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Estimating Innovation Spillovers: an International Sectoral and UK Enterprise Study

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1. Summary and Conclusions

1.1 Background

Spillovers and externalities are an important focus for government policy because their existence implies that individual private sector decision makers under-invest where there are positive spillovers and over-invest where the spillovers are negative. Left to itself, the market under-invests in knowledge because the investor cannot appropriate all of the benefits of producing new knowledge and over-invests in activities that create pollution insofar as the investor does not have to pay for restricting or cleaning up the pollution.

Therefore it is widely believed that spillovers drive a wedge between the private and socially optimal investments in activities such as R&D and innovation. The economic literature suggests that these are areas of under-investment by private investors because the results of the knowledge production and the resulting novel and improved products can be used productively by others in ways that the resulting benefits cannot be appropriated by the knowledge producer / product innovator.

This report focuses on rent spillovers, sometimes referred to as embodied spillovers. These occur because the knowledge producer fails to charge the amount that the user would be willing to pay for the knowledge. The report argues that this form of spillover is much more than just a price index measurement problem as suggested by Griliches. In practice, the knowledge producer cannot charge the right amount if they do not understand what the buyer might use the knowledge for, what benefit they will get from the knowledge and if they cannot price discriminate between buyers.

The ability to focus on spillovers that need not be entirely free opens up new areas of interest, such as the supply chain. It is well known that there are incentives for cooperation and collaboration along the supply chain, as the performance of any one firm is dependent on that of its suppliers. However, R&D and / or innovation by any firm or sector may affect the performance of other firms and sectors that it supplies irrespective of whether collaboration takes place or not.

At the heart of the present report, therefore, is the input-output matrix, which shows the flows of products and services from one sector to another (a part of the supply chain). Product innovation by one sector will produce opportunities and challenges for the sectors that buy its output. While this may affect the buying sectors' productivity and / or profits in the short-term, it may also produce opportunities or the need for the buyers themselves to innovate.

Unlike the restricted "pure" spillovers that have to be free, examples abound for these broader types of spillover: the way in which the Bessemer process revolutionised steel production and the opportunity this produced for building skyscrapers, radically altering the construction sector; the way in which computers have altered production processes, with CNC machine tools or 3D printers, and the effects these products have on what can be produced by other sectors and where production takes place.

1.2 Hypotheses

Two principle questions are explored in the present report:

- does R&D, learning and training (proxied by purchases from the education sector), employee skills etc. in one sector influence the productivity, profitability and export performance of other sectors;
- does innovation in one sector influence innovation in other sectors and does own-sector innovation or innovation by other sectors affect enterprise demographics (e.g. firm births or deaths)?

Both of these could be sources of endogenous growth.

In the first case, for example, if R&D in one sector raises the profitability of the sectors it supplies, the higher profits may lead to increased spending on R&D by those sectors, raising the profitability of the sectors it supplies, and so on. In the second case, if innovation by one sector increases the innovation in the sectors it supplies, then their innovation may increase the innovation in sectors that they supply, and so on. These flows through the input-output matrix may provide the mechanism for sustained endogenous growth.

The final question examined concerns Schumpter's concept of creative destruction. According to Schumpeter, a consequence of the innovation process will be the creation and destruction of enterprises. If creative destruction is the mechanism by which the economy transforms itself, it should be possible to see it as a link between own-innovation, exposure to innovation spillovers and firm demographics (births, deaths, churn – the sum of the birth and death rates – and survival rates).

1.3 Data and measures

The hypotheses are demanding in terms of the data needed to test them. The work has involved matching a variety of data sets at two levels, enterprise and sector:

- a UK enterprise level database was constructed by matching the Annual Respondents Database (ARD) and the UK Innovations Survey (UKIS)[1], with sector level data matched from the EU data set described below;
- a sector level data set was constructed using a variety of sources, including the World Input-Output Database (WIOD) and the WIOD Socio Economic

[1] The UK E-Commerce and ICT survey was also matched, but the resulting number of observations that covered all three surveys was small.

Accounts data, confidential Community Innovations Survey data from SAFE (Eurostat), confidential UKIS (from the SDS Virtual Laboratory), CE R&D data supplemented by Eurostat and OECD R&D data.

Key dependent variables follow the hypotheses set out in Section 1.2:

- enterprise performance
    - four measures of labour productivity and total factor productivity
    - gross profits and net profits per unit of value added
    - exports per unit gross output and the export / import ratio;

- innovation activities
    - product innovation
    - process innovation
    - innovation activities which saw the introduction of a new or significantly improved good or service by the firm onto its operating market before other competitors
    - business demographics (e.g. births, deaths, churn and survival).

All these measures are available at the sector level, but only two measures of productivity are available at the enterprise level (i.e. labour productivity and total factor productivity).

Independent variables in the enterprise performance level include:

- own-investments:
    - skill levels;
    - R&D expenditure;
    - educational purchases (i.e. the amount spent buying goods and services from the Education sector – schools, further and higher education institutions)[2];
- exposure to spillovers:
    - skill level spillovers[3];
    - R&D spillovers;
    - educational spillovers.

It is assumed that the exposure to supplying sectors' R&D, etc. is in proportion to the relative amounts of intermediate goods the sector in question purchased from the other sectors. A number of other variables taken from the UKIS were included in the enterprise level study:

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[2] These purchases may take a wide range of different forms, including training employees (e.g. MBAs), hiring specialist equipment to carry out measurement and testing, funding research laboratories, etc. The diversity of goods and services bought from the Education sector alleviates problems of collinearity with the R&D variable.

[3] High levels of collinearity between skill levels and skill level spillovers made it impossible to include both sets of variables in the model. So it was decided to control for skill levels.

- R&D (internal and external);
- training;
- innovation (product, process and new to market innovation).

At the sector level, independent variables influencing innovation included own-prior innovation (the three measures outlined above) and exposure to innovation spillovers (the corresponding three spillover variables).

1.5 European Sector Level Results: Sector Performance

1.5.1 Productivity model results

The productivity model was estimated on the quasi panel data set formed by country and sector over time. Three groups of measures of performance were examined: labour productivity; profit per unit of output; and international trade performance (export per unit of gross output and export/import ratios). All of the results gave support for some form of spillover from intermediate goods suppliers to buyers.

In the case of labour productivity, own-R&D and exposure to R&D spillovers both played a consistent positive role. In the case of R&D spillovers, there was tentative evidence that the size of the spillover coefficient was at least as large, and probably larger, than the own-R&D coefficient.

In the preferred regressions containing the R&D and R&D spillover interaction terms with sectors and countries, enterprises with higher proportions of medium skill hours had higher labour productivity than those with higher proportions of low skill hours; likewise, enterprises with higher proportions of high skill hours had higher labour productivity than those with higher proportions of medium skill hours.

While own-educational purchases were significantly positively related to labour productivity, educational spillovers were consistently significant negative. It is not at all clear what drives the latter result, but it clearly implies that either higher productivity firms have less need for inputs with high levels of education embedded in them or that, perhaps causality runs the other way and the higher own-skill levels of high productivity enterprises imply a lower necessity for inputs with higher education embeddedness.

1.5.2 Profitability results

An extensive literature has linked profits (or market value or dividends) to own-R&D and R&D spillovers, but focusing on technological distance or spatial distance. In the present case, where the research is focusing on rent or embodied spillovers, it becomes crucial to know if the exposure to spillovers is reflected in the buying enterprises' profits. If there is no increase in buyer-profit, it may be that the supplier is able to appropriate all of the benefits of its R&D or educational purchases.

Own-R&D and own-educational purchases were expected to have significant negative coefficients insofar as they are funded from retained profits. In the preferred measure, gross profit per unit of value added, the coefficients on own-R&D and own-education tend to be very small and insignificant (whether positive or negative). This appears to be because firms that do R&D continue to do so over time and past R&D raises current profits to a level that allows current investment in R&D.

The coefficient on both exposure to R&D spillovers and education spillovers are significant positive. This is true for all of the regressions in the case of education spillovers and the coefficient on R&D spillovers only goes insignificant when the R&D spillover interaction terms on country and sector are introduced into the regression. Many of the R&D spillover interaction coefficients are themselves significantly different to the chosen base country and sector (the UK and the chemicals sector).

The proportion of self-employed and the size of capital stock both have significant positive coefficients. The former is consistent with self-employed funding their income out of profit and the latter is consistent with the need for higher profit margins to cover greater capital consumption. The only unexpected negative coefficient is on the proportion of medium skill hours vis a vis low skill hours. This issue is not resolved by the inclusion of the interaction terms, as it was in the case of labour productivity.

1.5.3 International trade results

While it is not intended to imply that higher exports per unit of gross output or export / import ratio should necessarily be viewed as better than lower values, they appear a likely consequence of higher levels of R&D, educational output and innovation activities (other things equal). The idea is that improvements in product quality (vis a vis competitor countries) will lead to increases in exports and to domestic import substitution (so called “export led growth”).

The resulting estimates of both trade functions suggest that own-R&D is positive throughout for both variables, except when the sector R&D interaction variables are included in the export/import ratio equation. Its coefficients are largely significant at the 10 per cent level or higher.

However, R&D spillover coefficients are almost entirely negative in the export / gross output equation – it is only in the final regression, which includes the sector R&D interaction variables that it becomes positive and is significant at the 10 per cent level or higher. In this regression the coefficient is also considerably larger than the own R&D coefficient. However, the further lack of support for a positive R&D spillover effect in the export / import ratio equation suggest that the final positive coefficient in the export / gross output equation is probably spurious.

The higher proportion of medium skill hours generally has a small positive coefficient vis a vis the proportion of low skill hours, but a higher proportion of high skill hours generally have significant and positive coefficients. The introduction of the R&D and

R&D spillover interaction terms tend to have a disruptive effect on the coefficient estimates – particularly the introduction of the sector interaction variables.

Education and exposure to education spillovers both tend to have positive and significant coefficients. There is considerable evidence that the size of the spillover coefficient is considerably larger than the own-education coefficient. Again, the inclusion of the sector interaction terms tends to be disruptive.

1.6 European Sector Level Results: Innovation, Endogenous Growth and Creative Destruction

1.6.1 Innovation and endogenous growth

The first of the "dynamic" questions is whether past innovation activities affect future innovation. The expectation is that an innovative sector in one period will continue to be innovative in the next, although the degree of innovation may increase or decrease with the passage of time. Persistent levels of own-innovation are controlled for by the sector and country dummies, and interest focuses on whether increased levels of prior innovation impact on future levels. An even more interesting question is whether the innovation of suppliers in one period impacts on the subsequent innovation of the buyer sectors.

Own-innovation is measured as the proportion of enterprises in the sector reporting that they have carried out product, process or (new to market) product launch innovation in the preceding two years. Exposure to innovation spillovers is measured as the weighted sum of the innovation activity of supplying sectors, where the weights are the relative amounts of inputs purchased from those sectors.

The data are used in two ways: pairing consecutive CIS survey results (e.g. 2001 and 2004, 2004 and 2006, etc.) and by constructing a panel data set which pair the data in the same way, but merge all of the pairings together. Using these data sets, innovation in, say, 2004 is regressed on own-innovation in 2001 and the exposure to innovation by other sectors in 2001. The results control for country and sector dummies[4] and, also, in the case of the panel data set, for time dummies.

While the individual paired cross-section results are relatively weak, almost without exception, the results are consistent with the fact that not only is past own-innovation a significant positive determinant of current own innovation, but that exposure to past innovation of suppliers is also a significant positive determinant of the buyers' current own-innovation.

The results of the panel, which offers many more observations, are much stronger (see Table 1 for a summary). They suggest not only that each kind of innovation (i.e.

[4] These are important as they control for the fact that an innovative sector (or country) in one period is likely to still be innovative in the next.

product, process and new to market) is influenced by the corresponding prior innovation and innovation spillovers, but that there are cross relationships between the chosen of innovation and the prior values of other types of innovation. For example, prior process innovation has a positive and significant influence on subsequent product innovation. There is less evidence here that the spillover coefficients are *significantly* larger than the prior own-(innovation) coefficients, but they are larger for two of the three types of innovation.

Table 1: Summary of the Link between Prior Innovation and Subsequent Innovation

Subsequent: **Prior:**	**Product Innovation**	**Process Innovation**	**New to market Innovation**
Product Innovation	+	+	+
Process Innovation	+	+	
New to market innovation	+	(+)	+
Product Innovation Spillovers	+	(+)	-
Process Innovation Spillovers		+	
New to market innovation Spillovers			+

Notes: + positive sign and significant; (+) generally positive sign but not consistently significant; - negate sign and significant; shaded cells indicate the strongest results.

1.6.2 Innovation and enterprise demography: creative destruction

According to Schumpeter, the effects of innovation will be reflected in firm births and deaths, with new firms bringing in the latest technology (births) and existing firms using the old technology moving out (deaths). Thus, innovation should positively affect the birth rate, the death rate, churn (the sum of the birth and death rates) and reduce survival rates.

The results of regressing the various rates on different forms of past innovation suggest that recent past product innovation increases both the birth and death rates and, thereby, churn. In addition, there is some evidence that past own-product innovation reduces the five year rate of enterprise survival.

There is also a role for the exposure to product spillovers, with previous product spillovers reducing the birth and death rates and, thereby, at least prior to the recession, churn. In addition, there is some evidence that past exposure to product innovation spillovers increases the five year rate of enterprise survival. On the other hand, product innovation spillovers, where the supplying enterprises are the first to market have the opposite effect, raising both the birth and death rates (though the effects on churn and survival rates are less consistent).

While there is tentative evidence that the effects of prior innovation diminish with time, some of the effects appear to be quite long-lived. There are a number of significant coefficients from innovation in 2004 on the birth and survival rates in 2009 and 2010.

Table 2 summarises the correlations between prior innovation and business birth, death, churn and survival rates. The highlighted cells in these four columns provide evidence of “creative destruction”. Product innovation increases both the birth and death rates within the sector, as new products displace old products (and thereby increasing “churn” and lowering the firm survival rate), creating both “winners” and “losers” among competing firms in the sector. Interestingly, exposure to product innovation spillovers, seems to favour established firms, leading to drops in the birth, death and churn rates and an increase in the five year survival rates. Exposure to process innovation spillovers and new to market innovation spillovers, appears to have the opposite impact - exposure to these spillovers leads to “creative destruction”, with increases in both the birth rate and death rates and a drop in the survival rate.

Table 2: Summary of the Link between Prior Innovation and Business Demographics

Subsequent: / **Prior:**	**Birth Rate**	**Death Rate**	**Churn**	**5 Year Survival Rate**
Product Innovation	+	+	+	(-)
Process Innovation				
New to market innovation		(-)	(-)	
Product Innovation Spillovers	-	-	-	(+)
Process Innovation Spillovers	+	+	+	-
New to market innovation Spillovers	+	+		(+)[a]

Notes: + positive sign and significant; (+) generally positive sign but not consistently significant; - negate sign and significant; (-) generally negative sign but not consistently significant; shaded cells indicate the strongest results; a) “wrong” sign.

1.7 UK Enterprise level results

Using a matched panel dataset drawn from three large business data sources, this section combines mixed methods – including growth accounting methods and econometric modelling techniques – to study firms’ performance, as measured by labour productivity and total factor productivity.

The impacts of R&D and exposure to R&D spillovers at sector level on LP and TFP are also explored to investigate the importance of investment in R&D and innovation to firms’ economic performance. There are now two measures of R&D spillovers: one relating to the enterprise’s own sector (where technological distance should be relatively low) and one relating to the exposure to R&D carried out by suppliers. Equivalent variables are also used for own-educational purchases and exposure to educational spillovers.

The panel data analysis reveals that R&D variables and other innovation related activities affect labour productivity and total factor productivity differently. The R&D variables, including both own R&D spending and exposure to R&D spillovers from other firms, significantly influence the labour productivity – more R&D spending or spillovers lead to higher labour productivity. However, these variables appear to have no significant impact on TFP growth, at least in the panel regression.

In the case of labour productivity, the largest positive and most significant R&D coefficients are found for R&D spillovers along the supply chain, followed by own-sector spillovers, then by own-internal R&D and own purchases of external R&D.

Own-educational purchases and exposure to educational spillovers from knowledge embedded in intermediate goods, on the other hand, have a strong and positive role on TFP growth, compared to a negative one in labour productivity. In addition, while firms' own-R&D spending and innovation related activities increase firms' labour productivity significantly, they do not seem to affect firms' total factor productivity.

While matching the ARD and CIS enables the research to conduct a comprehensive study that no one has done before – with results which appear to make sense and look interesting, it also introduces selection biases which are hard to correct and require the results to be interpreted with care.

1.8 Comparison of Sector Level and Enterprise Level Results

Table 3 compares the impact of skills on performance at the sector and enterprise levels. Note that the table only covers the main variables and that care should be used in interpreting the outcomes (e.g. the expected sign is not always obvious, as in the case of own-R&D and own-educational expenditures in the profit equations).

Table 3: Summary of the Impact of Skills and Innovation on Productivity, Profits and Trade Performance

	LP (Sector)	LP (Enterprise)	TFP (Sector)	TFP (Enterprise)	Gross Profit (Sector)	Net Profit (Sector)	Export/Output (Sector)	Export/Import (Sector)
Employment	-	-	n/a	-	n/a	n/a	n/a	n/a
Capital Stock	+	+	n/a	-	+	+		
R&D (own)	+	+			(-)		(+)	+
R&D Own-sector Spillovers	n/a	+	n/a	n/a	n/a	n/a	n/a	n/a
R&D I-O Spillovers	+	+			+		(-)	
Med Skill Hours		+	+		-	-		(+)
High Skill Hours	+	+	+	-	+	+	+	+
Education Purchase	+		+	+			+	
Edu Spillovers	-	(-)	+	+	+	+	+	+
Training	na	+	na	n/a	na	na	na	na
Product Innovation	na	+	na	n/a	na	na	na	na
Process Innovation	na		na	n/a	na	na	na	na

	LP (Sector)	LP (Enterprise)	TFP (Sector)	TFP (Enterprise)	Gross Profit (Sector)	Net Profit (Sector)	Export/Output (Sector)	Export/Import (Sector)
New to market innovation	na		na	n/a	na	na	na	na

Notes: n/a – not applicable (no conceptual reason for the variable to be included); na – variable is not available or not sufficiently available to be included in the regression; + positive sign and significant; (+) generally positive sign but not consistently significant; - negate sign and significant; (-) generally negative sign but not consistently significant; shaded cells indicate the coefficient is of the "wrong" sign; empty cells indicate indeterminate sign, generally insignificantly different from zero.

The results show that the share of hours worked by highly skilled employees is positively linked to almost all of the measures of productivity, profits and trade performance. Expenditure on training is associated with increased labour productivity at the enterprise level. Purchases of goods and/or services from the Education sector (comprising schools, and further and higher education institutions) increases labour productivity at the sector level, total factor productivity at both the sector and enterprise level, and the ratio of exports to output at the sector level. Exposure to spillovers from education purchases is negatively correlated with labour productivity but positively and significantly correlated with all the other performance variables. Own-R&D spending (and product innovation at the enterprise level) are linked positively to labour productivity and export performance. Exposure to R&D spillovers from suppliers (R&D I-O Spillovers) is also linked with higher labour productivity and gross profits.

1.8 Overall conclusions

If the results of the present study are correct, R&D, education and innovation spillovers from suppliers to buyers are important mechanisms for growth and development in the economy. They appear to be linked to both the immediate and long-term performance of the UK and other European economies.

The present study provides empirical support for both R&D spillovers and education spillovers from suppliers, although their roles appear to differ, depending on what measure of economic performance is used. A role is found for R&D and / or educational spillovers in all of the performance measures examined (e.g. various forms of labour productivity, total factor productivity, profitability and export performance). However, it is not clear why R&D spillovers are positive and important in explaining various measures of labour productivity and educational spillovers are positive and important in explaining total factor productivity, but the result appears to be systematic as it occurs in both the European-wide sectoral model and the UK enterprise level model.

This study also finds empirical evidence that suggests not only that previous own-innovation affects subsequent own-innovation, but that previous innovation of supplying sectors affects subsequent own-innovation of the buyers. While the marginal effect of an innovation declines as it spawns further innovation around the input-output matrix, the cumulative amount of innovation can be large. Countries with higher innovation spillovers to own-innovation ratios will benefit more from investment in innovation.

Empirical evidence is found of creative destruction, whereby past product innovation increases the births and deaths of other enterprises in the sector and, thereby, the "churn" in the population of firms. While confirmation of Schumpeter's theory is important, the present modelling shows that innovation spillovers are perhaps even more important influences on firm demographics than own-innovation. In particular, product innovation amongst suppliers, lowers the birth and death rates of the buying sector and process innovation amongst suppliers raises the birth and death rates of buyers. These are new empirical findings and their policy implications have yet to be studied.

From an international competitive perspective, it is clear that there are important differences across countries in the extent to which their input-output systems translate R&D expenditures, educational purchases and innovation activity into the corresponding exposures to spillovers from suppliers. In addition, the report demonstrates that the "efficiency" with which spillovers are produced has been changing over time. For example, the ratio of R&D spillovers to own-R&D expenditure in 1995 ranged from 0.3 (Latvia) to 1.9 (France), with the UK ranked fourth highest, with a ratio of 1.4. By 2009, the ratio ranges from 0.5 (Turkey) to 2.5 (France) with the UK ranked only 17th, with a ratio of just under one. A similar result is demonstrated for educational spillovers, with the UK performing relatively poorly by 2009.

