011) | (0.009) |
| EU innovation support (0/1) | -0.285 | 0.215 | 0.021 | 0.006 | -0.370 | 0.286 |
| | (0.343) | (0.279) | (0.234) | (0.242) | (0.271) | (0.277) |
| Design-engaged firm (0/1) | 0.339*** | 0.225*** | 0.238*** | 0.210** | 0.240*** | 0.265*** |
| | (0.095) | (0.081) | (0.064) | (0.106) | (0.092) | (0.084) |
| Training-engaged firm (0/1) | 0.110 | 0.281*** | 0.240*** | 0.225** | 0.141* | 0.307*** |
| | (0.086) | (0.068) | (0.057) | (0.101) | (0.082) | (0.073) |
| Acquisition of existing knowledge (0/1) | 0.011 | 0.057 | 0.081 | -0.179* | 0.197* | -0.090 |
| | (0.118) | (0.087) | (0.075) | (0.106) | (0.106) | (0.093) |
| Market introduction of innovation (0/1) | 0.684*** | 0.676*** | 0.647*** | 0.553*** | 0.664*** | 0.630*** |
| | (0.102) | (0.068) | (0.060) | (0.123) | (0.084) | (0.076) |
| Acquisition of advanced machinery (0/1) | 0.390*** | 0.323*** | 0.360*** | 0.235** | 0.468*** | 0.272*** |
| | (0.083) | (0.064) | (0.053) | (0.112) | (0.078) | (0.068) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.415*** | 0.292** | 0.360*** | 0.888*** | 0.212 | 0.489*** |
| | (0.128) | (0.148) | (0.105) | (0.148) | (0.142) | (0.132) |

| | | | | | | |
|---|---|---|---|---|---|---|
| R&D without UK support (0/1) | 0.164* | 0.338*** | 0.310*** | 0.325*** | 0.182** | 0.363*** |
| | (0.090) | (0.081) | (0.067) | (0.093) | (0.093) | (0.081) |
| Employment (log) | 0.068** | 0.054** | 0.061* | 0.055 | 0.066 | 0.072*** |
| | (0.031) | (0.026) | (0.032) | (0.043) | (0.041) | (0.028) |
| Science graduates (%) | -0.002 | 0.003 | 0.002 | 0.005 | 0.002 | 0.005 |
| | (0.004) | (0.002) | (0.002) | (0.004) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.002 | 0.002 | 0.004* | 0.002 | 0.001 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.013 | -0.077 | -0.043 | -0.073 | 0.015 | -0.083 |
| | (0.083) | (0.080) | (0.064) | (0.086) | (0.088) | (0.075) |
| Innovation partners (0 to 7) | 0.343*** | 0.377*** | 0.345*** | 0.584*** | 0.353*** | 0.373*** |
| | (0.062) | (0.055) | (0.047) | (0.054) | (0.060) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.033*** | -0.048*** | -0.040*** | -0.073*** | -0.043*** | -0.043*** |
| | (0.010) | (0.009) | (0.008) | (0.009) | (0.010) | (0.009) |
| EU innovation support (0/1) | 0.064 | 0.372 | 0.267 | -0.334 | 0.116 | 0.361 |
| | (0.236) | (0.293) | (0.208) | (0.269) | (0.225) | (0.295) |
| Design-engaged firm (0/1) | 0.138 | 0.214** | 0.164** | 0.319*** | 0.285*** | 0.089 |
| | (0.092) | (0.088) | (0.072) | (0.091) | (0.092) | (0.089) |
| Training-engaged firm (0/1) | 0.317*** | 0.262*** | 0.262*** | 0.346*** | 0.374*** | 0.184** |
| | (0.082) | (0.076) | (0.063) | (0.083) | (0.082) | (0.078) |
| Acquisition of existing knowledge (0/1) | -0.091 | 0.074 | 0.021 | -0.066 | 0.163* | -0.079 |
| | (0.107) | (0.094) | (0.079) | (0.099) | (0.099) | (0.102) |
| Market introduction of innovation (0/1) | 0.049 | 0.308*** | 0.264*** | 0.002 | 0.095 | 0.364*** |
| | (0.092) | (0.076) | (0.066) | (0.086) | (0.086) | (0.079) |
| Acquisition of advanced machinery (0/1) | 0.768*** | 0.676*** | 0.725*** | 0.367*** | 0.594*** | 0.766*** |
| | (0.086) | (0.066) | (0.058) | (0.084) | (0.080) | (0.070) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.497*** | 0.420** | 0.443*** | 0.155 | 0.283** | 0.537*** |
| | (0.123) | (0.177) | (0.111) | (0.176) | (0.132) | (0.160) |
| R&D without UK support (0/1) | 0.420*** | 0.286*** | 0.354*** | 0.093 | 0.194** | 0.410*** |
| | (0.083) | (0.078) | (0.063) | (0.105) | (0.082) | (0.082) |
| Employment (log) | 0.108*** | 0.145*** | 0.172*** | 0.085 | 0.144*** | 0.124*** |
| | (0.032) | (0.024) | (0.029) | (0.070) | (0.038) | (0.023) |
| Science graduates (%) | 0.001 | 0.003 | 0.002 | 0.003 | 0.005** | -0.003 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.001 | 0.003** | 0.002 | 0.005* | 0.001 | 0.006** |
| | (0.003) | (0.001) | (0.001) | (0.003) | (0.001) | (0.003) |
| Exporting firm (0/1) | -0.054 | 0.120* | 0.062 | 0.043 | 0.083 | 0.046 |
| | (0.075) | (0.065) | (0.054) | (0.081) | (0.076) | (0.068) |
| Innovation partners (0 to 7) | 0.306*** | 0.290*** | 0.284*** | 0.416*** | 0.193*** | 0.365*** |
| | (0.065) | (0.056) | (0.047) | (0.074) | (0.060) | (0.061) |
| Innovation partners (squared) (0 to 49) | -0.042*** | -0.032*** | -0.034*** | -0.045*** | -0.018* | -0.047*** |
| | (0.011) | (0.010) | (0.008) | (0.011) | (0.010) | (0.011) |
| EU innovation support (0/1) | 0.077 | 0.478* | 0.340 | -0.077 | -0.130 | 0.708** |
| | (0.274) | (0.285) | (0.221) | (0.302) | (0.253) | (0.297) |
| Design-engaged firm (0/1) | 0.062 | 0.064 | 0.041 | -0.056 | 0.094 | 0.028 |
| | (0.089) | (0.091) | (0.071) | (0.116) | (0.090) | (0.091) |
| Training-engaged firm (0/1) | 0.167** | 0.160** | 0.161*** | 0.174* | 0.141* | 0.184** |
| | (0.080) | (0.069) | (0.059) | (0.098) | (0.078) | (0.076) |