If spillovers along the supply chain are important, which this study suggests they are, then the changes in the structure of the economy – which are partly the result of these spillovers – have reduced the UK's ability to exploit its investments in these intangible assets.

2. Introduction

The principal aim of the present research is to examine the direct and indirect effects of different forms of investment in intangible assets on enterprise performance. The direct effects can be thought of as the results of own-investment and innovation in activities such as skills, R&D and education on the firm's own performance. The indirect effects are the results of one firm's investment in such activities on the performance of other firms, in other words, the associated externalities or spillover effects.

In their pure form, spillovers are free,

> "By technological spillovers, we mean that (1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so acquired." (Grossman and Helpman, 1992: p.16)

The existence of externalities has important implications for government intervention as private investment decisions are sub-optimal from a societal perspective. In other words, because investors only take into account the benefits they receive, and not the benefits received by others, their investment will be less than socially optimal.

In practice, very little, if any benefits that one firm gets from other firms' new technologies are entirely free (Arora, et al. 2001, p. 49; Bosworth, 2005, pp. 69-103), but they may still be highly beneficial to the recipient firm. The associated beneficial effects are often referred to as embodied spillovers or rent spillovers (Griliches, 1992, p. 30) and they form an important focus of the present report. While Griliches dismisses such spillovers as a measurement problem, their existence may be much more fundamental than this and may even give insights about endogenous growth (e.g. the new growth theories).

The research has built two new databases to explore the existence of spillovers: an international, sectoral database; a national, UK, enterprise-level panel data set.

- Data have been assembled at the sector level by matching information from a range of data sets, including the WIOD input-output data and socio-economic accounts data, Community Innovations Survey data, Eurostat statistics, etc. The database comprises information for (up to) 28 European Countries, 34 sectors and 15 years.

- Data have been assembled at the enterprise level for the UK, primarily using the UK Innovations Survey (the UK version of the CIS) and the ONS, Annual Respondents Database (ARD). Sectoral data, corresponding to the previous bullet point, have also been matched on.

Two main questions are addressed: one a relatively "static" one and one of a more "dynamic" nature. Using the example of R&D, the static question is:

> Can evidence be found that sectoral performance is influenced, not only by its own R&D, but also by the R&D of other sectors? For example, is the productivity of sector i affected by the R&D carried out in sector j?

This is the standard question found in most of the empirical spillovers modelling. The more "dynamic" question is:

> Can evidence be found that the innovatory activities of different sectors are influenced not only by that sector's earlier innovation, but also by the earlier innovatory activities of other sectors? For example, is the innovatory activity of sector i influenced by prior innovatory activity in sector j?

This is the question that Griliches (1992, p. 30-31) identifies as being the more difficult to measure and the more interesting issue. For each sector, the other sectors in question are those that are the sector's intermediate goods suppliers, which are identified using input-output tables.

The Report continues with a brief review of the relevant literatures (Section 3). This sets out different types of spillovers (e.g. knowledge spillovers, technological spillovers, education and skill spillovers) and the various concepts of "distance" (e.g. technological distance and distance in the context of suppliers) which are used to define the "pool" which is the potential source of the spillovers.

Section 4 outlines what the present Report means by exposure to spillovers and what role intermediate goods suppliers and the supply chain may have in transmitting spillovers. While the input-output matrix, described in Section 4, does not represent the whole of a supply chain, it does represent the value of transactions between buyers and sellers (and between the sellers and the firms that sell to them) – the report uses the term supply chain in this context. This section also provides some descriptive statistics about the magnitude of such exposure, particularly in terms of R&D and educational spillovers, and how such exposure may differ across countries and over time.

Section 5 reports on the European-wide results from the "static" models. There is a methodological discussion that finalises the functions to be estimated. Then the empirical results are provided for three measures of performance: productivity (labour productivity and total factor productivity); gross and net profitability; and international trade performance. While various measures of productivity and profits are traditional candidates for performance measures, export performance is included alongside these because the government set a target to increase exports by 2020. Certainly, there is an *a priori* expectation that investments in intangibles (such as

R&D and education), as well as increased innovation should raise exports, other things being equal.[5]

Section 6 outlines the European-wide results from the “dynamic models”. Again, there is a brief methodological discussion that outlines the measures of innovation to be used and which also finalises the functions to be estimated. This section uses CIS data at the sectoral level to investigate whether past innovation, including past innovation spillovers affects current innovation. It investigates whether the flows around the input-output tables may be a source of endogenous growth. Finally it explores whether there is any evidence that innovation influences the births and deaths of enterprises in a manner consistent with Schumpeter’s creative destruction.

Section 7 focuses on the performance of UK enterprises. It works with matched data from a variety of sources, some of which are confidential and only made available in the ONS Virtual Laboratory. It constructs measures of enterprise performance (labour productivity and total factor productivity) that can be regressed upon own-enterprise R&D, the own-sector R&D pool and the exposure to spillovers from suppliers.

Section 8 provides an overview of the findings of the present study highlighting a number of the results that may have implications for government policy. It provides a summary of the findings of the “static” models, with a brief outline of the results relating to productivity, profits and exports. It also briefly discusses the findings with regard to the “dynamic” models, in particular, the impact of exposure to spillovers in the supply chain on subsequent innovation and performance and the effects on enterprise demographics. Finally it examines how some countries and/or sectors make better use of spillovers than others and the implications for government policy.

[5] Content of the 2012 budget, reported in the Guardian - http://www.theguardian.com/business/2012/mar/21/budget-osborne-exports-target-manufacturers

3. Review of the Literature

This section provides a brief review of the literature on the different types of spillovers (e.g. knowledge spillovers, technological spillovers, education and skill spillovers) and the various concepts of "distance" (e.g. technological distance and distance in the context of the supply chain) that are used to define the "pool", which is the potential source of the spillovers.

3.1 Introduction

This section reviews a wide range of the conceptual and empirical literature on various types of spillovers. Section 3.2 deals with the different types of spillovers in terms of whether they relate primarily to knowledge (as in the case of R&D spillovers), technology or education. This discussion deals with Griliches' argument that situations in which firms (and consumers) fail to pay the full "quality price" for their purchases are not "true spillovers", but simply a problem of measurement in official price indices (e.g. Griliches, 1992, p. 36). Thus, the literature generally makes a distinction between "rent" or "embodied spillovers" (where, for example, capital goods are purchased by firms at less than their full quality-adjusted price) and "true spillovers" (where the literature inevitably focuses on "knowledge spillovers" because of the characteristics of knowledge) (Cincera, 2005, p. 659). The present discussion of "technology spillovers" (Section 3.2.2) introduces a concept based upon "standing on the shoulders of giants".

3.2 Types of Spillovers

3.2.1 Knowledge Spillovers

Most goods and services, such as capital and labour are characterised by: rivalry – that only one person can make use of them at a given point in time; excludability – that one person (e.g. the owner) can prevent other individuals using them. Knowledge is a non-rival good and, insofar as it is not wholly appropriable – in other words, insofar as there are knowledge spillovers – it is also, in the main, non-excludable[6]. Thus, according to Cortright (2001, p. 4),

> "The centerpiece of New Growth Theory is the role knowledge plays in making growth possible. Knowledge includes everything we know about the world, from the basic laws of physics, to the blueprint for a microprocessor, to how to sew a shirt or paint a portrait. Our definition should be very broad including not just the high tech, but also the seemingly routine."

[6] Patents, for example, exclude the use of the invention by others in the production process, but do not exclude the information contained in the patent for use in the production of further inventions. Trade secrets are one method of excluding others from using the knowledge in their production processes.

Free markets fail to produce adequate amounts of knowledge because there is a "free rider" problem. If there is no way to exclude others from benefitting from the knowledge an individual produces, there is no effective way of making them contribute towards paying for its production. To put it slightly differently, there is no way the producer of knowledge can capture revenues that reflect all of the benefits other individuals receive from knowledge and, as a consequence, they under-invest in knowledge from a societal perspective.

The result is that, while there may be diminishing returns to investing in knowledge at the individual employer level (e.g. each additional unit of knowledge adds less to income than the previous unit of knowledge), there can be increasing returns to investment in knowledge at the national level (as not only the individual making the investment benefits, but so do other individuals and groups within the economy). The implication is that, if society can raise the investment in knowledge sufficiently, the increasing returns to knowledge produces a source of endogenous growth that, in principle, can carry on without an upper bound.

Griliches (1992 and 1995) argues that there are two kinds of spillovers: the first is one in which inputs are bought from other R&D-intensive sectors at less than their "full quality price" (Griliches, 1995, p. 65); the second, and what he terms "… the possibly more interesting and pervasive aspect of R&D externalities" is the effect of one firm or sector's R&D on the productivity of the R&D of other firms or sectors (Griliches, 1992, p. 31). The first of these he dismisses as a miss-measurement of price indices, which do not account for the (whole) increase in the quality of inputs to the user sectors. If, therefore, prices fully reflected quality, the quality improvement would appear in the (quality adjusted) output of the sector doing the R&D and as an increase in (quality adjusted) input in the sector using the R&D (see Bosworth, 2005, pp. 54-56). There would simply be a rebalancing of productivity downwards for the buying sector and upwards for the selling sector.

3.2.2 Technological Spillovers

This view of spillovers is too narrow. What it misses is that the new and improved products of one sector enable the buying sectors to innovate and, under certain circumstances, to do so without even understanding all of the technical knowledge developed in order to produce their own new or improved products[7].

In a sense, there is the issue raised by Griliches – that the improvement would not have taken place without the original invention by the supplier, but there is also the issue that the change to its inputs may also induce the buyer to invent and innovate. This has long been known as the issue of "standing on the shoulders of giants" and raises fundamental questions for the optimal design of IP laws, such as patent law. Scotchmer (1991, p. 30) argues that, "[t]he challenge is to reward early innovators fully for the technological foundation they provide to later innovators, but to reward

[7] It may be sufficient, for example, to understand the characteristics and properties of a new material (e.g. carbon fibre) without the need to understand how it is produced.

later innovators adequately for their improvements and new products as well". The implication is that not all of the benefit should be attributed to the first innovator (the supplier), but that some should be attributed to the second innovator (the buyer). Indeed, if the first innovator were able to appropriate the returns to all subsequent innovations, there would be no incentive for investment in these subsequent innovations.

In fact examples abound of important inventions associated with transfer across technological domains (Mowery and Rosenberg,1998; Ruttan, 2001; Arthur, 2007). The effects of various materials on the construction sector are well documented, such as the "Bessemer Process" for mass-producing steel on the growth of skyscrapers. Nemet and Johnson, (2012, p. 190) note that,

> "Jet engines for military aircraft provided the fundamental technology for high efficiency natural gas power plants; advances in ball bearings and tires for bicycles enabled development of automobiles; production of long wires for radial tires was instrumental for slicing silicon wafers to produce solar panels."

The economic and social effects are particularly important in the case of general purpose technologies, which have wide applications across the economy,

> "On a larger scale, general purpose technologies such as the steam engine, electric power, chemical engineering, and semi-conductors have had pervasive effects across multiple sectors of the economy. More specific technologies like lasers and synthetic fibres became useful for improving the performance of technologies far afield from their original area of application." (Nemet and Johnson, 2012, p. 190).

Many companies now identify key enabling technologies that allow them to invent and innovate in their product area.[8]

3.2.3 Education and Skill Spillovers

The new growth theories have mainly been couched in terms of human capital spillovers (Romer, 1986 and 1994; Lucas, 1988). There are two strands of new growth theories, one concerned with the accumulation (or "flow") of human capital and the other with the stock of human capital (Sianesi and Van Reenen, 2000, p.5). In the first of these, a measure, such as a subsidy to education which raises the level of human capital, will have a once-and-for-all effect on output, but, in the second approach, would increase the growth rate of the economy forever (*ibid*. pp. 5-6).

The concept of education spillovers dates back at least to Marshall (1920). Such spillovers are wide ranging, for example, Wolfe and Zuvekas (2000) outline a range

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[8] Rolls Royce note that, "All our products are enabled by significant underpinning technologies. These may allow more optimised designs, more capable services or more integrated power systems and as such are critical to our ability to engineer efficient systems that satisfy our customers' needs. E.g. control systems; electrical systems; monitoring systems; design systems and tools; high performance computing." http://www.rolls-royce.com/about/technology/systems_tech/

of positive effects of education on social and civic activities, health, crime, etc. While all of these are likely, in turn, to feed back into economic growth (Sianesi and Van Reenen, 2000, p. 4), they lie outside of the scope of the present study. Blaug (1968, p. 243) outlines nine types of economic and non-economic spillovers that result from improvements in education, of which a number are relevant here, including income gains to persons other than those who receive the additional education and the provision of an environment which stimulates research in science and technology.

There is empirical evidence that individual incomes are raised by the skills of others that they work with within the same workplace (Battu, *et al*. 2004), but this is not a conventional spillover as it is internal to an individual firm. Here the productivity increasing "employment related" spillovers (e.g. as envisaged by Blaug, 1968, p. 244) occur from the more to the less educated amongst employees in the same workplace. Insofar as the associated skills are specific, then the firm can capture the benefits and invest optimally, but insofar as they are general and are captured by the workers, the firm may employ too few such individuals to optimise employee income (Bosworth and Stanfield, 2009, p. 54). If employee incomes can be raised in this way, then there are also social benefits through higher taxes.[9]

3.3 Defining the "pool"—the concept of distance

3.3.1 Introduction

The economic and econometric literature on spillovers uses the concept of a "pool" of knowledge, which is external to the firm, but from which the enterprise can draw and, perhaps when combined with internal knowledge, the firm can use its augmented knowledge base to improve its performance. It is hypothesised that quanta of knowledge which are in some sense "closer" to the firm are either more likely to be more relevant to the enterprise or the firm will have a higher probability of discovering it or accessing it. Hence, the further the distance, however measured, between the firm and a potential source of spillovers, the less likely a spillover is to take place and, if a spillover occurs, the smaller its impact is likely to be.

In the case of R&D knowledge spillovers, two main forms of distance are identified as being important: technological distance may be crucial, in the sense that enterprises working in similar or overlapping areas of technology are more likely to benefit from each other's research findings if they cannot be fully appropriated; spatial distance also appears important, with firms located further apart less likely to benefit from spillovers, even if they work in the same area of technology. While other forms of distance have been investigated, such as cultural distance, their main focus has not been on spillovers, but often on various aspects of multinational investment (e.g. Shenkar, 2001).

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[9] There are other forms of spillover associated with labour, such as poaching trained workers rather than training workers (Bosworth and Stanfield, 2009, pp. 58-59)

Technological distance is the most important concept in the context of the present report and other forms of distance found in the literature, such as spatial, are not considered further. However, a new measure of distance is introduced, based upon trading between firms and sectors, drawing upon the supply chain literature.

3.3.2 Technological Distance

The two main approaches to measuring knowledge spillovers (Griliches, 1992, p. 37 and 1995, p. 66) have different implications for the nature of technological distance. The first of the two is the symmetric approach, in which every firm within a sector is equally exposed to the pool, for example, defined as the total R&D of that sector (e.g. Berstein and Nadiri, 1989). In the second, asymmetric approach, every possible pair of firms (industries or countries) is treated separately; thus if firm i has a strong knowledge base and firm j a moderate knowledge base, firm j is exposed to a larger potential spillover stock than firm i. In addition, firms i and j may be exposed to different firms within the sector (or beyond), which also affects the size of each of their spillover pools. Thus, in the case of symmetric knowledge, technological distance is not very, if at all important, while in the case of asymmetric knowledge spillovers, technological "distance" becomes extremely important.

The first major exercise measuring technological distance is attributed to Scherer (1982). He argued that, at that time, three quarters of U.S. industrial R&D focused on product (rather than process) improvements (*ibid*. p. 627). He further argued that while internal process R&D in industry i should improve productivity growth in that sector, much of the benefit of product R&D would be passed on to buyers (e.g., in industry j).[10]

The author used Federal Trade Commission "line of business data"[11] for 262 manufacturing and 14 non-manufacturing sectors. Each enterprise's R&D expenditures were allocated to the relevant sector(s) using the line of business information and then used to construct the total R&D for each sector. The author linked the R&D outlays (appropriately lagged) to 15,112 US patents. Each patent was examined to determine its industry of origin (and thereby linked to the R&D outlays of that sector) and the industry or industries which were likely to use the patented knowledge. The patents were also examined to see if they involved an internal process or an externally sold product.

The industry of origin of the patent and the industry of use determined the underlying "technology flow matrix". In other words an industry of use is exposed to the R&D outlays of the industry of origin and, in the case of inventions of widespread use, R&D outlay of the industry of origin (i) is allocated in proportion to patent knowledge flowing from industry i to industry j (Griliches, 1992, p. 38). Row sums for the

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[10] A factor likely to be accentuated as price deflators systematically underestimate the hedonic value of new products and, hence, under valuing the inputs used by industry i's customers.
[11] LB data do not allocate enterprises to sectors according to their principal product output, but collect data on all lines of production – the firm is then allocated, in proportion to its outputs, to all the sectors it works in.

technology flows matrix measured R&D by industry of origin, column sums R&D by industry of use, and diagonal elements corresponded to pure process R&D.

While Scherer (1982) develops a number of measures of R&D, they essentially take two forms: "user-R&D" (i.e. from internal process work and the purchase of R&D-embodying products); and "own-R&D" (i.e. R&D by industry of origin). The author concludes that the empirical results suggest, "… evidence of substantial returns to used R&D, i.e., from internal process work and the purchase of R&D-embodying products, but not … to the performance of product R&D" (*ibid*. p. 634). This work was taken forward by Jaffe (1986, 1988, 1989), where the firm's position in "technological space" is determined by the distribution of its patents over patent classes. Jaffe's results suggest significant positive effects of R&D spillovers both on firms' R&D intensities and productivities.

Somewhat closer to the present approach of using the input-output matrix is Mohnen's (1996) first set of technological proximities. Here the weights are measured on the basis of inter-firm or inter-industry flows of various types: goods and services; capital goods; R&D personnel; patents; innovations; citations; and R&D cooperative agreements. Thus, distances are smaller the more firm i purchases intermediate inputs or capital goods from firm j, or hires scientists from j, etc.. This approach is more closely related to economic transactions rather than pure technological links between the two actors, although the choice of dimensions (e.g. hire of scientists, collaborative R&D, etc.) is an attempt to get the best of both worlds.

Cincera (2005, pp. 665-667), following the approach adopted by Jaffe (1986), divides the potential stock of spillovers into two distinct components: a local stock corresponding to the sum of R&D stocks of firms in the same technology cluster; an external stock, computed from the other firms. The idea is that firms are aware of or track the research carried out by a relatively small number of technologically similar firms, but live within an environment where many other firms are doing research; the former are more likely to give rise to spillovers than the latter. The local pool can be constructed as the weighted sum of other firms' R&D for the firms belonging to the same cluster. In addition, it is possible to construct technological dummies based upon the clusters to identify the firms with sufficiently similar research interests to experience the same technological opportunity.

3.3.3 The supply chain, collaboration and reduction of "distance"

One particular thing that links companies and other organisations together is the "supply chain". At the individual firm level the supply chain can be thought of as a "tree" that branches backwards from the buying firm to its suppliers and, from there, to each of the suppliers of those suppliers, and so on. Likewise the tree branches forwards from the individual firm to those firms that it supplies and, onwards to firms that they supply.

At the sectoral level, a partial snap-shot of the buyer-supplier chains can be represented by each country's input-output matrix. Such matrices were first developed by Leontief and date back to the mid-1920s in Russia and Germany, but came to the fore when he moved to the USA (Leontief, 1941). They represent a sector by sector or product by sector matrix showing the flows of products and services between sectors (where the sectors of origin or products being supplied appear as the rows of the matrix and the buying or using sectors appear as the columns – see Section 4.2 for more detail).

Supply chains have become increasingly important as firms have concentrated on their core businesses and outsourced the non-core activities (Krause, *et al*. 2000, p. 33), often to developing countries with lower wages. Even at the turn of the present century, supplier networks produced as much as 70% of the value of a vehicle (Dyer and Nobeoka, 2000, p. 345) and suppliers' performance had become critical to the long-term success of the buying (assembly) firms (Krause, *et al*. 2000, pp. 33-34). As a consequence, buying firms developed strategies to improve supplier performance including: supplier assessment; incentives for improved performance; activities with suppliers such as training their personnel; codes of conduct for suppliers, which may be formally audited[12].

An innovation by one firm in the supply chain can have direct implications for others, for example, the adoption of just-in-time production by a buyer can have important consequences for their suppliers[13] (Matsui, 2007, p. 155). The adoption of JIT implies that suppliers must meet strict quality criteria if the supplies are reaching the customer just in time for them to be used. The timing and quality issues imply a considerable degree of coordination and collaboration between buyer and supplier, which may require buyers to make long-term contracts with suppliers. In turn, longer term contracts and higher levels of collaboration may have other implications, such as a greater exchange of technology between producer and supplier; a need for documentation of the supplier's process capability and quality; along with annual audits by the buyer of the supplier's plant (Kristensen, *et al*. 1999, p. 63).

There has been an increasing willingness to take a view of the enterprise that emphasises the key role of creating, storing, and applying knowledge (Kogut and Zander, 1992; Conner and Prahalad, 1996; Grant, 1996). While the initial focus was on the individual firm, this has subsequently shifted to networks of firms and inter-organisational learning in understanding firm-level learning (Powell, *et al*. 1996). Toyota, for example, created a closely tied network with a strong network identity, rules for entry and participation and a variety of institutionalized routines that facilitate multidirectional knowledge flows amongst suppliers. According to Dyer and Nobeoka (2000, p. 345) Toyota solved three fundamental dilemmas associated with knowledge sharing, "… devising methods to (1) motivate members to participate and openly share valuable knowledge (while preventing undesirable spillovers to

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[12] E.g. Nestlé (2010).
[13] JIT, a technique developed by Toyota, can be defined as "… the successful completion of a product or service in each stage of production activity from vendor to customer just-in-time for its use at a minimum cost" (Kristensen, *et al*. 1999, p. 61).

competitors), (2) prevent free riders, and (3) reduce the costs associated with finding and accessing different types of valuable knowledge." This close network means that, importantly, production knowledge is viewed as the property of the network.

Von Hippel (1988) found that a firm's customers and suppliers are its primary sources of innovative ideas. The author argues that a production network with superior knowledge-transfer mechanisms among users, suppliers, and manufacturers, will be able to "out innovate" production networks with less effective knowledge sharing routines. In a similar vein, Powell, *et al*. (1996) found that in the biotechnology industry the locus of innovation is the network, not the individual firm. The authors argue that biotech firms which are unable to create (or position themselves in) "learning networks" are at a competitive disadvantage.

3.3.4 Collaborative R&D and innovatory activities

The number of inter-firm strategic alliances has increased significantly during recent times, of these, R&D joint ventures among firms are an important component (e.g. Caloghirou, *et al*. 2003).

Tether (2002), using UK data from CIS 2 on 1275 innovating firms, found that cooperation tends to be associated with firms pursuing radical rather than incremental innovations. Of the 1275 firms identified as innovating, 575 (45%) had some form of co-operative arrangement for innovation, of which 541 (42%) had co-operative arrangements for innovation with external partners (only 29 firms had co-operative arrangements with other parts of their enterprise groups). Suppliers and customers were the most widely engaged co-operation partners, but significant proportions also engaged with competitors, consultants, universities and other organisations as partners in these arrangements.

Since the 1970s it has been recognised that using lead customers to help define a supplier's innovation helps to reduce the market risk associated with the new or modified product (Von Hippel, 1988). By implication, co-operating with customers is likely to be most common when the innovation under development is more novel or complex (e.g. new to the market rather than new to the firm), or when the market for the innovation is poorly defined (Tether, 2002, p. 951). The development of such relationships seems to be more dependent on joint learning and trust than on lowering costs (Tidd, *et al*. 1997). In contrast, cooperation with suppliers tends to focus on core business to reduce costs, with outsourcing activities coupled with cooperation on input quality improvements aimed at further cost reductions.

The study by Fritsch and Lucas (2001) is based upon a sample of 1800 German manufacturing firms. They report that R&D cooperation in their sample is quite widespread: slightly more than 60% of the enterprises in their sample have cooperative relationships with their customers; nearly 49% cooperate with their manufacturing suppliers; 33% with publicly funded research institutions; and 31%

with other enterprises (non-vertically related businesses, particularly competitors).[14] They report that innovative efforts directed at process improvement are more likely to involve collaboration with suppliers, whereas product innovations were associated with customer collaboration.

Belderbos, *et al*. (2003) report that cooperation is more likely to be chosen if the type of partner is considered an important source of knowledge for the innovation process, while more basic knowledge tends to be sourced from universities and research institutes. Collaboration with universities is more likely to be chosen by larger and more R&D intensive firms in sectors that exhibit faster technological and product developments (*ibid*.). This collaboration is generally aimed more at radical breakthrough innovations that may open up entire new markets or market segments (Tether, 2002; Monjon and Waelbroeck, 2003).

Belderbos, *et al*. (2004) analyse the impact of R&D cooperation on firm performance differentiating between four types of R&D partners (competitors, suppliers, customers, and universities / research institutes), and consider two performance measures: labour productivity and productivity in innovative (new to the market sales per employee). Using data on Dutch innovating firms in two waves of the CIS (1996, 1998), they examine the impact of R&D (collaboration) in 1996 on subsequent productivity growth in 1996-1998. They find that supplier and competitor cooperation had a significant impact on labour productivity growth and that cooperation with competitors and with universities / research institutes positively affects growth in innovative sales per employee. Their results suggest that "vertical" cooperation along the supply chain (buyer and supplier) results in non-radical innovation. They also found that innovative sales are furthermore stimulated by incoming spillovers (not due to collaboration) from customers and universities.

Powell, *et al*. (1996), however, suggest that more fundamental scientific and technological breakthroughs might have somewhat different groupings of partners. They report that patents are typically filed by a large number of individuals working for a number of different organizations, including biotech firms, pharmaceutical companies, and universities. They give two examples:

> "The development of an animal model for Alzheimer's disease appeared in a report … co-authored by 34 scientists affiliated with two new biotech companies, one established pharmaceutical firm, a leading research university, a federal research laboratory, and a non-profit research institute. Similarly, a publication identifying a strong candidate for the gene determining susceptibility to breast and ovarian cancer … featured 45 co-authors drawn from a biotech firm, a U.S. medical school, a Canadian medical school, an established pharmaceutical company, and a government research laboratory."

[14] The authors note that "… [a]ccording to our results, firms that are engaged in R&D cooperation tend to be relatively large, have a comparatively high share of R&D employees, spend resources for monitoring external developments relevant to their innovation activities … and are characterized by a relatively high aspiration level of their product innovation activities." (*ibid*. p. 310)

The authors note that, more important than the number of authors, is the diversity of sources of innovation and the range of different organizations involved.

The discussion of collaboration between organisations, particularly with regard to R&D, raises the issue as to whether the associated inventions or innovations are spillovers. In one sense it can be seen as a temporary forming of another "firm" or organisation, with resources drawn from other firms and organisations, whose output is an invention (Tether, 2002, p. 947). Thus, the new firm or organisation uses its own knowledge base, plus various resources and equipment "loaned" by the original organisations in the production of this inventive output. On the other hand, there are at least two reasons for viewing the output as a spillover: first, the crucial input is generally knowledge[15], where each partner's knowledge base is informing the other partners; second, additional knowledge is produced from the existing knowledge base than otherwise would have been the case.

[15] Powell, *et al*. (1996, p. 118) note that, "…breakthroughs demand a range of intellectual and scientific skills that far exceed the capabilities of any single organization …".

4. Buyer-Supplier Chain and Exposure to Spillovers

This section outlines what the present Report means by exposure to spillovers and what role the supply chain may have in transmitting spillovers. It also provides some descriptive statistics about the magnitude of such exposure, particularly in terms of R&D and educational spillovers, and how such exposure may have changed over recent years. If exposure to spillovers is important in driving enterprise performance and innovation, then countries with high levels of exposure spillovers will be at an advantage.

4.1 Introduction

This section outlines the way in which the supply chain is used to construct measures of potential exposure to spillovers. It adopts a harmonised set of input-output tables that are drawn from the World Input-Output Database (WIOD). For each sector in the database it enables the identification of the sectors which supply it with intermediate goods. The hypothesis is that, as these supplying sectors innovate, the buying sector benefits from the innovation, both directly in terms of increasing the quality of its products or reduction in its costs, but also in its own ability or need to innovate.

If exposure to spillovers is important in driving enterprise performance and innovation, then sectors and countries with high levels of exposure to spillovers will be at an advantage. It is also interesting to look at the ratio of the measure of exposure to spillovers to the scale of investment in R&D and educational purchases. Countries with higher ratios will have input-output systems that are, in some sense, more efficient in generating spillovers, giving them a greater advantage.

Section 4.2 explains in more detail how the flows throughout the input-output matrix may expose each sector to the innovations of other sectors. Section 4.3 provides descriptive statistics about both R&D activity and potential exposure to R&D spillovers over the period 1995 to 2009. Information is provided by country and, briefly, by sector. Section 4.4 carries out a similar descriptive exercise as 4.3, but, in this case, focusing on purchases from the educational sector. An important feature of educational purchases by enterprises and other organisations has been the very significant growth over the period 1995 to 2009. This growth is illustrated using the data for the UK, Germany and Poland.

4.2 Supply chains and the input-output matrices

4.2.1 Methodology

A cornerstone of the research is the use of the WIOD input-output (I-O) tables for each country, which identify the 35 industries used by Eurostat across European Member States.[16] I-O tables are key to identifying potential spillovers from investment in intangibles through inter-sectoral linkages. The tables show the movement of goods and services between sectors of each economy and how these flows have changed over time. They can be used to identify key parts of the buyer- and supplier-chains and are used in a novel way in the present study to identify the potential exposure of enterprises in one sector to the investments in intangibles in other sectors.

The immediate exposure through the I-O matrix is illustrated in Table 4 below, using just four sectors. The column proportions (y_{ij}) represent the flows of goods and services from sectors i=1, …,4 to sector j, where $y_{1j}+\ldots+y_{4j}=1$ (part of the supplier chains to j).[17] Thus, y_{ij} is a measure of exposure of sector j to sector i's products and services. The larger the proportion of sector j's inputs that come from a particular sector i, the greater the relative weight that is given to the spillover from i. As noted in the Introduction (Section 2), the I-O matrix, does not represent the whole of a supply chain, it does represent the value of transactions between buyers and sellers (and between the sellers and the firms that sell to them). For example, it shows what sector 1 buys from sector 2, what sector 2 buys from sector 3, and so on – the report uses the term supply chain in this context.

Table 4: The buyer-supplier chain and the input-output matrix

		Sector (buyer)			
		1	**2**	**3**	**4**
Sector (supplier)	1	y_{11}	y_{12}	y_{13}	y_{14}
	2	y_{21}	y_{22}	y_{23}	y_{24}
	3	y_{31}	y_{32}	y_{33}	y_{44}
	4	y_{41}	y_{42}	y_{43}	y_{44}

The exposure to spillovers is calculated in the same way for each sector, for example, exposure to the R&D of other sectors is a weighted sum of the R&D carried out by other sectors, where the weights are the relative amounts of goods or services purchased from the other sectors (see Bosworth, *et al*. 2014 Technical Annex, Section A2.1).[18] Thus, if a sector does not buy from one of the other sectors, it will not experience any *direct* effects of that sector's R&D no matter how much

[16] In practice only 34 are generally available as the "Private Household" sector is absent from many of the measures in many of the countries.

[17] Likewise, the row proportions, y_{ij} (not shown in the table), represent the flows of goods and services from sector i to each of the sectors j=1….4, where $y_{i1}+\ldots+y_{i4}=1$.

[18] In the case where sector 1 is the buyer, the relative weights are $y_{21}/(y_{21}+y_{31}+y_{41})$, $y_{31}/(y_{21}+y_{31}+y_{41})$ and $y_{41}/(y_{21}+y_{31}+y_{41})$.

R&D it does. In addition, a sector cannot experience any direct (or indirect) exposure to spillovers from another sector if that sector does not do any R&D.

The present report investigates two potential groups of spillover effects. The first, which is more static in nature, is where other sectors' expenditures on R&D or education affect the buying sectors' performance (productivity, profit, etc.). The other, which is more dynamic in nature, is where the innovation of the supplying sectors impacts on the future innovation of the buying sector. Both have the potential to create sustained endogenous economic growth. For example: insofar as exposure to spillovers increases profits, these can be invested in further own-R&D or education, which will affect the future growth of that sector and its spillovers to other sectors. Also, insofar as innovations take place in the products supplied to sector i which give rise to an innovation in sector i's product, this may also give rise to innovations in the sectors that i supplies. In turn, innovations induced by sector i in other sectors may feedback to sector i, and so on.

4.2.2 Measuring Exposure

Measurement of exposure to inter-industry spillovers is calculated using data from the WIOD database, which shows input-output industry-by-industry for up to 35 sectors from 1995 to 2009. The WIOD database contains data for 28 European countries. The sectors are defined using the 2002 Statistical Classification of Products by Activity in the European Economic Community (CPA, 2002), which corresponds to NACE 1. The input-output matrix is defined with "sectors of origin" (the selling sectors) on the vertical axis and the "sectors of destination" of goods and services (the buying sectors) on the horizontal axis.

Exposure to spillovers from other sectors is calculated for each sector based upon the amount it buys from other sectors. The first step therefore is to convert the values in each cell of the sector's column into a proportion of the column's total (the value for intra-industry trade is set to 0, but dealt with as a separate variable). This provides an estimate of the potential sources of inter-industry spillovers (e.g. the more a given sector contributes to the column total, then the more significant that sector is as a potential source of spillovers, other things being equal).

Next, a value is assigned to the source of, for example, R&D spillover exposure by multiplying each proportion by the source sectors' total investment in R&D.[19] Data from CE, supplemented by OECD and Eurostat information, is used to estimate the R&D expenditure for each sector and country. The CE data is based on the NACE 2 classification and a number of sectors are aggregated to make it directly comparable to the sectors in the WIOD tables. The CE data is in constant 2005 Euros (millions) as are the values of the resulting measures of exposure to spillovers.

A second potential source of spillover comes from the educational purchases of supplying sectors.[20] Suppliers that purchase more from the education sector may be embedding more advanced and up-to-date knowledge in their products and services than sectors that buy less. Information on each sector's own-purchases can be

[19] The same technique is applied to R&D, education and different forms of innovation, as reported below.
[20] An attempt was also made to identify the exposure to other sectors "skills", but this led to intractable econometric problems and had to be dropped.

obtained from the WIOD I-O data set and these are treated in the same way as the R&D expenditure data to obtain estimates of exposure to educational spillovers.

A final source of spillovers is associated with exposure to the innovation activities of suppliers. Such innovations may present opportunities and challenges for the buyers to modify their own products and processes. This set of variables, which is dealt with in more detail later in the Report, are constructed from both confidential and published CIS data at the sector level. Three own-innovation and three spillover variables are constructed relating to product innovation, process innovation and products new to market.

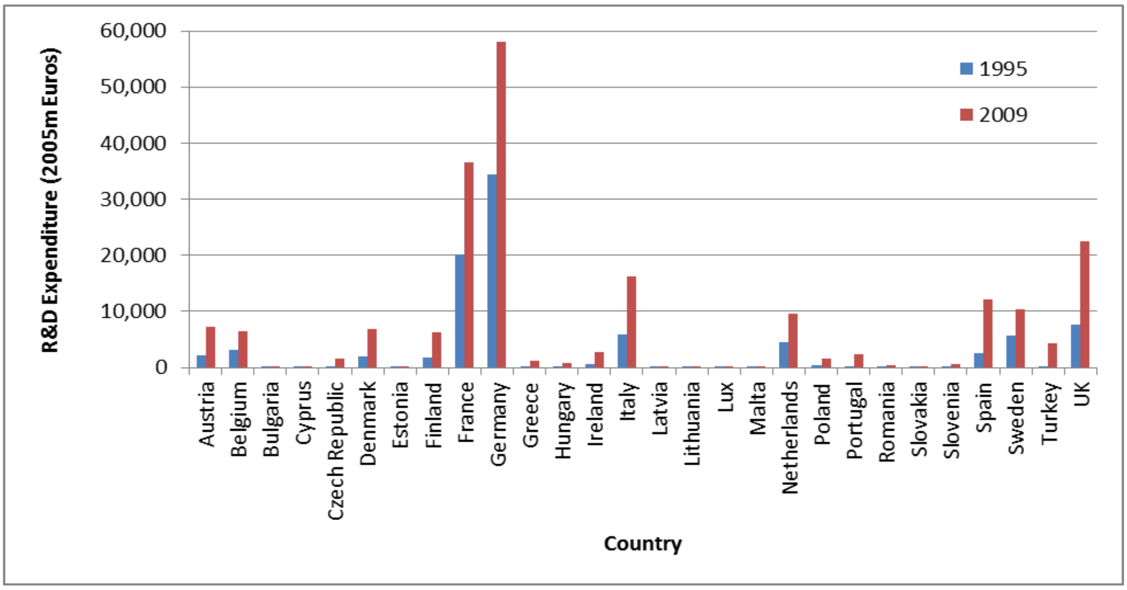
4.3 R&D Expenditure and Spillovers

4.3.1 R&D Expenditure

Figure 1 shows the R&D expenditure by country for 1995 and 2009. R&D expenditure increased in every country other than Luxembourg (for which data isn't complete) between 1995 and 2009. In both 1995 and 2009, the UK ranked third in overall R&D spending (behind Germany and France). The R&D expenditure in 2009 (in constant 2005 million Euros) is 58,000 in Germany, 36,000 in France and 23,000 in the UK.

From 1995 to 2009, the largest increase in R&D spending is seen in Germany (24,000 million Euros) and the largest relative increase in Lithuania (increased by a factor of 17, starting from a very low base). By comparison, R&D spending tripled (increased by 15,000 m Euros) in the UK. The UK's absolute increase in R&D spending between 1995 and 2009 is the third largest (behind Germany and France).

Figure 1: Total R&D Expenditure by Country, 2000 and 2009 (in millions of 2005 Euros)



Source: WIOD Exposures to Spillovers Summary.xls (derived from CE and ONS data)

The sectors with the highest R&D spending in 2009 are broadly similar across countries. The sectors with the highest R&D spending are Education, Electrical and Optical Equipment, Renting of Machinery and Equipment and other Business Activities[21] and Transport Equipment. In the UK, the top sectors are Education (7,000 2005m Euros), Chemicals and Chemical Products (5,000 2005m Euros), Transport equipment (3000 2005m Euros) and Machinery and Equipment and Other Business Activities (2,000 2005m Euros).

4.3.2 Exposure to R&D Spillovers

Table 5 shows the total exposure to R&D spillovers for 28 European countries in 1995 and 2009, ranked by their exposure to spillovers in 2009. In both 1995 and 2009, the countries with the highest exposure to spillovers are France (90,000 2005 m[22] Euros in 2009), Germany (60,000 2005m Euros in 2009) and the UK (22,000 2005m Euros in 2009). Between 1995 and 2009, exposure to spillovers increased in every country other than Luxembourg, which is a small country with a very incomplete I-O system. In absolute terms, exposure increased the most dramatically in France, but Germany, Spain and the UK also saw large increases.

Table 5: Total Exposure to R&D Spillovers by Country (2005m Euros), 1995 and 2009

Country	1995	2009	change	Country	1995	2009	change
France	37,762	90,178	52,417	Turkey	119	2,260	2,141
Germany	31,803	59,948	28,145	Greece	194	1,142	948
UK	10,590	21,880	11,291	Hungary	150	974	824
Spain	2,316	18,294	15,978	Poland	292	957	665
Italy	5,073	13,382	8,308	Slovenia	128	639	510
Denmark	2,003	12,420	10,417	Romania	160	391	231
Belgium	3,926	10,722	6,796	Estonia	7	307	300
Netherlands	4,503	9,930	5,427	Lux	411	193	-219
Sweden	5,982	9,923	3,941	Slovakia	88	159	71
Austria	2,157	9,477	7,320	Lithuania	2	155	153
Finland	2,044	6,043	3,999	Latvia	2	106	104
Ireland	539	4,444	3,905	Bulgaria	31	84	54
Portugal	230	2,945	2,715	Cyprus	3	62	59
Czech	326	2,391	2,064	Malta	0	28	27

Source: WIOD Exposure to Spillovers Summary.xlsx.

The countries with the highest levels of R&D (Germany, France and the UK) also saw the highest level of spillovers, although France is ranked second in R&D for 2009 and first in exposure to spillovers. The relationship between R&D expenditure and R&D spillovers is examined in Figure 2. Figure 2 shows the ratio of exposure to R&D spillovers relative to R&D spending. A ratio of greater than one indicates that the exposure is greater than R&D spending, a ratio of less than one indicates that

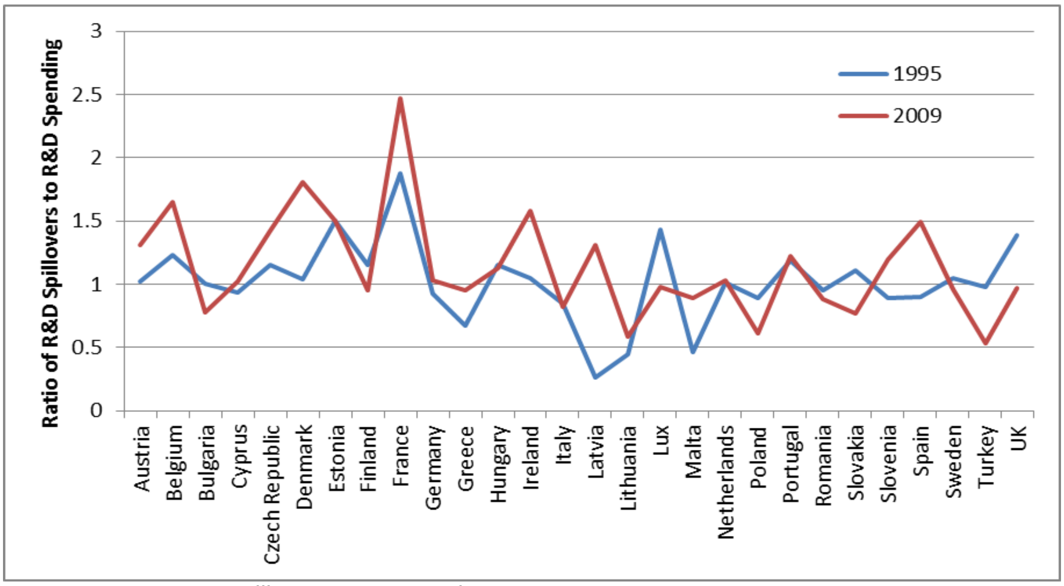
[21] This sector includes the R&D sector itself.
[22] 2005m indicates millions of Euros in constant 2005 prices.