| Acquisition of existing knowledge (0/1) | 0.114 | 0.206* | 0.176* | -0.195 | 0.367*** | 0.018 |
| | (0.105) | (0.106) | (0.090) | (0.120) | (0.102) | (0.119) |
| Market introduction of innovation (0/1) | 0.470*** | 0.737*** | 0.681*** | 0.576*** | 0.544*** | 0.762*** |
| | (0.090) | (0.071) | (0.062) | (0.112) | (0.081) | (0.076) |
| Acquisition of advanced machinery (0/1) | 0.592*** | 0.561*** | 0.575*** | 0.340*** | 0.634*** | 0.535*** |
| | (0.076) | (0.061) | (0.054) | (0.098) | (0.084) | (0.063) |
| | | | | | | |
| Number of observations | 2734.000 | 6994.000 | 7172.000 | 2557.000 | 3865.000 | 5864.000 |
| Chi-squared | 8.69e+13 | 17322.160 | 4178.764 | 2483.103 | 1949.934 | 3079.762 |

| | | | | | | |
|---|---|---|---|---|---|---|
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| bic | 86579.514 | 2.98e+05 | 3.56e+05 | 29068.764 | 1.38e+05 | 2.47e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table A4.3: Modelling the link between R&D engagement, innovation and turnover growth: sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Turnover growth model** | | | | | | |
| Product/service innovator (lag) | 0.101 | -0.553*** | -0.460*** | 0.749*** | 0.225 | -0.488*** |
| | (0.172) | (0.140) | (0.151) | (0.158) | (0.171) | (0.144) |
| Process innovator (lag) | 0.051 | 0.427*** | 0.379*** | -0.580** | 0.133 | 0.441*** |
| | (0.111) | (0.098) | (0.105) | (0.232) | (0.165) | (0.095) |
| Organisational innovator (lag) | -0.110 | 0.226** | 0.199** | -0.650** | -0.292 | 0.149** |
| | (0.278) | (0.092) | (0.100) | (0.262) | (0.281) | (0.071) |
| Employment (log) | 0.047*** | 0.079*** | 0.099*** | 0.088*** | 0.072*** | 0.077*** |
| | (0.016) | (0.014) | (0.017) | (0.031) | (0.018) | (0.015) |
| Science graduates (%) | 0.002 | 0.000 | 0.001 | -0.001 | 0.000 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.002) | (0.001) | (0.002) |
| Other graduates (%) | -0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.002* |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.048 | 0.030 | 0.035 | 0.062 | 0.047 | 0.035 |
| | (0.030) | (0.029) | (0.025) | (0.057) | (0.039) | (0.029) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.740*** | 0.358*** | 0.457*** | 0.540*** | 0.557*** | 0.428*** |
| | (0.089) | (0.066) | (0.060) | (0.108) | (0.084) | (0.070) |
| Employment (log) | -0.009 | 0.039* | 0.064** | -0.104*** | 0.011 | 0.044 |
| | (0.040) | (0.021) | (0.028) | (0.031) | (0.025) | (0.027) |
| Science graduates (%) | 0.002 | 0.003 | 0.002 | 0.007** | 0.003 | 0.004 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.000 | 0.002* | 0.002 | 0.004 | 0.003 | 0.002 |
| | (0.004) | (0.001) | (0.001) | (0.003) | (0.002) | (0.002) |
| Exporting firm (0/1) | 0.136 | 0.130** | 0.138** | 0.127 | 0.046 | 0.170** |
| | (0.085) | (0.064) | (0.055) | (0.097) | (0.082) | (0.067) |
| Innovation partners (0 to 7) | 0.460*** | 0.497*** | 0.501*** | 0.461*** | 0.477*** | 0.492*** |
| | (0.070) | (0.055) | (0.050) | (0.057) | (0.067) | (0.062) |
| Innovation partners (squared) (0 to 49) | -0.058*** | -0.067*** | -0.067*** | -0.050*** | -0.063*** | -0.065*** |
| | (0.012) | (0.009) | (0.008) | (0.009) | (0.011) | (0.010) |
| UK innovation support (0/1) | 0.437*** | 0.156 | 0.251*** | 0.244** | 0.293** | 0.216** |
| | (0.097) | (0.107) | (0.081) | (0.118) | (0.116) | (0.090) |
| EU innovation support (0/1) | -0.369 | 0.160 | -0.050 | -0.029 | -0.414 | 0.143 |
| | (0.312) | (0.283) | (0.229) | (0.272) | (0.274) | (0.262) |
| Design-engaged firm (0/1) | 0.333*** | 0.225*** | 0.245*** | 0.276** | 0.274*** | 0.248*** |
| | (0.095) | (0.075) | (0.066) | (0.116) | (0.093) | (0.080) |
| Training-engaged firm (0/1) | 0.105 | 0.240*** | 0.200*** | 0.321*** | 0.118 | 0.256*** |
| | (0.089) | (0.067) | (0.058) | (0.099) | (0.086) | (0.072) |
| Acquisition of existing knowledge (0/1) | -0.004 | 0.058 | 0.065 | -0.171 | 0.166 | -0.076 |
| | (0.115) | (0.083) | (0.075) | (0.115) | (0.110) | (0.090) |
| Market introduction of innovation (0/1) | 0.710*** | 0.632*** | 0.638*** | 0.498*** | 0.662*** | 0.611*** |
| | (0.098) | (0.068) | (0.065) | (0.099) | (0.082) | (0.079) |
| Acquisition of advanced machinery (0/1) | 0.370*** | 0.309*** | 0.320*** | 0.147 | 0.436*** | 0.272*** |
| | (0.084) | (0.062) | (0.054) | (0.101) | (0.079) | (0.067) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.184** | 0.328*** | 0.297*** | 0.302*** | 0.158* | 0.364*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.090) | (0.079) | (0.066) | (0.080) | (0.092) | (0.079) |
| Employment (log) | 0.045 | 0.018 | 0.003 | 0.015 | 0.029 | 0.025 |
| | (0.032) | (0.022) | (0.026) | (0.023) | (0.026) | (0.025) |
| Science graduates (%) | -0.002 | 0.003 | 0.002 | 0.004 | 0.002 | 0.005 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.002 | 0.001 | 0.004* | 0.002 | 0.000 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.004 | -0.083 | -0.053 | 0.011 | 0.017 | -0.076 |