R&D spending is higher than exposure. In 1995, the ratio ranges from 0.27 in Latvia to 1.9 in France. The UK ranked fourth in 1995 with a ratio of 1.4.

Although R&D expenditures and exposure to spillovers increased in most countries between 1995 and 2009, this does not mean that the ratio of the two increased in all cases. Between 1995 and 2009, the ratio of exposure to R&D spillovers to R&D spending increased in roughly half of the countries and decreased in the other half. The difference between the 2009 and 1995 ratios is highest in Denmark (the ratio increases by 0.8), Spain (an increase of 0.6) and France (an increase of 0.6). The countries with the largest decreases in the ratio are in Turkey (a decline it the ratio of 0.5), the UK (drop of 0.4) and Slovakia (decrease of 0.35).

In 2009, the ratio ranges from 0.5 in Turkey to 2.5 in France. Other countries with high ratios are Denmark (1.8, ranked second) and Belgium (1.7, ranked third). The UK ranks 17th with a ratio of 0.97, a large decline from its 1995 ratio and ranking.

Figure 2: Ratio of Exposure to R&D Spillovers to R&D Expenditure, 1995 and 2009

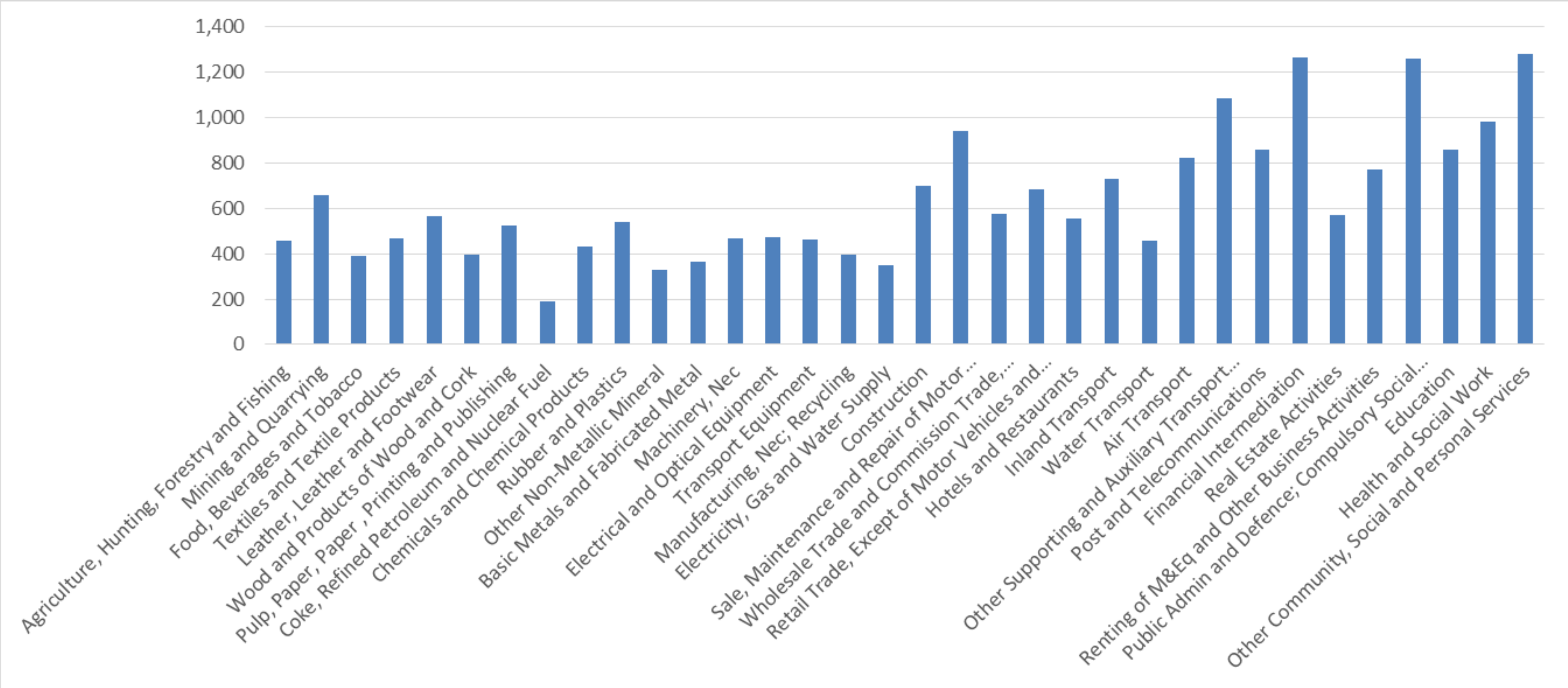


Source: WIOD Exposure to Spillovers Summary.xls

Exposure to R&D Spillovers by Sector in the UK

In most countries, the Financial Intermediation, Other Community, Social and Personal Services, Public Administration and Post and Telecommunications sectors have the highest exposure to spillovers. However, there is variation across countries, for instance, in the Netherlands, the Electrical and Optical Equipment sector has the highest exposure to spillovers and the top sector in Ireland is Chemicals. In the UK, the three sectors with the greatest exposure to spillovers in 2009 are the Other Community, Social and Personal Services, Public Administration and Defence, and Financial Intermediation. Exposure in these three UK sectors is 1,300 2005m Euros in 2009.

Figure 3: Exposure to R&D Spillovers in the UK (2005m Euros) by Sector, 2009



Source: UK WIOD Exposure to Spillovers with ONS Data.xls

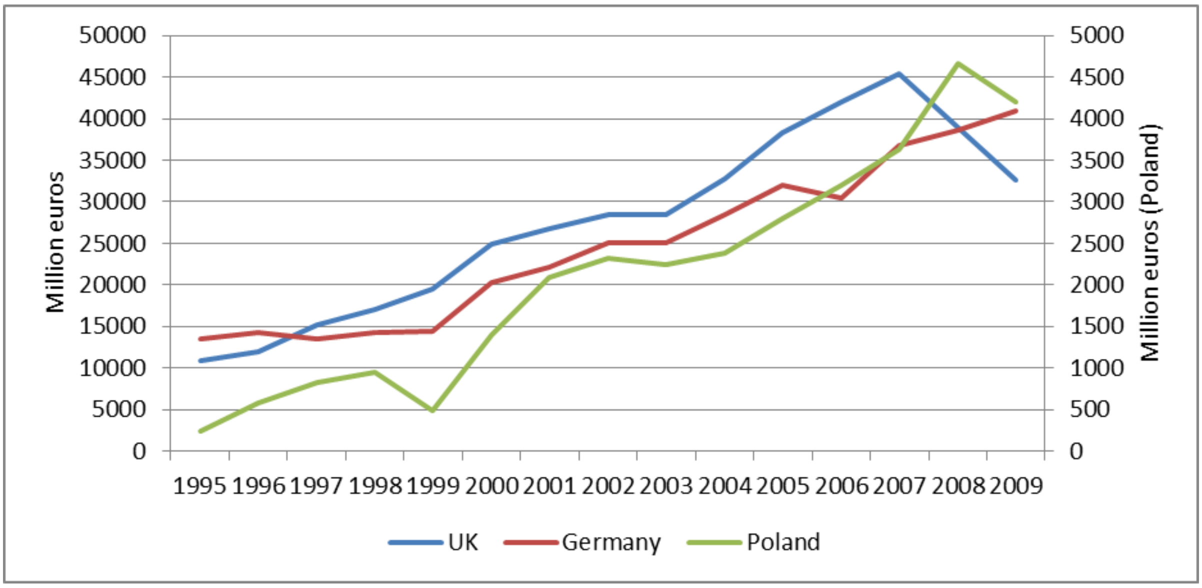
4.4 The education sector

4.4.1 Illustrating the changing role of education

The education sector has undergone remarkable change since 1995, reflecting the growing emphasis on skills and education amongst most national and economic union strategies, which have acknowledged the importance of the "knowledge economy". This transformation of the education system is reflected in the growth in demand for its services in both final demand and in the sectors producing goods and services. In addition, in some countries, education has become a major exporter of its services.

Despite the slightly larger German economy, the UK's education system is larger than Germany's throughout the sample period (see Figure 4), with the exception of 2009 (because of the effects of the recession).[23] Over the period 1995 to 2009, both the German and UK final plus intermediate demand for education doubled, while that of Poland (starting from a very low base) increased by a factor of 16. While both the UK and Poland see downturns because of the effects of the recession, Germany appears unaffected in terms of the growth in education, at least by 2009.

Figure 4: Intermediate plus final demand for education (constant 2005 prices)



Final demand for education increased by 57 per cent in Germany over the period 1995 to 2009, 103 per cent in the UK and a factor of just under 15 in Poland (Figure 5); Germany started from a relatively high base and Poland from a relatively low base. Intermediate consumption of educational outputs increase by a factor of just over three in the UK, a factor of seven in Germany and 29 in Poland, which started

[23] Given the somewhat larger German economy, the relative size of the German and UK education sectors may be driven by differences in their education and training systems, with more of the training, in particular, taking place outside of the education system

for an almost zero base (Figure 6). The effects of the recession on educational demands in the UK and, to a lesser extent, Poland are clear in both figures.

Figure 5: Final demand (2005 prices)

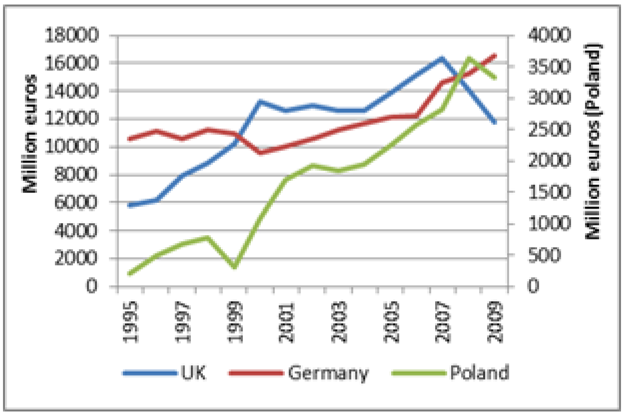
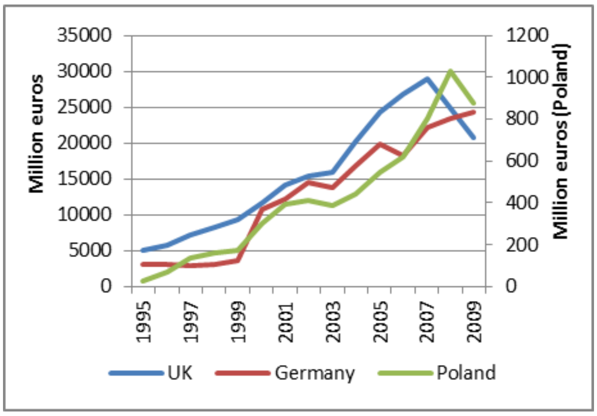


Figure 6: Intermediate demand (2005 prices)



The choice of 2009 as the end-point in the comparisons clearly paints a more adverse picture of the UK than a comparison based upon the peak prior to the recession, of 2007. Overall, intermediate consumption of education in the UK grew by a factor of 2.5 from 2000 to 2007 compared with 1.8 from 2000 to 2009; the corresponding German growth was only a factor of 2.1 to 2007 compared with 2.3 to 2009.

The downturn in the UK from 2007 to 2009, though, appears potentially very important. Not only did it reduce the final consumption of education by 28 per cent over the two years from 2007 to 2009 (when both Germany and Poland still managed higher 2009 values than in 2007), but it also severely reduced the intermediate consumption of education, with UK production sectors down by an average of 38 per cent on their 2007 values compared with a reduction of only 22 per cent across service sectors. A similar result is not found for Germany and, in fact, all of the changes across sectors (irrespective of the time periods chosen) show no correlation between the UK and Germany or the UK and Poland, but demonstrate a significant correlation between Germany and Poland.

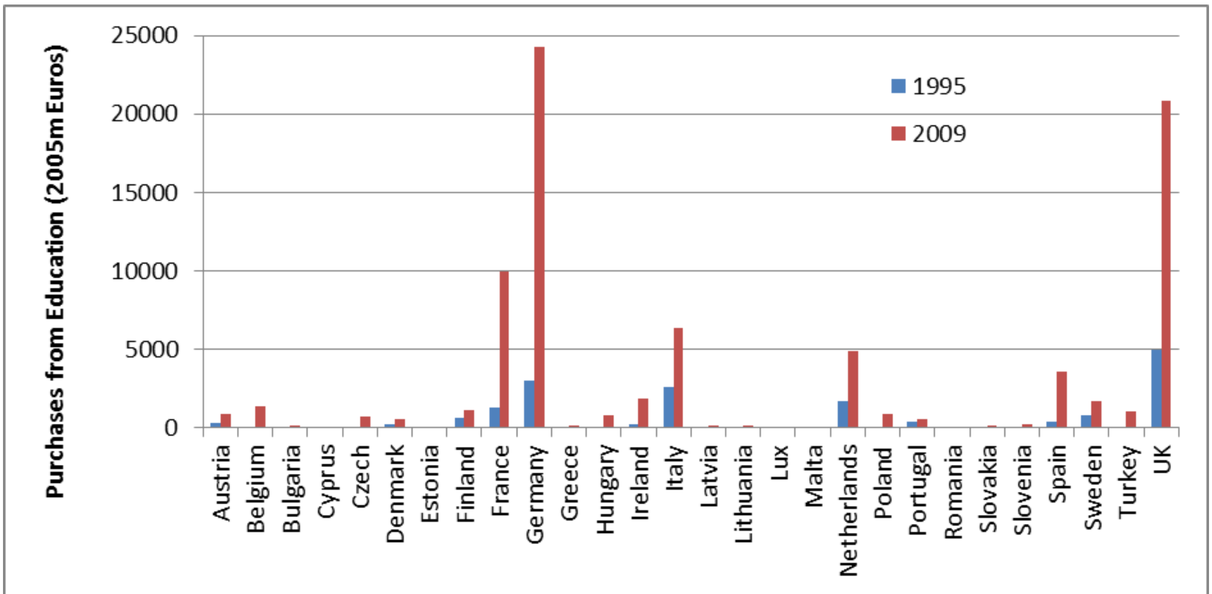
One of the highest growth rates in intermediate purchases of education is the growth in the transactions within the educational sector itself (e.g. where educational organisations trade with other educational organisations). The growth in this from 2000 to 2007 was by a factor of 3.0 in the UK compared with 3.1 in Germany and only 2.6 in Poland. The downturn from 2007 resulted in the growth in the educational sectors own educational expenditure rising by a factor of only 2.3 from 2000 to 2009 in the UK, compared with 3.6 in Germany and 2.9 in Poland.

4.4.2 Educational purchases and spillovers across Europe

Figure 7 shows the total educational purchases (i.e. the amount spent buying goods and services from the Education sector – schools, further and higher education institutions) by country for 1995 and 2009. In 1995, the UK had the highest total purchases from education (5,000 2005m Euros), followed by Germany (3,000 2005m Euros) and Italy (2,600 2005m Euros). In 2009, the UK ranked second with 21,000 2005m Euros, behind Germany (24,000 2005m Euros). France ranked third in 2009, with 10,000 2005m Euros in education purchases.

Purchases from Education increased in every country between 1995 and 2009. In this time period, Germany and the UK have the largest absolute increases in purchases (21,000 m Euros and 16,000 m Euros, respectively). Bulgaria and Turkey have the largest relative increases, starting from low bases.

Figure 7: Total Purchases from the Education Sector by Country, 1995 and 2009 (constant 2005 million Euros)



Source: Education Spillovers Summary.xls

Table 5 shows the total exposure to Education spillovers for 28 European countries in 1995 and 2009, ranked by their exposure to spillovers in 2009. In both 1995 and 2009, the countries with the highest exposure to spillovers are Germany (40,000 2005m Euros in 2009), the UK (28,000 2005m Euros in 2009) and France (21,000 2005m Euros in 2009). Between 1995 and 2009, exposure to educational spillovers increased in every country. Exposure increased the most in Germany, the UK and in

France in absolute terms. Large relative increases are seen in Hungary and Poland, starting from low bases.

The countries with the highest levels of purchases from the Education sector (Germany, the UK and France) also saw the highest level of spillovers (see Figure 8). Figure 8 shows the ratio of exposure to spillovers to spending. A ratio of greater than one indicates that the exposure is greater than purchases, a ratio of less than one indicates that purchases are higher than exposure. In 1995, the ratios ranged from 0.35 in Ireland to 3.2 in Turkey and 2.9 in Germany, with the UK ranked 16th among the 26 countries, with a ratio of 1.2. In 2009, the ratio ranges from 0.7 in Turkey to 2.7 in Belgium and the Netherlands (very similar to the range of ratios seen in R&D), with the UK ranked 20th out of 28 countries with a ratio of 1.3.

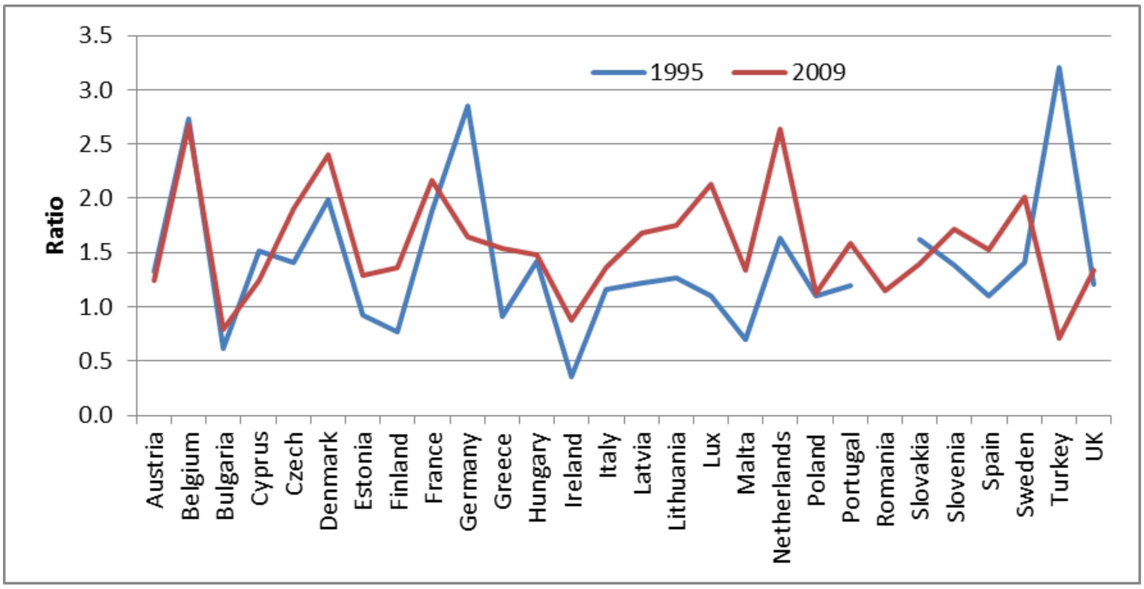
Table 5: Total Exposure to Educational Spillovers by Country (2005m Euros), 1995 and 2009

Country	1995	2009	change	Country	1995	2009	change
Germany	8,587	39,912	31,326	Poland	32	1,046	1,014
UK	6,033	27,751	21,718	Portugal	461	884	423
France	2,459	21,515	19,056	Turkey	15	739	725
Netherlands	2,767	12,982	10,216	Slovenia	50	411	361
Italy	3,046	8,730	5,683	Lithuania	18	320	303
Spain	489	5,448	4,959	Slovakia	47	273	226
Belgium	295	3,625	3,330	Latvia	5	254	248
Sweden	1,136	3,383	2,248	Greece	71	232	161
Ireland	77	1,687	1,610	Bulgaria		115	(115)
Finland	503	1,608	1,105	Romania		107	(107)
Denmark	532	1,368	836	Estonia	6	98	92
Czech	152	1,354	1,202	Lux	8	47	39
Hungary	129	1,237	1,107	Cyprus	2	29	27
Austria	383	1,103	720	Malta	3	24	20

Source: Education Spillovers Summary.xlsx.

In most countries in 2009, the Financial Intermediation and Post and Telecommunications sectors have the highest exposure to education spillovers. There is variation among the countries however. In the UK, the Real Estate (1,700 2005m Euros), Other Community, Social and Personal Services (1,500 2005m Euros) and Financial Intermediation (1,300 2005m Euros) sectors have the highest exposure to spillovers from Educational purchases.

Figure 8: Ratio of Exposure to Spillovers to Purchases, 1995 and 2009



5. Empirical Results: Productivity and other Performance Measures

This section reports on the European-wide results from the "static" models. There is a methodological discussion that finalises the functions to be estimated. Empirical results are provided for three measures of performance: productivity (labour productivity and total factor productivity); profitability (gross and net); and international trade (exports per unit of value added and the export / import ratio).

5.1 Introduction

This section deals with the results based upon the sectoral database, which comprises a quasi-panel of sectors and countries over time. The question addressed here is the "static" one outlined in the introduction: can evidence be found that sectoral performance is influenced, not only by its own (for example) educational purchases, but also by the educational purchases of other sectors? In other words, is the productivity of sector i affected by the educational purchases made in sector j?

In principle, there are 34 sectors[24], 28 countries and 15 years of observations (1995 to 2009). In practice, measures of capital stock are not available after 2007, which limits the time series dimension to 13 years. The years 2008 and 2009 are anyway quite distinct because most of the economies fell into recession. Nevertheless, where complete data are available (e.g. when a capital stock variable is not needed), the empirical results are estimated using the 15 years of data. A further small loss of observations occurs where logarithmic values are used – this is largely limited to the own-R&D variable, where a small number of sectors report zero R&D expenditure.[25]

5.2 Methodology

The principal measure of performance adopted in this section is labour productivity, measured as real value added per person (VA/E). However, a number of variants are tested: real value added per employee; real value added per person hour; and real value added per employee hour. Total factor productivity is also used as a measure of performance. Profits are generally adopted as a measure of performance in the private sector and they play quite an important role in the present study (see Section 5.2.2). The profit measures used are gross- and net-profit per unit of value added. Two other measures of international trade performance (exports per unit of gross output, X/GO, and exports per unit of imports, X/IM).

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[24] This is without the "Private Household" sector which is absent from many of the measures in many countries.
[25] A method to avoid this problem was tried, but created problems of its own. This is discussed in the Technical Annex, Section A4.1 (Bosworth, *et al*. 2014).

As noted in the introduction, while various measures of productivity and profits are traditional candidates for performance measures, export performance is included alongside these because the government set a target to increase exports by 2020. Certainly, there is an *a priori* expectation that investments in intangibles (such as R&D and education), as well as increased innovation should raise exports, other things being equal.

5.2.1 Productivity analysis

Labour Productivity

The specification of the productivity equation is based on a log-linear production function that, in principle, allows returns to scale[26] (α+β) to be estimated – see the first part of equation (1),

$$\frac{VA}{E} = AE^{\alpha-1}K^{\beta} = A'E^{\alpha-1}K^{\beta}RD^{\gamma}RS^{\tau}X^{\rho} \qquad (1)$$

with the expectation that α+β is reasonably close to unity. E is total employment, K the capital stock and A is the technical efficiency parameter. In the work on technological spillovers, it is hypothesised that A is influenced by its own R&D (RD), by the exposure to R&D carried out by other firms (RS) and, potentially, a range of other factors, X. In the present case, the main components of X are own-educational purchases and the exposure to educational purchases of other sectors, but a crude measure of "skills" is also included along with a range of dummy variables and interaction terms. Other variables are also included in the UK enterprise level work and are discussed in Section 7 below.

A number of variants on equation (1) were also estimated, replacing E by the number of employees (e.g. excluding the self-employed), the number of person hours worked and the number of employee hours worked. However, as no measures of the output produced by employees rather than the self-employed are available and as there are no measures of capital utilisation to match those of the hours of workers, then equation (1) was preferred for conceptual reasons. In addition, all of these variants produced very similar results to equation (1).

Total Factor Productivity

The present work undertakes a brief examination of the links between the level of total factor productivity and the R&D, skills and education variables.[27] Total factor productivity is defined as, VA/(αE+βK), but assumes constant returns to scale, VA/(αE+[1-α]K) and, following standard growth accounting theory uses the share of

[26] E.g. an estimate of how much output would increase if all inputs were increased in a given proportion. So if all inputs double, does output more than double (increasing returns to scale), just double (constant returns to scale) or less than double (decreasing returns to scale).

[27] The level of TFP is not independent of the units of measurement, but, if measurement is undertaken consistently by country and sector, the relative levels of TFP should be less problematic.

labour in total costs to represent α and the share of capital in costs to represent 1-α. Thus, the right hand side of equation (1) remains the same, except that the terms in E and K are dropped because of constant returns to scale.

5.2.2 Profits analysis

The question of which party benefits from the spillover should be reflected in the profits of the firms. If the innovating suppliers are able to price their products and services to appropriate all of the benefits, then the buyer will not capture any financial spillover. Given that this seems highly unlikely (see Section 3.2), the expectation is that the spillovers will raise profits within the buyer firms. A profit per unit of value added measure is constructed both in terms of gross profits and net operating surplus. The latter (net profits) is not available for some countries and, even when countries report it, the measure may not be available for every year.

A proxy measure of gross profit can be constructed using value added.[28] The income measure of value added is employee compensation plus net taxes, plus consumption of capital, plus net operating surplus. While net operating surplus and capital consumption are not available for some countries, the other variables are. The preferred measure is constructed as value added minus employee compensation minus net taxes. In addition, it is possible to control for the size of capital consumption to some extent, by including the size of capital stock in the explanatory variables. The issue of agricultural subsidies is dealt with by dropping that sector and four further sectors are dropped because in most, if not all countries, they are run by government or charities and / or are not profit oriented[29]. There remain a number of issues with the profit variables, which are dealt with in detail in the Technical Annex, Section A4.2 (Bosworth, *et al*. 2014).[30]

The function estimated is as close as possible to the productivity function and is as follows,

$$\frac{\pi}{VA} = \alpha RD^{\gamma} RS^{\tau} X^{\rho} \qquad (2)$$

where *π* is real sector profit. X contains the education variables described in Section 4.4, the proportion of employment hours provided by medium skill and high skill individuals (as in equation 1)[31], capital stock and the proportion of self-employment, along with a range of dummy variables and interaction variables.

[28] Gross operating surplus, which is available in the WIOD data set, is not a measure of profit - it is an industry level residual variable (output less intermediates) (Eurostat, 2008, p. 55).
[29] Public Administration and Defence, Compulsory; Education; Health and Social Work; Other Community, Social and Personal Services.
[30] E.g. a higher proportion of negative values, missing countries, differences in the scope of the public sector, different accounting standards, etc.
[31] As noted in Section 3, a measure of “skill spillovers” were constructed from this variable, but there proved to be major problems of collinearity between various elements of the own-skills and skill spillover variables. Hence, only own-skill levels have been included in the reported results.

Purchases from the educational sector and own-R&D are expenditures out of revenues that would otherwise go to profit, with the aim of increasing future profit, so their associated coefficients in the profit equation are expected to be negative (an accounting tautology). The capital stock proxies for the missing capital depreciation in the gross profit equation, as well as for the fact that higher absolute profits are needed in more capital intensive activities to satisfy shareholders. The proportion of self-employed in the workforce is a proxy for the profit orientation of the sector as well as the fact that income for the self-employed is drawn from gross profits. Country, sector and time dummies are included sequentially, with some experimentation with R&D interaction terms.

5.2.3 International trade analysis

Finally, there is sector level information available international trade performance available from Eurostat. There is an expectation that improvements to product quality will lead to greater exports and domestic import substitution – associated with "export led growth" – see, for example, Krugman, 1987; Havyrlyshyn, 1990 for surveys), and linked to the Government's 2020 target for exports.

Hence, the final static model examines whether any relationships can be found between education and R&D spillovers and trade. Two measures are investigated, exports per unit of gross output and the export / import ratio. The functional form remains the same, with the three main pairs of explanatory variables (own-R&D, R&D spillovers, own-educational expenditures and educational spillovers, medium own-skill and high own-skill proportions). No other variables are included except the country, sector and time dummies, with some experimentation with R&D interaction terms.

5.3 Productivity results

5.3.1 Labour productivity

The first six columns of Table 6 set out the results of the basic productivity regression in which all variables are contemporaneous. The equations estimated are log-linear in form, as set out in Section 5.2.1, so the dependent variable is the natural log of labour productivity and the independent variables are also logged. The reasons for assuming that R&D spillovers have an immediate effect on productivity are set out in Sections 3.3.3 and 3.3.4. The regressions contain all four pairs of independent variables: employment and capital stock to check on returns to scale; R&D and R&D spillovers; the proportions of medium and high skill hours used in production; and direct purchases from the education sector and exposure to education purchased by other sectors.

The regressions progressively add in various dummy variables: country dummies (regression 2); sector dummies (3); time dummies (4); interaction between the two R&D variables and the country dummies (5), which allow different R&D coefficients for each country; interaction between the two R&D variables and the sector dummies (6), which allow different R&D coefficients for each sector. The resulting dummy coefficient estimates are not included in the table, but shown in Figures A1-A3 of Technical Annex 3 and discussed further there.

The first regression, without any of the dummy variables, has a number of unexpected features. The returns to scale estimate (RTS) is normally close to unity in empirical studies, and a figure of 0.51 seems implausibly low. In addition, the expectation is that an increase in the proportion of medium skill hours (vis a vis low skill hours) would have a positive effect (not negative as in the regression) and an increase in the proportion of high skill hours would have a higher, but positive coefficient than medium skill hours (whereas the coefficient in regression one is higher, but negative). Finally, the coefficient on educational spillovers is negative, rather than an expected positive value.

As a general rule, the results appear to improve with the addition of each of the sets of dummy variables. The measure of the "fit" of the regression $\bar{R}^2$ increases with each set of dummy variables and, although the F statistic falls it is significant at the one per cent level and suggests that the variables and dummy variables make a significant contribution over and above the constant term. The employment and capital stock coefficients are broadly in line with expectations throughout the regressions that include at least one set of dummy variables (regressions two to six), although it seems that the estimated RTS is eroded slightly as the number of sets of dummies increases.

The coefficient on own-R&D takes a small, but significant positive coefficient (regressions one to five). In the final regression in this group (regression six), the insignificant coefficient is because of the inclusion of the sector x R&D interaction terms, which allow the R&D coefficient to be estimated for every sector (relative to chemicals). The first five regressions suggest that a one per cent increase in own-R&D is associated with a 0.03 per cent rise in labour productivity. At the mean value added per worker in the UK, over the period 1995 to 2009, of 45,160 Euros (2005 constant prices), the improvement in labour productivity of 0.03 is equivalent to 1,355 Euros per worker per annum.[32]

[32] The mean value added per worker across Europe, over the period 1995 to 2009, is only 17,239 Euros (2005 constant prices), the improvement in labour productivity of 0.03 is equivalent to only 517 Euros per worker per annum.

In the case of R&D spillovers, there is sufficient evidence of the positive effects of exposure to spillovers, with all six coefficients positive and significant at the five per cent level or higher. However, the likely magnitude of the effect is less certain, but the results suggest that it is at least as large as the effects of own-R&D and, probably, considerably larger (possibly in the 0.08-0.16 range). Taking 0.08 as the estimated effect, a one per cent increase in spillovers translates into 3,113 Euros per worker in the UK (based on the mean value added per person of 45,160 Euros, see above).[33]

Table 6: Basic regressions, labour productivity

Regression no.	1	2	3	4	5	6
(Constant)	1.820**	2.982**	3.836**	4.112**	4.065**	4.060**
Ln Employment	-.746**	-.551**	-.543**	-.542**	-.536**	-.554**
Ln Capital Stock	.257**	.456**	.411**	.405**	.379**	.378**
Ln R&D	.035**	.058**	.032**	.031**	.029**	-.003
Ln R&D Spillovers	.337**	.064**	.033**	.017*	.083*	.165**
Ln Med Skill Hours[a]	-1.095**	.168**	-.051*	-.035‡	.077**	.067**
Ln High Skill Hours[a]	-.067	.045**	.121**	.083**	.102**	.113**
Ln Education	.157**	.012**	-.001	-.001	.019**	.014**
Ln Education	-.216**	-.129**	-.110**	-.133**	-.148**	-.153**
Country dummies		√	√	√	√	√
Sector dummies			√	√	√	√
Time dummies				√	√	√
Country x R&D					√	√
Country x R&D spill					√	√
Sector x R&D						√
Sector x R&D spill						√
$\bar{R}^2$	.767	.904	.922	.923	.939	.944
F	491.6**	2790.9**	1784.8**	1542.0**	1192.9**	872.2**
RTS	0.511	.905	.868	.863	.843	.824

Note: a) base group is Ln Low skill hours.

The earlier discussion of the results noted that the sign of the coefficients on the medium and high skill proportion variables took the opposite sign to that expected (regression one). Regression two shows the expected positive signs, but the relative magnitude of the medium and high coefficients appear wrong. However, these problems appear to be corrected in regressions five and six, suggesting that a one per cent increase in the proportion of high skill hours (relative to low skill hours) results in about a 0.10-0.11 per cent increase in labour productivity, while a one per cent increase in the proportion of medium skill hours (relative to low skill hours) results in about a 0.07-0.08 per cent increase in labour productivity.

[33] But only an improvement of 1,379 based on the European average labour productivity.

The coefficients on own-educational purchases are positive and significantly different from zero in four of the six cases. If regression one is discounted for the reasons outlined earlier, this suggests that a one per cent increase in own-educational purchases probably results in a 0.01 to 0.02 per cent rise in labour productivity (about 452-904 Euros per person at the UK mean value added). The coefficient on exposure to educational spillovers, although highly significant throughout, remains negative. The coefficient estimates suggest that it is the sectors with higher own-educational purchases have higher labour productivity (as the own-education coefficients imply) and that none of the benefits of those educational purchases are passed on to their buyers.

The effects of lagging own-R&D by one year are shown in Table 7, allowing the outputs of the R&D a year to feed into productivity performance. The coefficient estimates on lagged own-R&D are at least as significant as on the corresponding contemporaneous variable. While the coefficients on R&D spillovers are now slightly less robust, they are still mainly significant at the 10 per cent level or higher and generally at the five per cent level or higher. The other results remain largely unchanged from the discussion of Table 6.

Table 7: Basic regressions, labour productivity, with lagged R&D

Regression no.	1	2	3	4	5	6
(Constant)	2.676**	2.933**	3.867**	4.188**	3.687**	3.829**
Ln Employment	-.639**	-.554**	-.541**	-.540**	-.537**	-.557**
Ln Capital Stock	.267**	.458**	.402**	.395**	.373**	.373**
Ln R&D	.094**	.068**	.053**	.051*	.075**	.090**
Ln R&D Spillovers	.212**	.070**	.032**	.011	.105‡	.095*
Ln Med Skill Hours[a]	.039*	.196**	-.038*	-.022	.074**	.067**
Ln High Skill Hours[a]	.198**	.035**	.131**	.088**	.098**	.109**
Ln Education	.013*	.011**	.001	.001	.019**	.015**
Ln Education	.096**	-.129**	-.119**	-.142**	-.130**	-.133**
Country dummies		√	√	√	√	√
Sector dummies			√	√	√	√
Time dummies				√	√	√
Country x R&D					√	√
Country x R&D spill					√	√
Sector x R&D						√
Sector x R&D spill						√
$\bar{R}^2$	.649	.912	.928	.929	.943	.948
F	2239.2**	2872.5**	1831.8**	1609.4**	1207.3**	884.9**

Note: a) base group is Ln Low skill hours.

The results for the other measures of labour productivity (value added per employee, value added per employment hour and value added per employee hour) are very similar to those reported in Table 6. This is despite the fact that these other measures are associated with some additional problems of measurement and specification (see Section 5.2.1 above).

5.3.2 Total factor productivity

The results for the levels of TFP are set out in Table 8. Regression two is so superior in terms of fit, regression one can largely be ignored. The discussion deals with the results that are largely consistent throughout. First, overall own-R&D plays almost no role in these regressions and the same is true for R&D spillovers, at least until regression five, where the coefficient is of the opposite sign to that expected. The discussion returns to these results below. Second both the coefficients on the proportions of high and medium skill hours are positive and significant vis a vis low skill hours. However, the medium skill hours coefficient is larger than the high skill hours throughout. Own-education purchases and exposure to education spillovers are both positive and significant at the one per cent level throughout. The coefficients on educational spillovers are much larger than those on own-education, by a factor of four or five (regressions 2-5). Not only is the magnitude of the educational spillover coefficient significantly larger than the own-education coefficient, but also the average size of educational spillovers is somewhat larger than own-educational expenditures. Combining the two effects (the coefficient and the mean values of the variables) suggests that the impact of educational spillovers on TFP is just less than twice the order of magnitude of the effect of own-educational expenditures on TFP.[34]

Table 8: Total Factor Productivity

Regression no.	1	2	3	4	5
(Constant)	-.448**	.051	.109	.284	1.056
Ln R&D	.085**	-.004	-.006	.028‡	.056
Ln R&D Spillovers	.024‡	.022*	.000	-.037	-.230**
Ln Med Skill Hours[a]	-.045	.236**	.235**	.272**	.194**
Ln High Skill Hours[a]	-.032*	.163**	.152**	.151**	.167**
Ln Education	.054**	.036**	.037**	.030**	.045**
Ln Education Spillovers	.189**	.217**	.198**	.187**	.182**
Country dummies	√	√	√	√	√
Sector dummies		√	√	√	√
Time dummies			√	√	√
Country x R&D				√	√
Country x R&D spill				√	√
Sector x R&D					√
Sector x R&D spill					√
$\bar{R}^2$	.271	.575	.577	.608	.643
F	127.2**	231.0**	192.2**	131.0**	102.2**

Note: a) base group is Ln Low skill hours.

Returning to the R&D and R&D spillover variables, what the regressions are telling the reader is that there is considerable variation in the effects of these two variables

[34] No comparison is made of absolute effects, as only the relative values are meaningful.

across countries and sectors. It is not saying that they are irrelevant, there are, in fact, 38 per cent of all country / sector R&D coefficient combinations with values greater than 0.230, which would, therefore, experience a positive effect of R&D spillovers on TFP.

5.3.3 Total factor productivity illustration of sector-specific results

Figure 9 shows the relative impact of own-Education purchases on TFP, by sector. The values shown in Figure 9[35] are the estimated increase in TFP caused by a one per cent increase in own-educational purchases, relative to the Chemicals and Chemical Products sector.[36] Own-educational purchases has the largest impact on TFP in the Public Administration (8.9 per cent higher than Chemicals), Renting & Other Business Activities (8.5 per cent higher) and Education (8.2 per cent higher) sectors. The smallest impact is seen in Leather Products (11.3 per cent lower than Chemicals) and Water Transport (10.0 per cent lower).

In all 34 sectors, exposure to education spillovers has a greater impact on TFP than own-education purchases, however, relative to Chemicals the range of effects is narrower. Figure 10 shows the relative impact of exposure to education spillovers on TFP by sector. Spillovers have the largest impact on Financial Intermediation (8.9 per cent higher than Chemicals), Post and Telecommunications (6.1 per cent higher) and Other Community, Social and Personal Services (4.9 per cent higher) sectors. The sectors with the smallest increases in TFP due to exposure to education spillovers are Food, Beverage and Tobacco (8.4 per cent lower than Chemicals), Wood and Wood Products (7.5 per cent lower) and Renting and Other Business Activities (7.4 per cent lower).

Figure 11 and Figure 12 show sector-specific educational effects obtained from regressions of educational spending and educational spillovers on TFP.[37] The dummy variables allow each sector's TFP to benefit to different degrees from the own-education purchases and spillovers. The sector dummies for educational spending are the highest for the Mining (22.8 per cent higher than Chemicals and Chemical Products), Health and Social Work (21.5 per cent higher) and Education (10.4 per cent higher) sectors. The Real Estate sector, has the smallest benefit from own-education purchases (30.1 per cent lower than Chemicals and Chemical Products).

The educational spillover dummies tend to be slightly higher than the educational purchase dummies. The education spillover dummies range from Mining and Quarrying (22.8 per cent below Chemicals and Chemical Products) to the high

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[35] The estimated values of the impact on TFP of each sector are constructed as using a representative coefficient value of own-educational purchases on TFP multiplied by the mean educational purchases of each sector. Taking an exponential of each value gives an estimate of the absolute value of the TFP increase. However, as the value is not independent of the units of measurement, their values relative to a base sector, Chemicals and Chemical Products (where the base sector takes a value of 100).

[36] There are no sector-specific educational effects in these results (but these are included in Figures 3-6).

[37] Thus, in addition to the effects of own-educational purchases and exposure to educational spillovers which are common across sectors, a coefficient is estimated on these two variables for each sector. Again, the results are presented relative to the benefit obtained by the Chemicals and Chemical Products sector.

impact sectors of Public Administration and Defence (48.4 per cent above Chemicals and Chemical Products), Transport Equipment (44.2 per cent higher) and Hotels and Restaurants (42.6 per cent higher). It can be concluded that there are very important sectoral differences in the impact of both the own-purchases and the exposure to spillovers.