| | (0.084) | (0.080) | (0.063) | (0.085) | (0.088) | (0.076) |
| Innovation partners (0 to 7) | 0.341*** | 0.368*** | 0.330*** | 0.511*** | 0.342*** | 0.367*** |
| | (0.062) | (0.055) | (0.046) | (0.063) | (0.062) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.032*** | -0.047*** | -0.039*** | -0.061*** | -0.042*** | -0.044*** |
| | (0.010) | (0.009) | (0.008) | (0.009) | (0.010) | (0.009) |
| UK innovation support (0/1) | 0.369*** | 0.284** | 0.299*** | 0.489*** | 0.203* | 0.369*** |
| | (0.097) | (0.117) | (0.084) | (0.119) | (0.117) | (0.102) |
| EU innovation support (0/1) | -0.079 | 0.116 | 0.064 | -0.475* | -0.070 | 0.098 |
| | (0.232) | (0.298) | (0.206) | (0.246) | (0.234) | (0.272) |
| Design-engaged firm (0/1) | 0.137 | 0.178** | 0.141* | 0.303*** | 0.290*** | 0.065 |
| | (0.093) | (0.090) | (0.072) | (0.083) | (0.093) | (0.090) |
| Training-engaged firm (0/1) | 0.318*** | 0.276*** | 0.276*** | 0.258*** | 0.382*** | 0.187** |
| | (0.084) | (0.075) | (0.062) | (0.079) | (0.084) | (0.079) |
| Acquisition of existing knowledge (0/1) | -0.092 | 0.049 | 0.025 | -0.044 | 0.167* | -0.066 |
| | (0.103) | (0.095) | (0.080) | (0.091) | (0.098) | (0.101) |
| Market introduction of innovation (0/1) | 0.049 | 0.316*** | 0.267*** | 0.064 | 0.095 | 0.369*** |
| | (0.091) | (0.077) | (0.066) | (0.082) | (0.087) | (0.081) |
| Acquisition of advanced machinery (0/1) | 0.760*** | 0.685*** | 0.736*** | 0.418*** | 0.613*** | 0.762*** |
| | (0.089) | (0.066) | (0.057) | (0.077) | (0.080) | (0.069) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.430*** | 0.298*** | 0.352*** | 0.038 | 0.193** | 0.425*** |
| | (0.087) | (0.078) | (0.064) | (0.095) | (0.087) | (0.080) |
| Employment (log) | 0.111** | 0.085*** | 0.090*** | 0.054** | 0.097*** | 0.088*** |
| | (0.043) | (0.018) | (0.023) | (0.027) | (0.023) | (0.021) |
| Science graduates (%) | -0.000 | 0.002 | 0.002 | 0.003 | 0.004** | -0.003 |
| | (0.005) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.001 | 0.003** | 0.003 | 0.005* | 0.001 | 0.006** |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | -0.059 | 0.131* | 0.071 | 0.123 | 0.069 | 0.053 |
| | (0.076) | (0.067) | (0.056) | (0.083) | (0.077) | (0.069) |
| Innovation partners (0 to 7) | 0.292*** | 0.290*** | 0.277*** | 0.358*** | 0.215*** | 0.361*** |
| | (0.065) | (0.057) | (0.049) | (0.076) | (0.065) | (0.061) |
| Innovation partners (squared) (0 to 49) | -0.041*** | -0.031*** | -0.033*** | -0.035*** | -0.022* | -0.047*** |
| | (0.011) | (0.010) | (0.009) | (0.011) | (0.012) | (0.011) |
| UK innovation support (0/1) | 0.270*** | 0.208 | 0.225** | 0.077 | 0.259** | 0.198* |
| | (0.099) | (0.134) | (0.091) | (0.122) | (0.120) | (0.120) |
| EU innovation support (0/1) | -0.066 | 0.317 | 0.173 | -0.152 | -0.303 | 0.565* |
| | (0.278) | (0.308) | (0.236) | (0.259) | (0.288) | (0.309) |
| Design-engaged firm (0/1) | 0.061 | 0.066 | 0.045 | -0.078 | 0.086 | 0.034 |
| | (0.090) | (0.097) | (0.075) | (0.110) | (0.095) | (0.094) |
| Training-engaged firm (0/1) | 0.151* | 0.184** | 0.184*** | 0.115 | 0.133 | 0.197*** |
| | (0.086) | (0.072) | (0.061) | (0.085) | (0.083) | (0.076) |
| Acquisition of existing knowledge (0/1) | 0.114 | 0.200* | 0.212** | -0.139 | 0.418*** | 0.021 |
| | (0.106) | (0.110) | (0.091) | (0.115) | (0.101) | (0.119) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Market introduction of innovation (0/1) | 0.458*** | 0.750*** | 0.680*** | 0.569*** | 0.563*** | 0.753*** |
| | (0.095) | (0.071) | (0.063) | (0.111) | (0.081) | (0.078) |
| Acquisition of advanced machinery (0/1) | 0.574*** | 0.580*** | 0.607*** | 0.347*** | 0.655*** | 0.538*** |
| | (0.090) | (0.060) | (0.052) | (0.089) | (0.083) | (0.063) |
| | | | | | | |
| Number of observations | 2734.000 | 6997.000 | 7175.000 | 2557.000 | 3867.000 | 5865.000 |
| Chi-squared | 35207.014 | 37453.235 | 4014.834 | 49301.559 | 1720.200 | 2844.421 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| bic | 86309.671 | 2.88e+05 | 3.47e+05 | 27388.976 | 1.31e+05 | 2.43e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table A4.4: Modelling the link between UK-supported and unsupported R&D engagement, innovation and turnover growth – sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Turnover growth model** | | | | | | |
| Product/service innovator (lag) | 0.083 | -0.556*** | -0.462*** | 0.749*** | 0.226 | -0.489*** |
| | (0.123) | (0.138) | (0.149) | (0.157) | (0.173) | (0.143) |
| Process innovator (lag) | 0.047 | 0.430*** | 0.387*** | -0.576** | 0.140 | 0.444*** |
| | (0.103) | (0.097) | (0.102) | (0.228) | (0.171) | (0.094) |
| Organisational innovator (lag) | -0.085 | 0.231** | 0.198** | -0.654** | -0.297 | 0.148** |
| | (0.183) | (0.093) | (0.098) | (0.260) | (0.290) | (0.071) |
| Employment (log) | 0.046*** | 0.079*** | 0.099*** | 0.088*** | 0.072*** | 0.077*** |