Figure 9: Impact of Educational Purchases on TFP by Sector

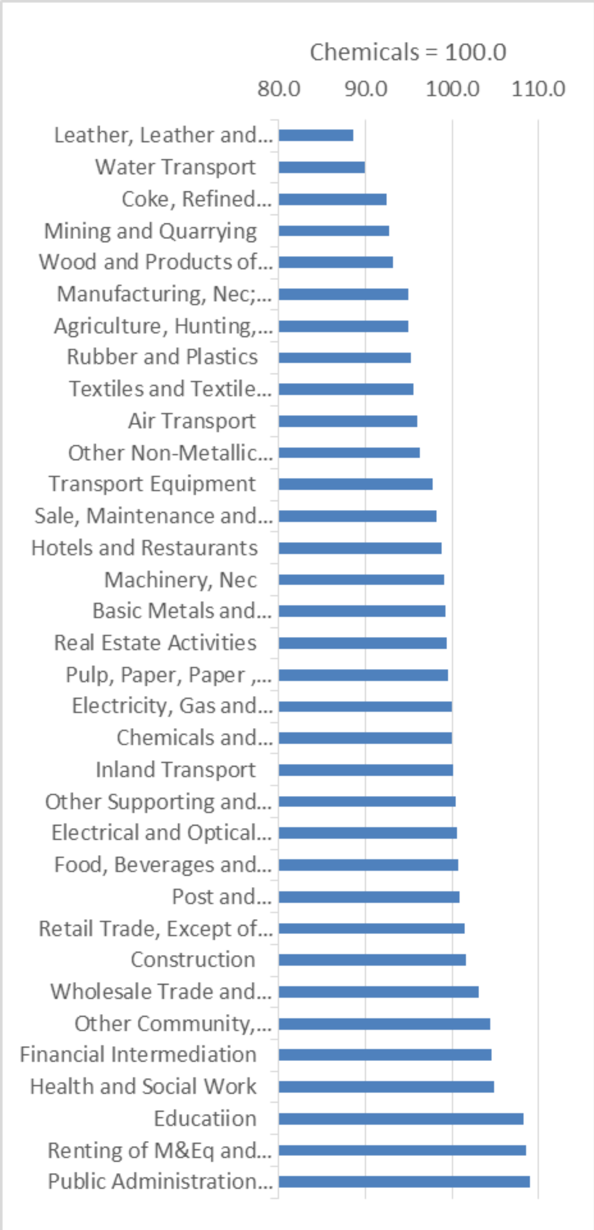
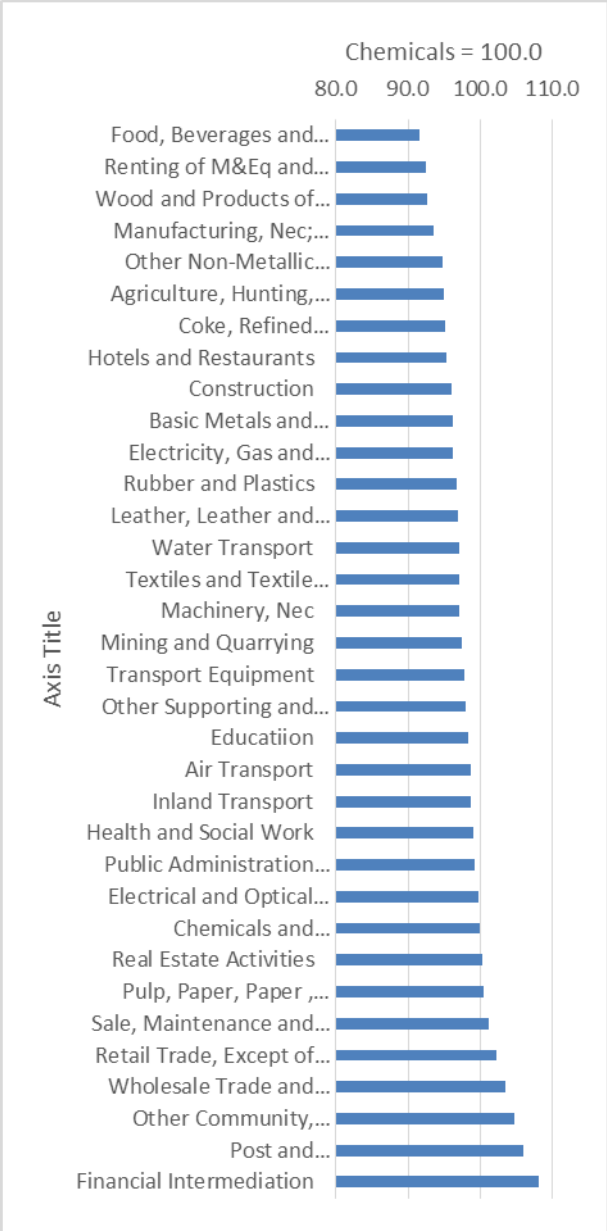


Figure 10: Impact of Exposure to Education Spillovers on TFP by Sector



Source: Education Sector Results.xlsx.

Figure 11: Educational Purchase Dummies by Sector

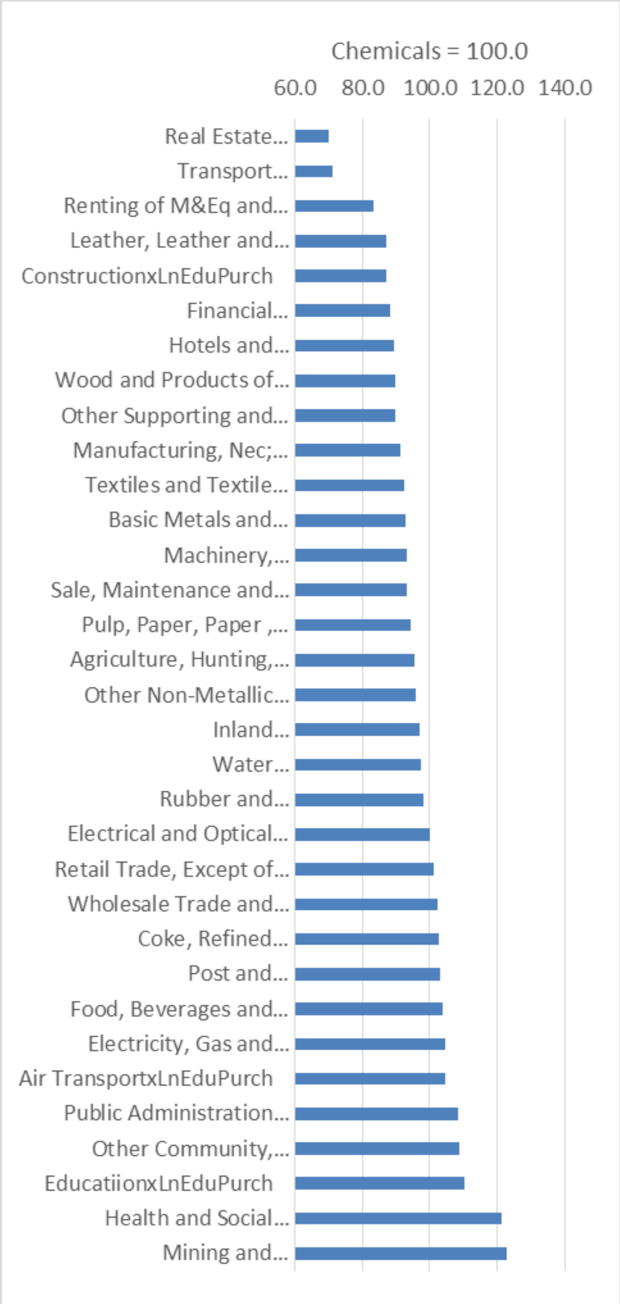
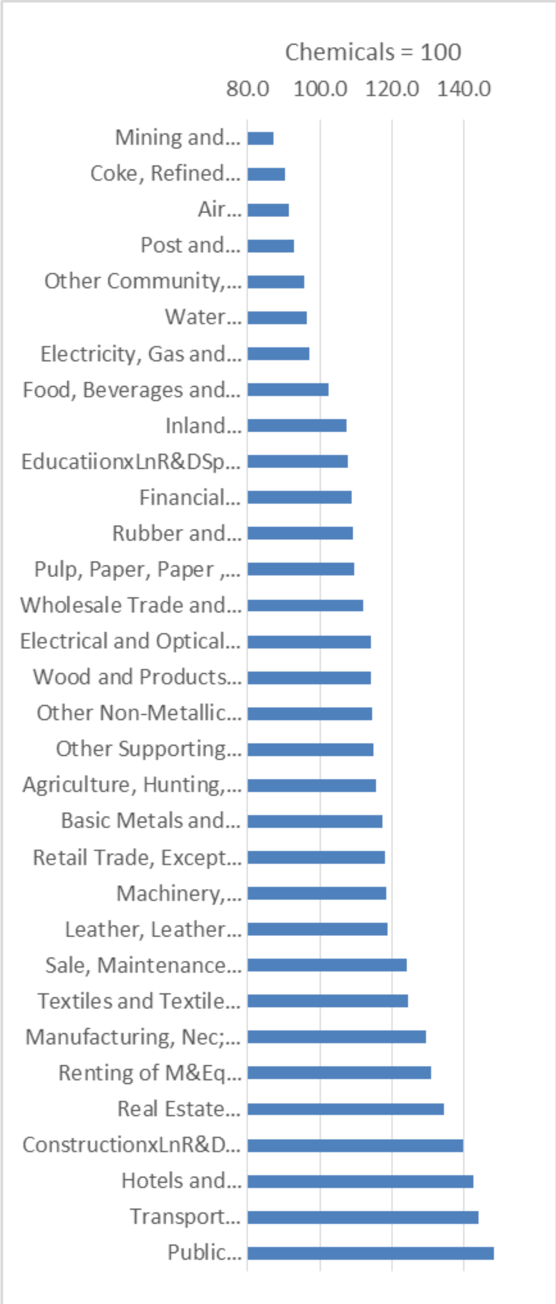


Figure 12: Education Exposure to Spillovers Dummies by Sector



Source: Education Sector Results1

Figure 13 and 14 shows the impact of the combined common sector and the sector specific effects.[38] The highest own-education purchase impacts (Figure 13) are in Education (50.3 per cent higher than Chemicals and Chemical Products), Public

[38] The Regression used has both own-education coefficient (0.089) and exposure to education spillover coefficient (0.075) significant at the 1 per cent level (these coefficients are common across sectors). Of the sector-specific own-education coefficients, four sectors have significant positive values at the 10 per cent level and 15 significant negative values at the 10 per cent level. Of the sector-specific exposure to education spillover coefficients, 24 are significant positive and 4 significant negative at the 10 per cent level.

Administration and Defence (38.9 per cent higher) and Renting of Machinery and Equipment / Other Business Activities (34.9 per cent higher). The smallest own-education purchase impacts are to be found in Leather and Leather Goods (34.2 per cent lower than Chemicals and Chemical Products), Electrical and Optical Products (26.5 per cent lower) and Wood and Wood Products (23.2 per cent lower).

Figure 13: Educational Purchase Sector Dummy Coefficients

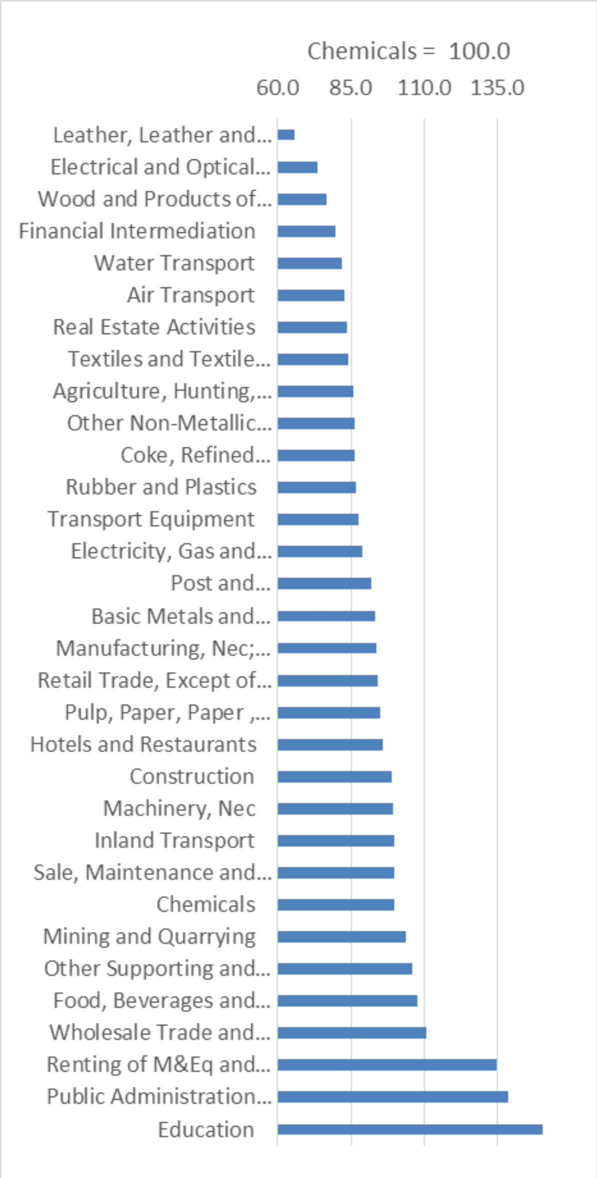
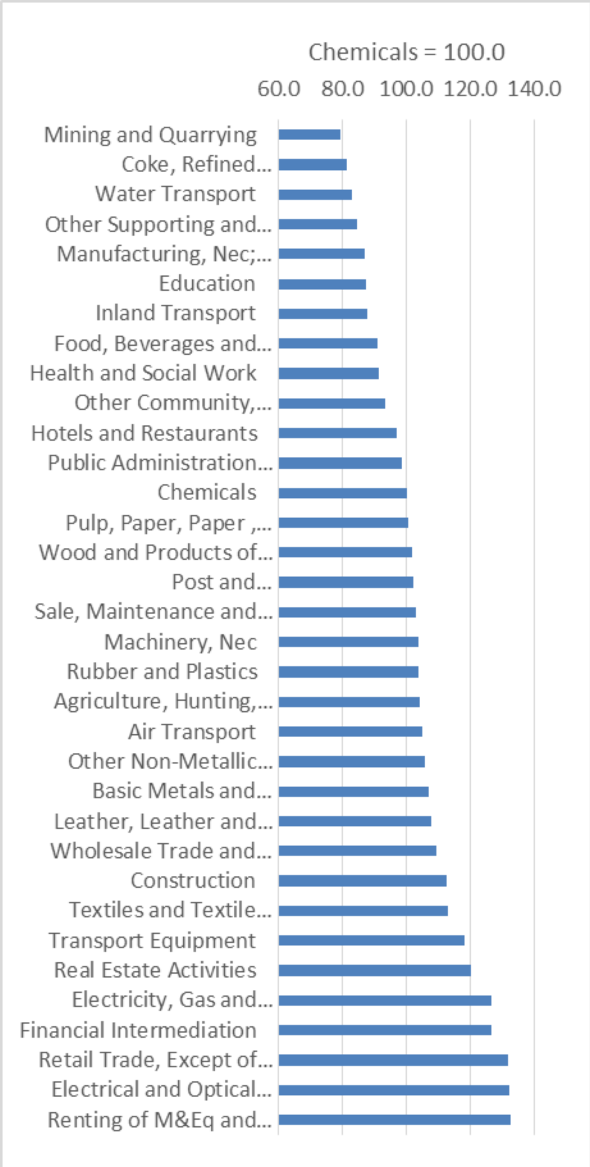


Figure 14: Exposure to Education Spillovers Sector Dummy Coefficients



Source: Education Sector Results

Figure 14 shows the combined common sector spillover and the sector specific spillover effects. The largest impact of educational spillovers is in Other Community, Social and Personal Services (32.4 per cent higher than Chemicals and Chemical Products), followed by Electrical and Optical Equipment (32.1 per cent higher) and Retailing (31.7 per cent higher). The smallest effects are found in Mining and Quarrying (20.7 per cent lower than Chemicals and Chemical Products), Coke and Refined Petroleum, etc. (18.6 per cent lower) and Water Transport (17 per cent lower).

5.3 Gross and Net Profit

This section investigates whether the R&D, skills and education variables are related to profitability. Two measures of profit are available, gross and net profit, as outlined in Section 5.2.2, which enter the regressions divided by value added. Five sectors are omitted from the observations on the grounds that they are generally subsidised[39] or largely state provided or otherwise non-profit[40]. Two further controls are entered: the capital stock of each sector (the larger the capital stock, the higher capital consumption and, thereby, the required profit per unit value added); and the proportion of self-employed (as profits are the source of income for the self-employed and sectors with higher proportions of self-employment may be more profit oriented).

The main results of the profit regressions are shown in Table 9 and Table 10, with those for gross profits generally stronger than those for net profits (both are estimated as log-linear functions). In both the gross and net cases, the addition of the country dummies adds substantially to the explanatory power over and above that of the R&D, skill, education and the other two control variables. The same is true of the addition of the sector dummies, but further improvements from adding the time dummies and the interaction terms are relatively small. However, many of the estimated coefficients from these dummies and interaction terms are significantly different to the chosen base groups (the UK in terms of country dummies, Chemicals and Chemical Products in terms of the sector dummies and 1995 in terms of the year dummies).

Taking the gross profit first, R&D and educational expenditures are argued to be likely to produce significant negative coefficients, based upon the premise that they are investments rather than current expenditures. In the case of R&D, this can only really be judged from the first three equations (the interactions give values relative to the UK). There is marginal evidence that R&D has a negative effect in the gross profit equations (Table 9), but little or no evidence in the net profit results (Table 10). Excluding regression one, the coefficient on own-education expenditure is very small and insignificantly different from zero in the case of gross profits and positive and significantly different from zero (at the 10 per cent level or higher) in regressions two and three of the net profit results.

Our interpretation of this is that sectors that do more R&D or purchase more from the educational sector probably do so on an on-going basis over time. Thus, past investments are being reflected in present profits to a degree that off-sets the magnitude of current investments in R&D and educational inputs.

In the case of gross profits, the R&D and education spillover coefficients have significant positive values in all cases (in the final two equations, the significant coefficients appear on the interaction variables). The likely size of the effect of a one per cent increase in the exposure to R&D spillovers is about 0.10-0.11 per cent,

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[39] Agriculture, Hunting, Forestry and Fishing

[40] Public Administration and Defence; Compulsory Social Security; Education; Health and Social Work; Other Community, Social and Personal Services.

while the size of the effect of education spillovers is between 0.06-0.08 per cent. Of the other variables, the proportion of high skill hours has a highly significant, positive coefficient in all three cases, while the proportion of medium skill hours has the opposite sign to that expected (unlike the labour productivity equations, adding the country and the sector R&D interaction terms does not resolve the problem). The coefficients on the capital stock and self-employment variables are positive and significant at the one per cent level throughout.

Table 9: Gross profit regressions, all countries

Regression no.	1	2	3	4	5
(Constant)	-2.945**	-3.347**	-3.088**	-2.549**	-2.731**
Ln R&D	-.043**	-.006	-.009‡	-.112**	.005
Ln R&D Spillovers	.103**	.109**	.095**	.111	-.004
Med Skill Hours[a]	-.237**	-.176**	-.164**	-.159**	-.234**
High Skill Hours[a]	.212**	.146**	.137**	.161**	.175**
Ln Education	-.035**	-.001	.002	.001	-.010
Ln Education Spillovers	.115**	.079**	.062**	.037**	.045**
Ln Capital stock	1.236**	.817**	.812	.901**	.902**
Ln Self employment	.132**	.195**	.193**	.179**	.182**
Country dummies	√	√	√	√	√
Sector dummies		√	√	√	√
Time dummies			√	√	√
Country x R&D				√	√
Country x R&D spillovers				√	√
Sector x R&D					√
Sector x R&D spillovers					√
$\overline{R}^2$	.707	.799	.800	.816	.829
F	447.8**	380.9**	317.9**	216.4**	158.9**

Note: a) base group is Ln Low skill hours.

The net profit results are considerably weaker. The coefficients on own-R&D and R&D spillovers are (ignoring equation one) insignificant throughout. Both variables are ejected from the regression on the inclusion of the R&D interaction terms, but a considerable number of the coefficients on the interaction terms are significantly different to zero at the 10 per cent level or higher. While the estimated education expenditure coefficient is significantly positive in two instances, the associated coefficients are very small. However, education spillovers are significant positive throughout at the one per cent level or higher, suggesting that a one per cent increase in exposure to educational spillovers has between 0.05 and 0.09 per cent increase in profit per unit of value added. Using the mean value of gross profits per value added of 1.658 as an example, a 0.07 per cent increase would shift the ratio to 1.659. Of the other variables, the coefficient on the proportion of high skill hours is again highly significant and positive throughout, but the medium skill variable again carries an unexpected significantly negative coefficient. Both the capital stock and proportion of self-employment have positive and significant coefficients throughout.

Table 10: Net profit regressions, all countries reporting net profit data

Regression no.	1	2	3	4	5
(Constant)	-1.581**	-2.448**	-2.305**	-2.446**	.002
Ln R&D	-.030**	.006	.003	-[b]	-[b]
Ln R&D Spillovers	.028	.020	.004	-[b]	-[b]
Med Skill Hours[a]	-.256**	-.221**	-.205**	-.152**	-.203**
High Skill Hours[a]	.236**	.194**	.177**	.195**	.174**
Ln Education	-.028**	.015‡	.017*	.007	-.001
Ln Education Spillovers	.140**	.085**	.065**	.053**	.051**
Ln Capital stock	1.528**	1.060**	1.055**	1.164**	1.180**
Ln Self employment	.124**	.025**	.242**	.222**	.242**
Country dummies	√	√	√	√	√
Sector dummies		√	√	√	√
Time dummies			√	√	√
Country x R&D				√	√
Country x R&D spillovers				√	√
Sector x R&D					√
Sector x R&D spillovers					√
$\bar{R}^2$	.502	.637	.639	.656	.671
F	185.4**	164.2**	136.9**	92.1**	65.7**

Note: a) base group is Ln Low skill hours; b) variable dropped by software.

5.4 Trade: exports and spillovers

This section examines the relationship between two measures of trade performance and the R&D, skills and education variables. Other influences are controlled for via the country, sector and time dummies. The two measures of trade performance are (natural log) exports divided by gross output[41] and (natural log) the export / import ratio. The results for the two dependent variables are set out in Table 11 and Table 12. The improvement in fit from using just the country dummies to the inclusion of the sector dummies is so large that regression one can be ignored in both tables.

While there are differences between the two sets of results, they are sufficiently similar to deal with them both at the same time. The key result is the positive significant coefficient that occurs on the educational spillover variable. This coefficient is consistent in size in each equation, but quite different in scale across the two functions. A one per cent increase in educational spillovers produces a 0.05 to 0.07 per cent rise in exports per unit of output, but a 0.4 to 0.6 per cent rise in exports per unit of imports, which reflects the greater variation in the second measure.

[41] Exports to gross output appears a more testing measure than exports to value added, as the latter would ignore the contribution of intermediate goods suppliers to export success and make it more likely to find spillover effects. In practice both measures give similar results.

The other strong feature is the importance of highly skilled labour, which has a highly significant positive coefficient in regressions two to four in both tables, and only becomes insignificant when all dummy and interaction variables are included (regression five). The estimated effect here appears to be large, with a one per cent rise in the proportion of workers with high skill level resulting in a 0.4 per cent rise in the export/gross output ratio and a 0.2 per cent rise in the export/import ratio. The own-educational expenditure coefficient also has a positive sign in the export per unit of gross-output equation and is significant at the 10 per cent level or higher (regressions two to four), but is insignificant throughout in the export/import equations.

Unlike some of the earlier regressions, R&D and R&D spillovers show mixed results. R&D has a positive coefficient throughout in the export/gross output function, but is only significant at the 10 per cent level or higher in the final two equations, which include all the dummy and interaction terms. It is also has a significant positive coefficient at the 10 per cent level or higher in all but the final regression in Table 11. The R&D spillover coefficients tend to take the wrong sign in Table 11, but the coefficient is significant positive at the 10 per cent level (along with the own-R&D coefficient) in regression five. While the R&D spillover coefficient is positive in regressions two, three and five in Table 12, the coefficients are not significantly different from zero at the 10 per cent level.

Table 11: Export/gross output regressions, all countries

Regression no.	1	2	3	4	5
(Constant)	.641**	4.589**	4.628**	3.878**	1.656**
Ln R&D	.294**	.009	.009	.135**	.100‡
Ln R&D Spillovers	-.181**	-.129**	-.135**	-.115	.255‡
Med Skill Hours[a]	-.337**	.042	.035	.002	.070
High Skill Hours[a]	-.325**	.438**	.444**	.397**	.076
Ln Education	-.330**	.032**	.032**	.021‡	-.004
Ln Education Spillovers	.345**	.052**	.051**	.071**	.074**
Country dummies	√	√	√	√	√
Sector dummies		√	√	√	√
Time dummies			√	√	√
Country x R&D				√**	√**
Country x R&D spillovers				√**	√**
Sector x R&D					√**
Sector x R&D spillovers					√**
$\bar{R}^2$	.225	.659	.658	.675	.735
F	87.4**	311.9	260.7**	161.9**	149.7**

Note: a) base group is Ln Low skill hours.

Table 12: Export/import regressions, all countries

Regression no.	1	2	3	4	5
(Constant)	-.885**	.143	.140	2.175*	0.514
Ln R&D	.152**	.020‡	.022*	.092**	-.043
Ln R&D Spillovers	-.088**	.002	.009	-.361*	.061
Med Skill Hours[a]	-.170*	.047	.053	.194**	.308**
High Skill Hours[a]	.091*	.238**	.215**	.228**	-.056
Ln Education	-.174**	-.001	-.003	.006	-.006
Ln Education Spillovers	.292**	.153**	.147**	.172**	.139**
Self-employment	-2.409**	.433**	.431**	.592**	.170
Country dummies	√	√	√	√	√
Sector dummies		√	√	√	√
Time dummies			√	√	√
Country x R&D				√**	√**
Country x R&D spillovers				√**	√**
Sector x R&D					√**
Sector x R&D spillovers					√**
$\bar{R}^2$	.194	.488	.489	.537	.612
F	70.7**	152.0**	124.7**	88.9**	84.2**

Note: a) base group is Ln Low skill hours.

6. Empirical Results: the Knowledge Production Function, Endogenous Growth and Creative Destruction

This section outlines the European-wide results from the "dynamic models". There is a brief methodological discussion that outlines the measures of innovation to be used and the functions to be estimated. This section uses CIS data at the sectoral level to investigate whether past innovation, including past innovation spillovers, affect current innovation. It investigates whether the flows around the input-output tables may be a source of endogenous growth. Finally it explores whether innovation influences the births and deaths of enterprises in a manner consistent with Schumpeter's creative destruction.

6.1 Introduction

This section shifts attention to the question of whether one firm's or sector's R&D impacts on the "productivity" of the R&D of other firms or sectors (Griliches, 1992, p. 31). While this is difficult to test, if such a link exists, it will increase the amount of R&D carried out by the other firms or sectors. Thus, a key question addressed in the present section is whether innovation in the supply chain (e.g. amongst the suppliers of intermediate goods) affect subsequent innovation by the buyers. This would be a potentially important mechanism to underpin the new growth theories as buyers from various sectors are also suppliers to others. If innovation in one sector causes innovation in another, and that innovation causes innovation elsewhere, this would produce a very powerful innovation multiplier mechanism that could underpin continuous technological progress.

Innovation in an intermediate good or service may produce an "opportunity" or even a "need" for the buyer to innovate. The change in specification means that the buyer can themselves make a change which will either improve its product or service or make its production more efficient and lower costs. One historical example is Whitworth's development of a system of standard gauges, graduated to a fixed scale, which enabled different engineers to work with a constant measure of size.[42] This not only transformed the machine tool sector, which effectively had been a

[42] http://www.whitworthsociety.org/history.php?page=2

cottage industry, but also allowed any manufacturer to mass-produce standard, interchangeable parts at much lower costs (e.g. threads on nuts, bolts and screws).

The I-O matrix is also endogenous in the sense that, as new products emerge to replace old (e.g. new forms of paper for car bodies[43] to replace steel), demands will shift between sectors.

> "The entrepreneur carries out innovations, and, by doing so, destroys and creates anew the structure of the economy 'from within'. The Schumpeterian entrepreneur introduces new knowledge, reconfigures generic rules, and enables agents to use a new set of operations inducing a reallocation in the commodity space." (Dopfer, 2012, p. 143)

Finally this section explores whether the new data sets provide any evidence of creative destruction (Schumpeter, 1942, p. 83). Creative destruction is a process by which "… better products render previous ones obsolete. Obsolescence exemplifies an important general characteristic of the growth process, namely that progress creates losses as well as gains…" (Aghion and Howitt, 1992, p. 323).

6.2 Methodology

As the OECD (2008, p. 239) report points out, "The knowledge production function approach assumes that the production of new knowledge depends on current and past investment in new knowledge (*e.g.* current and past R&D expenditures) and on other factors such as knowledge flows from outside the firm." However, this is not what most of the work on knowledge production function does – most of it does something similar to the work reported in Section 4, where spillovers are contemporaneous with innovation and / or productivity growth (e.g. Crépon, *et al*. 1998). The crucial question, however, is whether past innovation activities affect future activities and, in particular, whether past innovation activities spill over to other firms or sectors to affect their future innovation activities.

The model estimated is as follows,

$$Logit(INN)_{t+x} = \alpha + \beta INN_t + \gamma INNS_t + X_t \quad (3)$$

where *INN* denotes the proportion of enterprises in the sector innovating, *INNS* is the exposure to innovations carried out by suppliers and X is a vector of other variables, including country, sector and, where appropriate, time dummies. The independent innovation variables are measured at time t, while the dependent innovation variable is measured at time t+x (where x is normally two years). The expectation is that β>0, as more innovatory sectors at time t are likely to be more innovatory at t+x, and, if the spillover hypothesis is correct, γ>0, as innovations in the supply chain give rise to an opportunity or a need to innovate amongst buyers. Persistence in innovation is dealt with by the sector and country dummies.

Three measures of innovation are used at the sectoral level, taken from the Community Innovations Survey (CIS). While these questions have tended to

[43] http://www.dailymail.co.uk/sciencetech/article-1079095/Future-planes-cars-paper-500-times-stronger-steel.html

become more detailed over time, they can be recombined to provide at least three consistent measures of innovation over the period 2001 to 2010,

- did your enterprise introduce new or significantly improved products (goods or services) over the last two years;
- did your enterprise introduce new or significantly improved production processes (including method of supplying services and ways of delivering product) over the last two years;
- did your enterprise engage in goods and services innovations new to your market?

Note that, at the sector level, these questions result in proportions of innovators, which take values from zero to one, unlike the R&D expenditure variable used in the static model. The exposure to innovations variable will also be bounded from zero to one, formed as a weighted sum of innovation proportions of supplying sectors, where the weights are the relative expenditures on each of the supplying sectors.

Given that some countries do not report data in all of the years of the survey, matching one year's survey to the next at the sector and country level means that not only are some countries lost from the sample, but also different countries appear in different year pairings. However, a number of countries, such as Spain, are available throughout. In addition, the recession hit all of the countries in 2007, so the effects of past innovation on current innovation may well change between 2006 and 2008 and, possibly, between 2008 and 2010. Hence, there is no reason to expect corresponding coefficient estimates to show immediate patterns over time. It also means that sample size varies depending on the pairings. These paired data sets are mainly cross-sectional in nature, but there is a single panel formed by combining the four cross-sectional paired data sets.

6.3 Innovation spillovers influencing the innovation process ("standing on the shoulders of giants")

The first set of EU wide results are obtained by pooling sectors and countries and pairing adjacent Community Innovation Surveys. The first set of rows in the first column of data in Table 13 shows the results of regressing the natural log of the odds (logit) of being involved in product innovation in 2004 on the corresponding log of the odds of product innovation in 2001, the (logit) exposure to the product innovations of supplying sectors in 2001, as well as a set of country and sector dummies, which control for persistence in innovation. As all the innovation variables are in logit form, the coefficients have a simple interpretation – they show the effect of a one per cent rise in the log of the odds of previous innovation (e.g. two years ago) on the percentage change of the log of the odds of current innovation.

Table 13: Innovation and Prior Innovation, Matched Surveys

	2001-4	2004-6	2006-8	2008-10	"Panel"
Product innovation					
Constant	.078	-.246	-.215	.947**	-.359
Product innovation	.175**	.384**	.218**	.127‡	.402**
Product spillovers	.152	.274‡	.575**	.011	.210**
Process innovation					.175**
Process spillovers					-.076
New to market innovation					.105**
New to market innovation spillovers					-.039
Country dummies	√	√	√	√	√
Sector dummies	√	√	√	√	√
Time dummies					√
$\bar{R}^2$	.750	.752	.685	.645	.526
F	23.7**	22.0**	12.5**	11.1**	25.6**
Process innovation					
Constant	-.310	-.032	-.230	.261	-.796**
Product innovation					.215**
Product spillovers					.119*
Process innovation	.072*	.318**	-.032	.076	.269**
Process spillovers	.129	.372*	.496‡	-.056	.284**
New to market innovation					.059*
New to market innovation spillovers					-.066‡
Country dummies	√	√	√	√	√
Sector dummies	√	√	√	√	√
Time dummies					√
$\bar{R}^2$	.715	.773	.668	.606	.543
F	20.6**	24.7**	11.4**	9.4**	27.4**
New to market innovation					
Constant	-1.023**	-1.698**	-1.184*	-.638	-.796**
Product innovation					.133**
Product spillovers					-.272**
Process innovation					.070
Process spillovers					.009
New to market innovation	.127*	.417**	.154‡	.096	.338**
New to market innovation spillovers	.140	.107	.328*	-.053	.396**
Country dummies	√	√	√	√	√
Sector dummies	√	√	√	√	√
Time dummies					√
$\bar{R}^2$	.653	.775	.760	.675	.548
F	15.0**	24.1**	16.8**	10.9**	26.3**

C:\Users\Derek\Dropbox\Spillovers\Regressions\results of endogenous growth. Note: all variables, except the dummies, are in logit format.

6.3.1 Results from the paired surveys

The results of the paired data sets, shown in the first four columns of Table 13, are discussed first. Sample sizes were quite small and usable results are only obtained from the corresponding prior innovation variables (e.g. that product innovation is only influenced by prior product innovation and prior product innovation spillovers).

The product innovation and product spillover coefficients in the first four columns are positive throughout, with the product innovation coefficient significantly different from zero at the ten per cent level throughout and the product innovation spillover coefficient is significantly different from zero in two of the four columns at the 10 per cent level or higher. As noted in Section 6.2, the countries covered and the state of the economic climate, amongst other things, differ between survey dates, so there is no expectation of simple patterns over time.

While, at the beginning of this work, there was no expectation that process innovation would work in a similar way, and the results in first four columns of the second set of rows in Table 13 suggest if there is a relationship it appears weaker than for product innovation. In each of the first four columns, only two of the own-process innovation coefficients and two of the exposure to spillover coefficients are significantly different from zero at the ten per cent level or higher. This suggests that the impact of process innovation and process innovation spillovers on future product innovation may be weaker than the impact of prior product innovation on future product innovation. However, it is worth noting that, in three of the four cases the spillover coefficients are larger than the own-innovation coefficients.

The final results for the cross-sectional data sets, shown in the first four columns of the final set of rows of Table 13, relate to product innovations which are new to the market (not just to the enterprise). All of the coefficients on own-new to market product innovation in the first four columns are positive, with three of the four coefficients significant at the ten per cent level or higher. While three of the four coefficients on new to market innovation spillovers are positive, only one is significant positive (at the five per cent level) – the negative coefficient is insignificantly different from zero.

6.3.2 Results from the combined paired surveys (panel data set)

Finally, the data are arranged into a type of panel format for estimation, the results of which are shown in the final column of Table 13. The results of enlarging the data set by adding together the paired years are much better than those based upon the individual pairings. The additional sample size also makes it possible to test whether, for example, it is only prior product innovation that affects subsequent product innovation or whether prior process innovation and new to market product innovation also play a role.

The first set of rows now demonstrate that prior own-product innovation and prior product innovation spillovers both have significant positive coefficients at the one per cent level, although the coefficient on own-product innovation is nearly twice the size of prior product innovation spillovers. The slope coefficients for own-process innovation and own-new to market product launch are both positive and significant at the one per cent level. The corresponding process and new to market spillover variables have insignificant negative coefficients.

The second set of rows now demonstrate that process innovation is significantly affected by prior process innovation and prior process innovation spillovers, with both coefficients significant at the one per cent level and the spillover coefficient slightly larger than the own-innovation coefficient. Both prior own-product innovation and prior product innovation spillovers also have positive coefficients, significant at the ten per cent level or higher. New to market product innovation also has a positive and significant coefficient (at the five per cent level or higher), but product launch spillovers has a marginally significant negative coefficient.

The final set of rows, in the panel column, show the linkage between new to market product launch and the various prior own-innovation and innovation spillovers. The coefficients on own-new to market product innovation and new to market spillovers are positive and significant at the one per cent level, with the spillover coefficient larger than the own-innovation coefficient. While neither of the process variables have significant coefficients, the product innovation coefficients are both significant at the one per cent level, although prior own-innovation has a positive influence and the prior innovation spillovers coefficient is negative.

6.3.3 Implications for endogenous growth

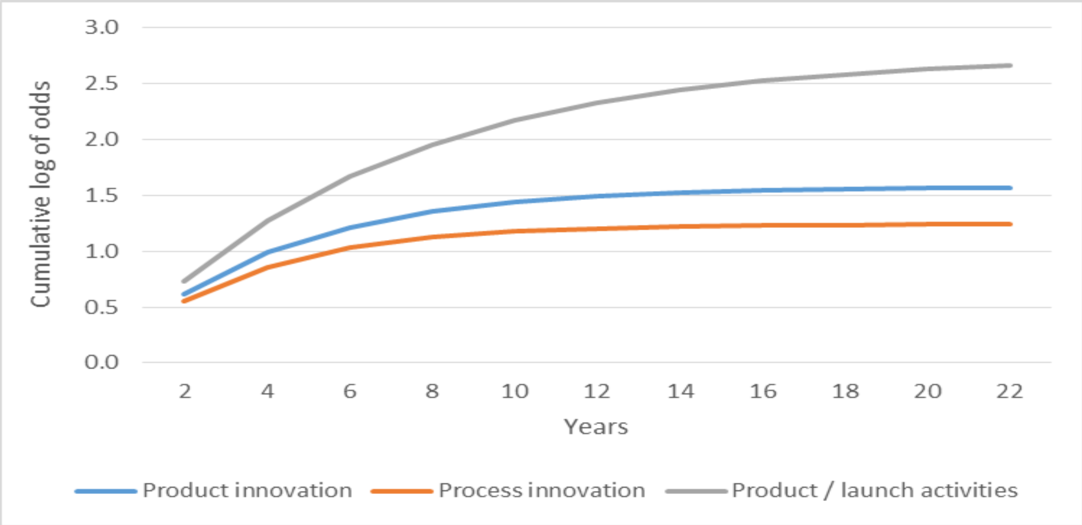
Innovation has a cumulative impact on further innovation over time. For instance, the initial effect of own-product innovation is to increase product innovation two years ahead. A one percentage point increase own-product innovation, which corresponds to an increase from 26 to 27 per cent of firms at the average value, leads to a 0.49 percentage point increase in the proportion of firms undergoing product innovation two years later. This translates approximately to a situation at the mean in which a one per cent increase own-product innovation, leads to a 0.32 per cent increase in the proportion of firms undergoing a product innovation two years later.

Exposure to product innovation spillovers has a similar, although slightly smaller impact. Increasing the per cent of suppliers undergoing product innovation (corresponding to an increase from 18 to 19 per cent at the mean) leads to a 0.35 percentage point increase in the proportion of firms undergoing product innovation as a result of exposure to spillovers from the suppliers. Again, translating this approximately to a percentage change, a one per cent increase in supplier product innovation leads to a 0.14 per cent increase in the proportion of firms undergoing product innovation two years later as a result of exposure to spillovers.

While these calculations give some impression of the relative effects of prior own-innovation and prior innovation spillovers on subsequent innovation, it is not possible to simply sum the two together – as a certain change in own innovation across the economy determines the change in innovation spillovers. As an approximation, the change in the mean of own-innovation is applied to the mean of product innovation spillovers to link the two together – so spillovers rise from the observed mean in proportion to the rise in own-product innovation.[44] Thus a one percentage point rise in own-product innovation is associated with a 0.7 percentage point rise in spillovers (not a one percentage point rise). Thus, raising prior own-product innovation by one percentage point has the effect of raising product innovation spillovers by 0.67 of one percentage point, which, when combined, raise subsequent product innovation by 0.73 of a percentage point (of which 0.49 are linked to prior own-innovation and 0.23 to prior product innovation spillovers).

[44] (0.272/0.262)*0.176=0.182 rather than 0.186.

Figure 15: The cumulative effects of innovation



Eurostat CIS regression results.xlsx

Figure 15 illustrates the cumulative nature of the innovation over time using the logit coefficients, which greatly simplifies the calculations, without losing the implications of the changes.[45] The initial effect of own-product innovation and product innovation spillovers is to increase the log of the odds of product innovation two years ahead by 0.61 and, assuming the effect remains constant over time, raises innovation a further two years ahead by 0.37. Within 10 years the marginal effect is relatively small at less than 10 per cent. The cumulative effects of process innovation at the margin is smaller than product innovation and new to market product launch are larger, as shown in Figure 15 .