| | (0.014) | (0.014) | (0.017) | (0.031) | (0.018) | (0.015) |
| Science graduates (%) | 0.002 | 0.000 | 0.001 | -0.001 | 0.000 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.002) | (0.001) | (0.002) |
| Other graduates (%) | -0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001* |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Exporting firm (0/1) | 0.049* | 0.030 | 0.035 | 0.063 | 0.048 | 0.035 |
| | (0.029) | (0.029) | (0.025) | (0.057) | (0.039) | (0.029) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 1.192*** | 0.430*** | 0.698*** | 0.688*** | 0.874*** | 0.633*** |
| | (0.129) | (0.145) | (0.116) | (0.156) | (0.146) | (0.134) |
| R&D without UK support (0/1) | 0.684*** | 0.359*** | 0.438*** | 0.536*** | 0.531*** | 0.412*** |
| | (0.090) | (0.067) | (0.060) | (0.109) | (0.086) | (0.072) |
| Employment (log) | -0.006 | 0.039* | 0.065** | -0.105*** | 0.011 | 0.045* |
| | (0.037) | (0.021) | (0.027) | (0.031) | (0.025) | (0.027) |
| Science graduates (%) | 0.003 | 0.003 | 0.002 | 0.007** | 0.003 | 0.004 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.000 | 0.002* | 0.002 | 0.004 | 0.002 | 0.002 |
| | (0.004) | (0.001) | (0.001) | (0.003) | (0.002) | (0.002) |
| Exporting firm (0/1) | 0.138 | 0.131** | 0.138** | 0.128 | 0.045 | 0.168** |
| | (0.084) | (0.064) | (0.055) | (0.097) | (0.081) | (0.067) |
| Innovation partners (0 to 7) | 0.470*** | 0.500*** | 0.504*** | 0.464*** | 0.479*** | 0.496*** |
| | (0.070) | (0.055) | (0.050) | (0.057) | (0.068) | (0.062) |
| Innovation partners (squared) (0 to 49) | -0.060*** | -0.067*** | -0.068*** | -0.050*** | -0.063*** | -0.065*** |
| | (0.012) | (0.009) | (0.008) | (0.009) | (0.011) | (0.010) |
| EU innovation support (0/1) | -0.273 | 0.270 | 0.062 | 0.071 | -0.367 | 0.268 |
| | (0.345) | (0.278) | (0.240) | (0.267) | (0.280) | (0.273) |
| Design-engaged firm (0/1) | 0.335*** | 0.227*** | 0.245*** | 0.272** | 0.275*** | 0.248*** |
| | (0.095) | (0.075) | (0.066) | (0.116) | (0.093) | (0.080) |
| Training-engaged firm (0/1) | 0.116 | 0.241*** | 0.204*** | 0.323*** | 0.126 | 0.257*** |
| | (0.088) | (0.066) | (0.058) | (0.099) | (0.086) | (0.072) |
| Acquisition of existing knowledge (0/1) | -0.002 | 0.058 | 0.067 | -0.169 | 0.169 | -0.074 |
| | (0.116) | (0.083) | (0.076) | (0.115) | (0.110) | (0.090) |
| Market introduction of innovation (0/1) | 0.698*** | 0.634*** | 0.638*** | 0.500*** | 0.660*** | 0.611*** |
| | (0.097) | (0.068) | (0.065) | (0.099) | (0.082) | (0.078) |
| Acquisition of advanced machinery (0/1) | 0.391*** | 0.311*** | 0.327*** | 0.149 | 0.439*** | 0.278*** |
| | (0.083) | (0.062) | (0.054) | (0.101) | (0.079) | (0.067) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.412*** | 0.321** | 0.357*** | 0.823*** | 0.193 | 0.487*** |
| | (0.132) | (0.144) | (0.105) | (0.147) | (0.145) | (0.132) |
| R&D without UK support (0/1) | 0.161* | 0.345*** | 0.306*** | 0.272*** | 0.169* | 0.363*** |
| | (0.091) | (0.081) | (0.068) | (0.082) | (0.092) | (0.082) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Employment (log) | 0.046 | 0.017 | 0.004 | 0.015 | 0.028 | 0.026 |
| | (0.031) | (0.022) | (0.026) | (0.023) | (0.026) | (0.025) |
| Science graduates (%) | -0.002 | 0.003 | 0.002 | 0.004 | 0.002 | 0.006 |
| | (0.005) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.002 | 0.001 | 0.004* | 0.002 | 0.000 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.009 | -0.076 | -0.048 | 0.006 | 0.023 | -0.071 |
| | (0.084) | (0.079) | (0.063) | (0.085) | (0.088) | (0.075) |
| Innovation partners (0 to 7) | 0.351*** | 0.376*** | 0.339*** | 0.513*** | 0.348*** | 0.377*** |
| | (0.062) | (0.055) | (0.046) | (0.063) | (0.062) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.034*** | -0.047*** | -0.039*** | -0.062*** | -0.042*** | -0.044*** |
| | (0.010) | (0.009) | (0.008) | (0.010) | (0.010) | (0.009) |
| EU innovation support (0/1) | 0.060 | 0.364 | 0.280 | -0.441* | 0.067 | 0.370 |
| | (0.236) | (0.296) | (0.208) | (0.254) | (0.226) | (0.282) |
| Design-engaged firm (0/1) | 0.143 | 0.184** | 0.147** | 0.298*** | 0.293*** | 0.073 |
| | (0.092) | (0.090) | (0.072) | (0.083) | (0.093) | (0.089) |
| Training-engaged firm (0/1) | 0.327*** | 0.280*** | 0.280*** | 0.261*** | 0.387*** | 0.191** |
| | (0.084) | (0.074) | (0.062) | (0.079) | (0.083) | (0.078) |
| Acquisition of existing knowledge (0/1) | -0.081 | 0.044 | 0.027 | -0.042 | 0.168* | -0.063 |
| | (0.103) | (0.095) | (0.080) | (0.091) | (0.098) | (0.101) |
| Market introduction of innovation (0/1) | 0.045 | 0.319*** | 0.270*** | 0.062 | 0.096 | 0.372*** |
| | (0.090) | (0.076) | (0.066) | (0.082) | (0.087) | (0.081) |
| Acquisition of advanced machinery (0/1) | 0.774*** | 0.688*** | 0.742*** | 0.421*** | 0.619*** | 0.766*** |
| | (0.088) | (0.065) | (0.057) | (0.077) | (0.080) | (0.069) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.514*** | 0.460** | 0.445*** | 0.079 | 0.307** | 0.555*** |
| | (0.132) | (0.182) | (0.116) | (0.159) | (0.151) | (0.163) |
| R&D without UK support (0/1) | 0.427*** | 0.292*** | 0.353*** | 0.038 | 0.195** | 0.419*** |
| | (0.084) | (0.081) | (0.066) | (0.096) | (0.088) | (0.083) |
| Employment (log) | 0.109*** | 0.085*** | 0.092*** | 0.054** | 0.097*** | 0.089*** |
| | (0.036) | (0.018) | (0.023) | (0.027) | (0.023) | (0.021) |
| Science graduates (%) | 0.001 | 0.002 | 0.002 | 0.003 | 0.004** | -0.003 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.001 | 0.003** | 0.003 | 0.005* | 0.001 | 0.006** |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | -0.056 | 0.130* | 0.072 | 0.124 | 0.071 | 0.052 |
| | (0.075) | (0.067) | (0.056) | (0.083) | (0.076) | (0.069) |
| Innovation partners (0 to 7) | 0.305*** | 0.294*** | 0.284*** | 0.358*** | 0.221*** | 0.367*** |
| | (0.065) | (0.057) | (0.049) | (0.075) | (0.065) | (0.061) |
| Innovation partners (squared) (0 to 49) | -0.042*** | -0.032*** | -0.034*** | -0.035*** | -0.023* | -0.047*** |
| | (0.011) | (0.010) | (0.009) | (0.011) | (0.012) | (0.011) |
| EU innovation support (0/1) | 0.084 | 0.469 | 0.333 | -0.115 | -0.156 | 0.717** |
| | (0.277) | (0.295) | (0.233) | (0.252) | (0.284) | (0.298) |
| Design-engaged firm (0/1) | 0.068 | 0.067 | 0.050 | -0.078 | 0.091 | 0.037 |
| | (0.088) | (0.097) | (0.075) | (0.110) | (0.095) | (0.094) |
| Training-engaged firm (0/1) | 0.161* | 0.186** | 0.186*** | 0.115 | 0.136* | 0.199*** |
| | (0.084) | (0.072) | (0.061) | (0.085) | (0.082) | (0.076) |
| Acquisition of existing knowledge (0/1) | 0.124 | 0.200* | 0.214** | -0.138 | 0.418*** | 0.023 |
| | (0.105) | (0.110) | (0.091) | (0.115) | (0.101) | (0.119) |
| Market introduction of innovation (0/1) | 0.462*** | 0.751*** | 0.681*** | 0.569*** | 0.562*** | 0.754*** |
| | (0.091) | (0.071) | (0.062) | (0.110) | (0.081) | (0.077) |
| Acquisition of advanced machinery (0/1) | 0.586*** | 0.582*** | 0.611*** | 0.348*** | 0.660*** | 0.542*** |
| | (0.082) | (0.060) | (0.052) | (0.089) | (0.083) | (0.063) |
| | | | | | | |
| Number of observations | 2734.000 | 6997.000 | 7175.000 | 2557.000 | 3867.000 | 5865.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Chi-squared | 35420.161 | 36333.480 | 4035.155 | 41246.647 | 1727.061 | 2845.677 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| bic | 86493.016 | 2.88e+05 | 3.47e+05 | 27451.455 | 1.31e+05 | 2.44e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table A4.5: Modelling the link between R&D engagement, innovation and employment growth: sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Employment growth model** | | | | | | |
| Product/service innovator (lag) | 0.137 | 0.464*** | 0.319*** | 0.885*** | 0.113 | 0.155 |
| | (0.145) | (0.075) | (0.071) | (0.129) | (0.202) | (0.136) |
| Process innovator (lag) | 0.207 | -0.062 | 0.228*** | -0.255 | 0.540*** | 0.316*** |
| | (0.169) | (0.192) | (0.083) | (0.256) | (0.122) | (0.087) |
| Organisational innovator (lag) | -0.365*** | -0.513*** | -0.514*** | -1.116*** | -0.658*** | -0.377*** |
| | (0.061) | (0.072) | (0.043) | (0.177) | (0.092) | (0.091) |
| Employment (log) | 0.085*** | 0.201*** | 0.229*** | 0.281*** | 0.230*** | 0.146*** |
| | (0.014) | (0.022) | (0.024) | (0.106) | (0.028) | (0.023) |
| Science graduates (%) | 0.000 | 0.001 | 0.000 | 0.002 | 0.001** | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.004) | (0.001) | (0.001) |
| Other graduates (%) | 0.000 | 0.000 | -0.000 | 0.006*** | -0.001 | 0.002* |
| | (0.001) | (0.001) | (0.000) | (0.002) | (0.001) | (0.001) |
| Exporting firm (0/1) | -0.009 | 0.000 | -0.017 | -0.035 | -0.007 | -0.019 |
| | (0.019) | (0.025) | (0.019) | (0.071) | (0.028) | (0.025) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.737*** | 0.397*** | 0.481*** | 0.486*** | 0.561*** | 0.453*** |
| | (0.088) | (0.075) | (0.061) | (0.111) | (0.083) | (0.079) |
| Employment (log) | -0.061 | -0.095*** | -0.112*** | -0.235*** | -0.016 | -0.052 |
| | (0.060) | (0.026) | (0.034) | (0.048) | (0.075) | (0.045) |
| Science graduates (%) | 0.002 | 0.004* | 0.003* | 0.006** | 0.003 | 0.006 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.001 | 0.003* | 0.002 | 0.005* | 0.003 | 0.003 |
| | (0.004) | (0.002) | (0.001) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.132 | 0.119* | 0.141** | 0.149 | 0.058 | 0.168** |
| | (0.085) | (0.071) | (0.058) | (0.095) | (0.084) | (0.073) |
| Innovation partners (0 to 7) | 0.452*** | 0.510*** | 0.496*** | 0.440*** | 0.476*** | 0.547*** |
| | (0.070) | (0.052) | (0.048) | (0.059) | (0.071) | (0.059) |
| Innovation partners (squared) (0 to 49) | -0.057*** | -0.067*** | -0.066*** | -0.044*** | -0.063*** | -0.072*** |
| | (0.012) | (0.009) | (0.008) | (0.009) | (0.012) | (0.010) |
| UK innovation support (0/1) | 0.439*** | 0.152 | 0.235*** | 0.242** | 0.295** | 0.226** |
| | (0.095) | (0.107) | (0.078) | (0.110) | (0.118) | (0.103) |
| EU innovation support (0/1) | -0.378 | 0.183 | 0.015 | -0.037 | -0.437 | 0.240 |
| | (0.297) | (0.285) | (0.235) | (0.263) | (0.276) | (0.293) |
| Design-engaged firm (0/1) | 0.349*** | 0.201** | 0.215*** | 0.226** | 0.263*** | 0.258*** |
| | (0.094) | (0.086) | (0.069) | (0.114) | (0.096) | (0.090) |
| Training-engaged firm (0/1) | 0.109 | 0.283*** | 0.229*** | 0.264** | 0.116 | 0.297*** |
| | (0.088) | (0.073) | (0.062) | (0.106) | (0.085) | (0.083) |
| Acquisition of existing knowledge (0/1) | 0.029 | 0.047 | 0.063 | -0.235* | 0.163 | -0.085 |
| | (0.113) | (0.093) | (0.082) | (0.124) | (0.110) | (0.107) |
| Market introduction of innovation (0/1) | 0.714*** | 0.705*** | 0.716*** | 0.598*** | 0.677*** | 0.714*** |
| | (0.094) | (0.068) | (0.059) | (0.106) | (0.088) | (0.079) |
| Acquisition of advanced machinery (0/1) | 0.376*** | 0.334*** | 0.360*** | 0.181 | 0.444*** | 0.237*** |
| | (0.088) | (0.067) | (0.059) | (0.113) | (0.083) | (0.074) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.195** | 0.314*** | 0.280*** | 0.295*** | 0.189** | 0.343*** |
| | (0.085) | (0.080) | (0.064) | (0.089) | (0.087) | (0.076) |
| Employment (log) | -0.028 | 0.034 | -0.093** | 0.087 | -0.126*** | -0.069** |
| | (0.077) | (0.074) | (0.045) | (0.104) | (0.043) | (0.033) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Science graduates (%) | -0.002 | 0.003 | 0.002 | 0.005 | 0.002 | 0.004 |
| | (0.005) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.001 | 0.002 | 0.002 | 0.004* | 0.002 | 0.000 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.021 | -0.084 | -0.024 | -0.047 | 0.053 | -0.054 |
| | (0.081) | (0.082) | (0.063) | (0.091) | (0.079) | (0.076) |
| Innovation partners (0 to 7) | 0.334*** | 0.368*** | 0.305*** | 0.566*** | 0.298*** | 0.327*** |
| | (0.059) | (0.060) | (0.047) | (0.064) | (0.056) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.032*** | -0.048*** | -0.036*** | -0.069*** | -0.035*** | -0.038*** |
| | (0.010) | (0.010) | (0.008) | (0.010) | (0.009) | (0.009) |
| UK innovation support (0/1) | 0.357*** | 0.305** | 0.286*** | 0.522*** | 0.167 | 0.351*** |
| | (0.096) | (0.119) | (0.084) | (0.126) | (0.103) | (0.104) |
| EU innovation support (0/1) | -0.104 | 0.052 | 0.076 | -0.436 | -0.123 | 0.152 |
| | (0.229) | (0.294) | (0.200) | (0.271) | (0.228) | (0.246) |
| Design-engaged firm (0/1) | 0.135 | 0.221** | 0.134* | 0.314*** | 0.225*** | 0.064 |
| | (0.085) | (0.091) | (0.070) | (0.093) | (0.084) | (0.083) |
| Training-engaged firm (0/1) | 0.314*** | 0.279*** | 0.297*** | 0.294*** | 0.362*** | 0.264*** |
| | (0.082) | (0.080) | (0.061) | (0.084) | (0.074) | (0.075) |
| Acquisition of existing knowledge (0/1) | -0.032 | 0.067 | 0.059 | -0.032 | 0.164* | -0.018 |
| | (0.106) | (0.096) | (0.075) | (0.104) | (0.085) | (0.094) |
| Market introduction of innovation (0/1) | 0.048 | 0.299*** | 0.262*** | 0.014 | 0.154* | 0.329*** |
| | (0.090) | (0.078) | (0.064) | (0.099) | (0.081) | (0.077) |
| Acquisition of advanced machinery (0/1) | 0.759*** | 0.680*** | 0.767*** | 0.403*** | 0.627*** | 0.797*** |
| | (0.085) | (0.075) | (0.056) | (0.089) | (0.072) | (0.071) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D firm (0/1) | 0.435*** | 0.238*** | 0.342*** | 0.028 | 0.154** | 0.385*** |
| | (0.077) | (0.070) | (0.054) | (0.074) | (0.074) | (0.078) |
| Employment (log) | 0.245*** | 0.267*** | 0.360*** | 0.398*** | 0.273*** | 0.237*** |
| | (0.047) | (0.037) | (0.046) | (0.106) | (0.044) | (0.050) |
| Science graduates (%) | -0.001 | 0.002 | 0.002 | 0.006** | 0.004** | -0.004 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.003** | 0.004** | 0.003 | 0.002 | 0.005* |
| | (0.003) | (0.002) | (0.001) | (0.002) | (0.001) | (0.003) |
| Exporting firm (0/1) | -0.043 | 0.104* | 0.036 | 0.122* | 0.049 | 0.053 |
| | (0.073) | (0.061) | (0.050) | (0.066) | (0.070) | (0.064) |
| Innovation partners (0 to 7) | 0.262*** | 0.309*** | 0.290*** | 0.229*** | 0.214*** | 0.341*** |
| | (0.057) | (0.051) | (0.043) | (0.073) | (0.054) | (0.057) |
| Innovation partners (squared) (0 to 49) | -0.034*** | -0.037*** | -0.037*** | -0.024** | -0.023** | -0.045*** |
| | (0.010) | (0.009) | (0.007) | (0.010) | (0.009) | (0.010) |
| UK innovation support (0/1) | 0.263*** | 0.209* | 0.228*** | 0.086 | 0.257*** | 0.217** |
| | (0.087) | (0.118) | (0.079) | (0.089) | (0.100) | (0.107) |
| EU innovation support (0/1) | 0.016 | 0.345 | 0.255 | 0.005 | 0.007 | 0.406* |
| | (0.254) | (0.265) | (0.217) | (0.159) | (0.330) | (0.242) |
| Design-engaged firm (0/1) | 0.016 | 0.131 | 0.064 | 0.082 | 0.085 | 0.082 |
| | (0.079) | (0.083) | (0.063) | (0.075) | (0.079) | (0.087) |
| Training-engaged firm (0/1) | 0.152** | 0.136** | 0.128** | 0.086 | 0.121* | 0.171** |
| | (0.074) | (0.064) | (0.054) | (0.066) | (0.070) | (0.074) |
| Acquisition of existing knowledge (0/1) | -0.002 | 0.230** | 0.172** | 0.020 | 0.328*** | 0.065 |
| | (0.102) | (0.097) | (0.078) | (0.078) | (0.084) | (0.111) |
| Market introduction of innovation (0/1) | 0.428*** | 0.673*** | 0.610*** | 0.350*** | 0.471*** | 0.675*** |
| | (0.085) | (0.067) | (0.055) | (0.104) | (0.072) | (0.076) |
| Acquisition of advanced machinery (0/1) | 0.529*** | 0.474*** | 0.499*** | 0.224*** | 0.584*** | 0.489*** |
| | (0.090) | (0.061) | (0.052) | (0.072) | (0.070) | (0.075) |
| | | | | | | |
| Number of observations | 2734.000 | 6997.000 | 7175.000 | 2557.000 | 3865.000 | 5867.000 |
| Chi-squared | 1.24e+06 | 9793.413 | 4762.954 | 1919.968 | 2561.566 | 2849.175 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| bic | 69396.834 | 2.56e+05 | 2.99e+05 | 25651.571 | 1.21e+05 | 2.04e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

## Table A4.6: Modelling the link between UK-supported and unsupported R&D engagement, innovation and employment growth – sub-sample estimates

| | Manuf-acturing firms | Service firms | SMEs | Larger firms | HT/KI firms | LT/LKI firms |
|---|---|---|---|---|---|---|
| **A. Employment growth model** | | | | | | |
| Product/service innovator (lag) | 0.248*** | 0.462*** | 0.311*** | 0.885*** | 0.112 | 0.149 |
| | (0.070) | (0.082) | (0.071) | (0.129) | (0.185) | (0.139) |
| Process innovator (lag) | -0.066 | -0.056 | 0.238*** | -0.249 | 0.541*** | 0.322*** |
| | (0.182) | (0.223) | (0.079) | (0.256) | (0.113) | (0.087) |
| Organisational innovator (lag) | -0.324*** | -0.514*** | -0.513*** | -1.118*** | -0.656*** | -0.375*** |
| | (0.079) | (0.073) | (0.044) | (0.176) | (0.089) | (0.093) |
| Employment (log) | 0.088*** | 0.201*** | 0.229*** | 0.282*** | 0.229*** | 0.146*** |
| | (0.015) | (0.022) | (0.024) | (0.106) | (0.028) | (0.023) |
| Science graduates (%) | 0.000 | 0.001 | 0.000 | 0.002 | 0.001** | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.004) | (0.001) | (0.001) |
| Other graduates (%) | 0.000 | 0.000 | -0.000 | 0.006*** | -0.001 | 0.001* |
| | (0.001) | (0.001) | (0.000) | (0.002) | (0.001) | (0.001) |
| Exporting firm (0/1) | -0.020 | 0.000 | -0.017 | -0.035 | -0.008 | -0.018 |
| | (0.019) | (0.025) | (0.019) | (0.071) | (0.028) | (0.026) |
| **B. Product/service innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 1.129*** | 0.495*** | 0.718*** | 0.641*** | 0.881*** | 0.678*** |
| | (0.126) | (0.150) | (0.111) | (0.152) | (0.149) | (0.148) |
| R&D without UK support (0/1) | 0.653*** | 0.394*** | 0.461*** | 0.480*** | 0.535*** | 0.435*** |
| | (0.088) | (0.078) | (0.063) | (0.113) | (0.086) | (0.081) |
| Employment (log) | -0.087** | -0.094*** | -0.109*** | -0.236*** | -0.016 | -0.049 |
| | (0.041) | (0.026) | (0.035) | (0.048) | (0.070) | (0.046) |
| Science graduates (%) | 0.003 | 0.004* | 0.003* | 0.006** | 0.003 | 0.006 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | -0.002 | 0.003* | 0.002 | 0.005* | 0.003 | 0.003 |
| | (0.004) | (0.002) | (0.001) | (0.003) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.145* | 0.120* | 0.141** | 0.150 | 0.057 | 0.166** |
| | (0.082) | (0.071) | (0.058) | (0.095) | (0.083) | (0.073) |
| Innovation partners (0 to 7) | 0.457*** | 0.513*** | 0.500*** | 0.442*** | 0.478*** | 0.552*** |
| | (0.067) | (0.052) | (0.048) | (0.059) | (0.071) | (0.059) |
| Innovation partners (squared) (0 to 49) | -0.056*** | -0.068*** | -0.067*** | -0.044*** | -0.063*** | -0.072*** |
| | (0.011) | (0.009) | (0.008) | (0.009) | (0.012) | (0.010) |
| EU innovation support (0/1) | -0.269 | 0.279 | 0.114 | 0.055 | -0.391 | 0.367 |
| | (0.308) | (0.286) | (0.251) | (0.259) | (0.282) | (0.306) |
| Design-engaged firm (0/1) | 0.363*** | 0.202** | 0.217*** | 0.222* | 0.264*** | 0.258*** |
| | (0.093) | (0.087) | (0.070) | (0.113) | (0.095) | (0.090) |
| Training-engaged firm (0/1) | 0.141* | 0.284*** | 0.232*** | 0.266** | 0.124 | 0.299*** |
| | (0.085) | (0.073) | (0.062) | (0.106) | (0.085) | (0.083) |
| Acquisition of existing knowledge (0/1) | 0.029 | 0.048 | 0.064 | -0.233* | 0.166 | -0.083 |
| | (0.112) | (0.093) | (0.082) | (0.124) | (0.110) | (0.107) |
| Market introduction of innovation (0/1) | 0.667*** | 0.706*** | 0.717*** | 0.600*** | 0.675*** | 0.713*** |
| | (0.096) | (0.068) | (0.059) | (0.106) | (0.087) | (0.079) |
| Acquisition of advanced machinery (0/1) | 0.440*** | 0.336*** | 0.364*** | 0.183 | 0.447*** | 0.242*** |
| | (0.085) | (0.067) | (0.058) | (0.113) | (0.082) | (0.073) |
| **C. Process innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.438*** | 0.310** | 0.309*** | 0.843*** | 0.205 | 0.421*** |
| | (0.135) | (0.150) | (0.104) | (0.154) | (0.129) | (0.131) |
| R&D without UK support (0/1) | 0.181* | 0.332*** | 0.290*** | 0.263*** | 0.201** | 0.344*** |
| | (0.093) | (0.082) | (0.065) | (0.091) | (0.086) | (0.078) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Employment (log) | 0.085 | 0.032 | -0.095** | 0.084 | -0.127*** | -0.069** |
| | (0.098) | (0.083) | (0.043) | (0.104) | (0.041) | (0.032) |
| Science graduates (%) | -0.002 | 0.003 | 0.003 | 0.005 | 0.002 | 0.004 |
| | (0.005) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.002 | 0.002 | 0.004* | 0.002 | 0.000 |
| | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) |
| Exporting firm (0/1) | 0.014 | -0.075 | -0.018 | -0.053 | 0.059 | -0.048 |
| | (0.083) | (0.082) | (0.063) | (0.091) | (0.079) | (0.075) |
| Innovation partners (0 to 7) | 0.336*** | 0.376*** | 0.313*** | 0.571*** | 0.303*** | 0.335*** |
| | (0.065) | (0.061) | (0.047) | (0.064) | (0.056) | (0.056) |
| Innovation partners (squared) (0 to 49) | -0.032*** | -0.048*** | -0.036*** | -0.070*** | -0.035*** | -0.038*** |
| | (0.010) | (0.010) | (0.008) | (0.010) | (0.009) | (0.009) |
| EU innovation support (0/1) | 0.061 | 0.316 | 0.297 | -0.384 | -0.002 | 0.427* |
| | (0.243) | (0.294) | (0.199) | (0.284) | (0.221) | (0.250) |
| Design-engaged firm (0/1) | 0.149 | 0.229** | 0.142** | 0.307*** | 0.227*** | 0.075 |
| | (0.095) | (0.091) | (0.069) | (0.094) | (0.084) | (0.082) |
| Training-engaged firm (0/1) | 0.306*** | 0.282*** | 0.300*** | 0.298*** | 0.363*** | 0.269*** |
| | (0.092) | (0.080) | (0.060) | (0.085) | (0.074) | (0.074) |
| Acquisition of existing knowledge (0/1) | -0.094 | 0.065 | 0.062 | -0.030 | 0.165* | -0.014 |
| | (0.121) | (0.096) | (0.075) | (0.105) | (0.085) | (0.093) |
| Market introduction of innovation (0/1) | 0.034 | 0.301*** | 0.265*** | 0.013 | 0.156* | 0.333*** |
| | (0.092) | (0.078) | (0.064) | (0.099) | (0.080) | (0.077) |
| Acquisition of advanced machinery (0/1) | 0.745*** | 0.687*** | 0.773*** | 0.407*** | 0.631*** | 0.802*** |
| | (0.110) | (0.077) | (0.056) | (0.089) | (0.072) | (0.071) |
| **D. Organisational innovator (lag) model** | | | | | | |
| R&D with UK support (0/1) | 0.551*** | 0.416** | 0.454*** | 0.066 | 0.259** | 0.527*** |
| | (0.109) | (0.166) | (0.106) | (0.111) | (0.125) | (0.150) |
| R&D without UK support (0/1) | 0.466*** | 0.229*** | 0.338*** | 0.028 | 0.158** | 0.378*** |
| | (0.076) | (0.072) | (0.056) | (0.075) | (0.074) | (0.080) |
| Employment (log) | 0.237*** | 0.268*** | 0.360*** | 0.398*** | 0.272*** | 0.236*** |
| | (0.049) | (0.037) | (0.046) | (0.105) | (0.044) | (0.051) |
| Science graduates (%) | 0.000 | 0.002 | 0.002 | 0.006** | 0.004** | -0.004 |
| | (0.004) | (0.002) | (0.002) | (0.003) | (0.002) | (0.004) |
| Other graduates (%) | 0.002 | 0.003** | 0.004** | 0.003 | 0.002 | 0.005* |
| | (0.003) | (0.002) | (0.001) | (0.002) | (0.001) | (0.003) |
| Exporting firm (0/1) | -0.023 | 0.103* | 0.036 | 0.123* | 0.052 | 0.051 |
| | (0.071) | (0.061) | (0.050) | (0.066) | (0.069) | (0.064) |
| Innovation partners (0 to 7) | 0.261*** | 0.313*** | 0.297*** | 0.231*** | 0.220*** | 0.348*** |
| | (0.058) | (0.051) | (0.043) | (0.073) | (0.054) | (0.057) |
| Innovation partners (squared) (0 to 49) | -0.035*** | -0.038*** | -0.038*** | -0.024** | -0.023** | -0.045*** |
| | (0.010) | (0.009) | (0.007) | (0.010) | (0.009) | (0.010) |
| EU innovation support (0/1) | 0.107 | 0.491** | 0.406** | 0.050 | 0.151 | 0.574** |
| | (0.254) | (0.247) | (0.206) | (0.150) | (0.321) | (0.229) |
| Design-engaged firm (0/1) | 0.022 | 0.133 | 0.069 | 0.082 | 0.091 | 0.085 |
| | (0.079) | (0.083) | (0.063) | (0.075) | (0.079) | (0.087) |
| Training-engaged firm (0/1) | 0.127* | 0.138** | 0.131** | 0.086 | 0.126* | 0.173** |
| | (0.073) | (0.064) | (0.054) | (0.066) | (0.070) | (0.074) |
| Acquisition of existing knowledge (0/1) | 0.022 | 0.231** | 0.174** | 0.021 | 0.328*** | 0.068 |
| | (0.107) | (0.097) | (0.078) | (0.077) | (0.084) | (0.111) |
| Market introduction of innovation (0/1) | 0.460*** | 0.673*** | 0.610*** | 0.350*** | 0.471*** | 0.675*** |
| | (0.085) | (0.067) | (0.055) | (0.104) | (0.071) | (0.076) |
| Acquisition of advanced machinery (0/1) | 0.492*** | 0.477*** | 0.505*** | 0.226*** | 0.590*** | 0.495*** |
| | (0.082) | (0.061) | (0.052) | (0.073) | (0.070) | (0.075) |
| | | | | | | |
| Number of observations | 2734.000 | 6997.000 | 7175.000 | 2557.000 | 3865.000 | 5867.000 |
| Chi-squared | 1.46e+06 | 10092.218 | 4800.932 | 1989.430 | 2545.536 | 2849.642 |
| p | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| bic | 70117.359 | 2.56e+05 | 2.99e+05 | 25607.492 | 1.22e+05 | 2.04e+05 |

**Notes:** Coefficients are reported with standard errors below. Models contain both wave and sector dummies. Observations are weighted to give representative results. * denotes significance at the 10 per cent level, ** denotes significance at the 5 per cent level and *** denotes significance at the 1 per cent level.

**Source:** UK Innovation Surveys 4 to 8

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