Putting this in a more positive way – the innovative activity stimulated two years on also produces further innovation activity four years on. If it could be assumed that the coefficients remained fixed for some while, the cumulative effect of a one per cent rise in (the log of the odds of) product innovation at year zero is a stimulus to (log of the odds of) product innovation of 1.4 per cent by year 10. The corresponding cumulative effects on (log of the odds) of process innovation is 1.2 per cent and of new to market innovation by 2.2 per cent by year 10. These changes can be compared with the initial impacts after two years shown in the final column of Table 13. The cumulative effect of product innovation and spillovers of over 1.4 per cent is over two times the size of the effect after two years (0.61 per cent); the corresponding cumulative process effect of 1.2 is about two times the effect after two years of 0.55 per cent; finally, the cumulative effect of new to market products of 2.2 per cent is about three times the effect after two years (0.73 per cent).

[45] It means that, by looking at a 1 per cent change in the log of the odds of both own-product innovation and product innovation spillovers, it is possible to simply add together their associated coefficients to obtain their overall, combine effect on subsequent product innovation.

6.4 Innovation and Business Demographics (Creative Destruction)

6.4.1 Background

This section examines whether innovation affects birth, death and five year survival rates of enterprises. Firm demographics form a mechanism by which innovations transmit improvements in performance throughout the economy, as new firms based on an innovation replace existing firms based on an old technology. In addition, innovations by firms in the supply chain may cause opportunities for or barriers to the emergence of new firms and, similarly, opportunities for or challenges to existing firms.

Data on enterprise births, deaths and five year survival rates are available from Eurostat's business demography statistics.[46] For the following discussion and the regression analysis, the NACE 2 data has been converted into NACE 1[47] to match up with data from previous years and the WIOD input-output tables. Thirty-one sectors corresponding to those in the WIOD input-output tables are examined. Data are available for 30 countries (the EU 27 plus Norway, Switzerland and Turkey) in the years 1998 to 2010 (all years are not available for all countries).[48]

Enterprise birth and death rates are calculated as the number of births or the number of deaths in a given year divided by the total number of active enterprises in that year. Churn is a measure of the overall demographic changes amongst the population of enterprises and is defined as the sum of the birth and death rates in a given year. The final demographic statistic used is the five year survival rate of enterprises (i.e. the proportion of enterprises born five years ago that are still in business today).

6.4.2 Descriptive Statistics

6.4.2.1 Birth Rates

Between 2004 and 2010, average birth rates increased in half of the European countries and decreased in the other half (Table 14). Latvia (6 percentage points), Slovakia (4) and France (3) have some of the largest increases in enterprise birth rates. The largest declines are in Romania (10 percentage points) and Bulgaria (seven percentage points). In the UK, the enterprise birth rate dropped by two percentage points between 2004 and 2010.

[46] Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/european_business/special_sbs_topics/business_demography, accessed August 2013.
[47] Eurostat classifies the sectors using NACE1 (earlier years) and NACE 2 (later years).
[48] Further details appear in the Technical Annex, Section 4.3 (Bosworth, *et al*. 2014).

Table 14: All-Sector Average Enterprise Birth, Death and Churn Rates by Country, 2004 and 2010

	Birth			Death			Churn		
	2004	2010	change	2004	2010	change	2004	2010	change
Austria	6.4	6.3	-0.06	4.5	5.1	0.5	10.9	11.4	0.5
Belgium		5.0			3.0			8.0	
Bulgaria	16.5	10.0	-6.50	6.9	6.9	0.0	23.4	16.9	-6.5
Cyprus	4.5	4.1	-0.42		6.7		4.5	10.8	-0.4
Czech Republic	8.5	10.7	2.26	9.3	7.1	-2.2	17.8	17.9	0.1
Denmark	9.3	9.1	-0.22	8.8	13.2	4.4	18.1	22.3	4.2
Estonia	6.8	9.6	2.79	10.7	10.0	-0.6	17.5	19.7	2.2
Finland	6.9	7.7	0.77	6.3	9.1	2.8	13.2	16.7	3.5
France	7.8	11.1	3.33	5.9	5.5	-0.4	13.8	16.7	2.9
Germany	10.1	7.8	-2.34		6.9		10.1	14.7	-2.3
Greece	5.5			4.7			10.3		
Hungary	8.5	9.3	0.75	7.7	9.2	1.5	16.2	18.5	2.3
Ireland		5.6			12.3			17.8	
Italy	7.6	6.6	-1.04	5.8	7.1	1.3	13.4	13.7	0.2
Latvia	12.8	18.4	5.61	10.9	15.5	4.6	23.7	33.9	10.2
Lithuania	16.2	17.1	0.95	12.8	30.2	17.4	29.0	47.3	18.4
Luxembourg	8.8	8.2	-0.56	6.9	7.1	0.2	15.6	15.3	-0.3
Malta		6.6							
Netherlands	7.3	8.5	1.27	6.8	6.5	-0.3	14.1	15.0	1.0
Poland	11.0	13.5	2.52	8.9	9.6	0.7	19.9	23.1	3.2
Portugal	10.7	8.4	-2.23	10.0	13.8	3.8	20.6	22.2	1.6
Romania	19.2	8.8	-10.45	9.4	10.8	1.4	28.6	19.6	-9.1
Slovakia	9.2	12.7	3.53	8.9	13.6	4.7	18.1	26.3	8.2
Slovenia	7.2	9.2	2.04	6.6	6.0	-0.6	13.8	15.2	1.4

	Birth			Death			Churn		
	2004	**2010**	**change**	**2004**	**2010**	**change**	**2004**	**2010**	**change**
Spain	8.5	6.8	-1.74	5.2	7.6	2.4	13.7	14.3	0.6
Sweden	4.9	5.8	0.92	4.7	5.4	0.7	9.6	11.2	1.6
UK	11.0	9.3	-1.70	10.8	10.2	-0.6	21.9	19.6	-2.3

Source: Birthrates.xls, Churn and Deathrates.xls (based on Eurostat data)

Enterprise birth rates by NACE 1, declined in about two-thirds of the sectors from 2004 to 2010 (see Technical Annex, Section 4.3, Table A1). The sectors with the biggest declines are Other Community, Social and Personal Services (down four percentage points) and Financial Intermediation (three percentage points). Electricity, Gas and Water Supply exhibits the largest increase in birth rate by far (11 percentage points).

In the UK, the sectors with the highest birth rates in 2010 are Electricity, Gas and Water Supply (27 per cent), Post and Telecommunications (15 per cent) and Air Transport (14 per cent). Between 2003 (the earliest year of data for the UK) and 2010, birth rates decrease or remained the same for virtually all the sectors. Three sectors (Air Transport, Health and Social Work and Manufacturing nec) show slight increases over the time period.

6.4.2.2 Death Rates

In 2010, Table 14 shows that Lithuania (30 per cent) and Latvia (16 per cent) exhibit the highest death rates across sectors. Belgium has the lowest death rate (three per cent) in 2010. The UK's death rate in 2010, for comparison, is 10 per cent.

The death rates by sector (i.e. the sector average across all countries) range from a low of five per cent in Health and Social Work to a high of 16 per cent in Post and Telecommunications in 2010. In the UK, enterprise death rates range from eight per cent in Education, Financial Intermediation, Manufacture of Rubber and Plastic Products and Sale, Maintenance and Repair of Motor Vehicles and Motorcycles, Retail Sale of Automotive Fuel to 16 per cent in Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel. (see Technical Annex Table A.4).

From 2004 to 2010, the average death rate across all sectors increased in most (15) countries with Lithuania seeing the largest increase (17 percentage points) (see Table 14). The death rate by sector also increased between 2004 and 2010 in almost all cases (see Technical Annex Table A.4). The Post and Telecommunications and the Other Community, Social and Personal Services have the highest increase in death rate over this time period (five percentage points). The only two sectors that do not show an increase in death rates are Electricity, Gas and Water Supply and Financial Intermediation.

6.4.2.3 Churn

The rate of churn (birth rate plus death rate) is compared across countries in Table 14. In 2010, churn ranged from a low of eight per cent in Belgium to a high of 47 per cent in Lithuania. The UK is in the middle, with a churn rate of 20 per cent in 2010. Between 2004 and 2010, churn increased in most (17 out of 23) countries. The largest increase in churn rate is seen in Lithuania (18 percentage points) and the largest decrease in Romania (nine percentage point drop).

6.4.2.4 Enterprise Survival Rates

In 2010, enterprise five year survival rates (the number of enterprises surviving in year t that were born in year t-5) by country range from 40 per cent in Lithuania to 66 per cent in Slovenia and Sweden (see Technical Annex Table A.5). By sector, survival in 2010 range from a low of 41 per cent in Retail Trade, except of Motor Vehicles and Motorcycles to a high of 67 per cent in Air Transport (see Technical Annex Table A.6). Based on the few countries for which there is data for 2004 and 2010, it appears that survival rates by sector are declining.

Technical Annex Table A.3 shows the five year survival rates by sector for the UK. In 2010, the sectors with the highest five year survival rates in the UK are: Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel (60 per cent), Health and Social Work (58 per cent) and Real Estate Activities (56 per cent). In general, survival rates did not change much between 2003 and 2010. However, a few sectors saw large increases in survival rates such as Electricity, Gas and Water Supply (an increase of 11 percentage points which is interesting in light of the high increase in birth rate over the time period), Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel (17 percentage point increase), Manufacture of Textiles and Textile Products (16 percentage point increase) and Manufacture of Machinery and Equipment nec (13 percentage point increase).

6.4.3 Econometric Estimates

There are a number of problems that, potentially, might obfuscate the empirical results. In particular, the country coverage changes between the surveys – while this is a more minor concern from 2004 to 2010, the changes between 2001 and 2004 are much more significant. In addition, the preliminary analysis of the data, which regressed each subsequent year of firm demographics on the innovation measures from each of the CIS in turn, suggested that the effects of innovation were either long lasting or they were being confused with the effects of subsequent innovation activity. The specifications estimated here test for both long-term effects and whether earlier innovation has an effect alongside subsequent innovation. This issue is further compounded by the fact that all of the economies moved into recession around 2008 and this will have resulted in major effects on firm demographics over and above the effects of innovation.

There are several other potential problems. First, the fact that the innovations are only measured every two years means that those of, for example, 2004 and / or 2006 must proxy for 2005. Second, while it would be reassuring to find that a particular innovation type has a very similar effect on firm demographics irrespective of which survey year it comes from, in practice, there is no reason why the innovations of a particular type in, say, 2001 necessarily have the same effects on firm demographics as the innovations in 2004[49] (although this is generally the case).

Of the firm demographic regressions, those for survival rates are the most problematic. While data are available for births, deaths and churn for most countries over much of the period, this is not true for survival rates. Data prior to around 2004

[49] For example, product innovations at one time may produce entirely new products or services which do not compete with existing products and services (though they may compete to be bought out of the same income), while those at another time may be intensely rivalrous.

are probably inadequate for the present analysis and data for 2010 are the latest at the time of writing. However, there is a further issue, which is that the survival rates relate to a five year period. As the usable CIS relate to 2004, 2006, 2008 and 2010, this means that the 2010 CIS has no matching subsequent firm demographics data. As a consequence, the present study uses the CIS from 2004 and 2006 to explore firm demographics in 2007 and 2008, and it uses the CIS from 2004, 2006 and 2008 in conjunction with the firm demographics in 2008 and 2009.

It can be seen that, although there is always a lag between the last CIS used and the end year of the firm survival rates, the two CIS used for the 2007 and 2008 firm demographics are embedded in the period over which survival is calculated, while two of the three CIS used are embedded in the survival periods for the 2008 and 2009 end periods.

Sample sizes are now relatively small and a “backwards” regression is applied to allow the study to focus on the significant coefficients.[50] Nevertheless, there are sufficient observations to include country and sector dummy variables. The final outcomes of the backwards regressions are supplemented by information about the results when all the explanatory variables are entered into the regression. As will be seen, in general, many fewer of the innovation coefficients are significant in the full regression than the backward regression, but, equally, it is interesting that the backward regressions retain so many of the innovation variables.

Table 15 sets out the results for 2007 and 2008. The 2007 year lies just before the recession took hold and 2008 contains the early part of the recession. Compared with Table 16, which relates to 2009 and 2010, these results are likely to be less affected by the impact of the recession. The principal feature of Table 15 is that almost the only role played by the own-innovation variables is that of own-product innovation in 2006, whose coefficients are significant at the one per cent level in four of the six “backwards” regressions of births, deaths and churn. In addition, the coefficient is significantly different from zero at the 10 per cent level or higher in the further two columns in the full regression results (coefficients shown in parentheses). The result is consistent with creative destruction, with higher levels of own product innovation raising both the birth and death rates of enterprises and, thereby, the level of churn in the economy.

[50] “Backward” or “step-down” regressions start with a full model but then eliminate variables that do not make a significant contribution to the regression equation, resulting in a partial model. As a consequence, the variables kept in the regression tend to have significant coefficients.

Table 15: Innovation and Firm Demographics, 2007 and 2008

	Births		Deaths		Churn		Survival	
Variables[a]	**2007**	**2008**	**2007**	**2008**	**2007**	**2008**	**2007**	**2008**
(Constant)	-3.092**	-3.489**	-2.925**	-2.015**	-2.534**	-2.393**	-.217	.320
Product Innovation 2004			-.114**		-.133**			
Process Innovation 2004								
New to market Innovation 2004			-.106**			-.085*		
Product Innovation 2006	.231**	.141**	(.090‡)	.157**	(.199*)	.180**		
Process Innovation 2006								
New to market Innovation 2006				-.143**			-.119**	
Product Innovation Spillovers 2004	-.291**	-.693**						.774**
Process Innovation Spillovers 2004	.232*			(1.031*)	.397**	.305**		
New to market Innovation Spillovers 2004		.803**			-.414**		.459**	
Product Innovation Spillovers 2006		-.425**		-.947**	-.565**	-.641**	.354*	
Process Innovation Spillovers 2006				.946**			-.829**	-.505*
New to market Innovation Spillovers 2006					.347**			
Country dummies	√	√	√	√	√	√	√	√
Sector dummies	√	√	√	√	√	√	√	√
R^2 adjusted	.392	.644	.665	.437	.376	.543	.265	.499
F	7.0**	14.6**	35.9**	9.2**	15.2**	13.1**	5.2**	12.178

Note: all coefficients are from the backward regressions, except those in parentheses, which are from the full regression; highlighted cells are those whose coefficient is significant at the 10 per cent level or higher in the "full" regression; [a] variables are expressed in logit form during the regression and based on the CIS variables, INPDT, INPCS and RMAR.

The negative values on own-product innovation in 2004 for deaths and churn are only significant for 2007 – there is no matching evidence for 2008 or for births and survival in either of the years. However, there is some matching evidence from new to market product innovation in 2004. Overall, however, it is difficult to find a consistent role for anything other than own-product innovation in 2006. For example, although the other product innovation (2004) and new to market product innovation (2004 and 2006) have negative coefficients for deaths and churn, the new to market innovation in 2006 has an inconsistent negative coefficient for survival.

The remainder, indeed the majority, of the influences come from the spillover variables. While it is fair to say that most these effects only emerge in the "backwards" regressions, there are some interesting and largely consistent results. Where they are significant, product innovation spillovers have a negative effect on births, deaths and churn, and a positive effect on survival. If the results for the 2004 and 2006 own-product variables are combined, a fairly comprehensive picture of the negative effects on births, deaths and churn can be found, alongside a positive effect on survival. The opposite is true for process innovation spillovers. Again, combining the 2004 and 2006 results, process innovation spillovers have a positive effect on births, deaths and spillovers, but a negative effect on survival.

The results for the 2009 and 2010 firm demographics are shown in Table 16. Again, given the data issues, the 2001 information has not been utilised, but the CIS surveys for 2004, 2006 and 2008 are now incorporated, providing data on the different types of innovation. The weakest results are again for the five year survival rate, for the reasons described earlier. The years covered for the firm demographics are centred close to the middle of the recession for most countries and this may change the results somewhat to those of 2007 and 2008.

The results suggest that the effects of innovation and innovation spillovers on births and deaths can be long-lasting. Amongst the 2004 own-innovation results, relatively small positive effects are found on process innovation for births and product innovation for deaths, significant at the 10 per cent level or higher. As in the previous table, the own-product innovation variable for 2006 is the most important of the own-innovation variables, with the 2008 version of this variable insignificantly different from zero at the 10 per cent level or higher throughout. If the results for the 2004 and 2006 own-product innovation are combined a clear picture emerges of the positive effects on the rates of births, deaths and churn, and the negative effects on survival, consistent with creative destruction.

Table 16: Innovation and Firm Demographics, 2009 and 2010

	Births		Deaths		Churn		Survival (five year)	
Variables[a]	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
(Constant)	-3.689**	-3.640**	-1.747**	-1.879**	-2.070	-1.806**	.539**	-.120
Product Innovation 2004			.107*	.111*				
Process Innovation 2004	.134‡	.158*	(-)	(-)			.170*	(+)
New to market innovation 2004							-.142*	
Product Innovation 2006	.179**	.195**	(+)	(+)	.153*	.182**	(-)	-.133**
Process Innovation 2006	-.218**	-.198*						
New to market innovation 2006					.105*			
Product Innovation 2008								
Process Innovation 2008								
New to market innovation 2008							-.084*	
Product Innovation Spillovers 2004	-.428**	-.401**				-.278*		
Process Innovation Spillovers 2004	.766**	.707**	.594*	.587*	.926**	.389**		-.347**
New to market innovation spillovers 2004			-.382**	-.371**	-.327**	.151*	.399**	
Product Innovation Spillovers 2006	-1.115**	-1.052**	-2.550**	-2.408**	-1.613**		.337**	
Process Innovation Spillovers 2006			1.645**	1.506**	.435*		-.442**	
New to market innovation spillovers 2006	.321**	.328**	.549**	.512**	.341*	-.312*		.286**
Product Innovation Spillovers 2008	.152**	.121**			.175‡			
Process Innovation Spillovers 2008								
New to market innovation spillovers 2008			.307**	.281**				
Country dummies	√	√	√	√	√	√	√	√
Sector dummies	√	√	√	√	√	√	√	√
R^2adjusted	.664	.659	.561	.591	.564	.662	.336	.399
F	13.0**	11.8**	12.1**	13.7**	8.5**	17.9**	6.9**	6.8**

Note: all coefficients are from the backward regressions, except those in parentheses, which are from the full regression; highlighted cells are those coefficient significant at the 10 per cent level or higher in the "full" regression; [a] variables are expressed in Logit form during the regression and based on the CIS variables, INPDT, INPCS and RMAR.

Turning to product innovation spillovers from 2004 and, more particularly, 2006, there is fairly convincing evidence that they reduce birth, death and churn rates, and raise survival rates (at least in 2009). If the 2004 and 2006 product innovation spillover results are combined, this pattern, which is the opposite of creative destruction, emerges even more clearly. Likewise, combining the 2004 and 2006 results, indicates that process innovation spillovers raise birth, death and churn rates, and lower survival rates.

The results of Tables 15 and 16 are largely consistent insofar as they show:

- prior product innovation raises the birth, death and churn rates, whilst lowering the survival rates;
- prior product innovation spillovers lower the birth, death and churn rates, whilst raising the survival rates;
- prior process innovation spillovers raise the birth, death and churn rates, whilst lowering the survival rates.

The main difference between the two sets of results is associated with the positive and significant coefficients on the new to market innovation spillovers in 2006 for births and deaths in Table 16, which is absent from Table 15. However, there is some inconsistency in the results for this variable in Table 16, both in the churn and survival rate results and the difference in sign for this variable between its 2004 and 2006 coefficients.

The worry that the more recent results would be obscured by the effects of the recession on firm demographics was unfounded – it may be that the recession actually accentuated the effects of the prior innovation.

7. UK Results at the Enterprise Level

This section focuses on the performance of UK enterprises. There is a brief methodological discussion about data and the equations to be estimated. The research uses matched data from a variety of sources, some of which are confidential and only made available in the ONS Virtual Laboratory. It constructs measures of enterprise performance (labour productivity and total factor productivity) that can be regressed upon own-enterprise R&D, the own-sector R&D "pool" and the "pool" defined by the exposure to spillovers along the supply chain, as well as educational purchases and educational spillovers.

7.1 Introduction

Using panel datasets of UK firms and a variety of estimation techniques, this chapter combines growth accounting methods and econometric modelling techniques to uncover how R&D spillovers influence the performance of individual firms in the UK. The sample is, therefore, quite different from the sector by country databases reported in earlier sections. Both cross-sectional analysis and panel data analysis have been employed, but panel data analysis has a number of econometric advantages.[51]

The normal method is to estimate spillovers as a relationship between measures of enterprise performance and its own-investment in R&D, skills, etc., alongside the total sectoral investment in these areas. In the empirical literature, total sectoral investment is generally argued to capture technological spillovers, as firms in a given sector are thought more likely to have more similar products and production processes. In the present research, the authors not only have the technological pool (e.g. the total R&D spending of firms in each sector), but also the pool defined by the supply chain, as discussed in Sections 3 and 4.

The measures of performance adopted are based upon labour productivity (LP) and total factor productivity (TFP). These are discussed in Section 5.2.1 and the rate of change form of TFP in the Technical Annex (Bosworth, *et al*. 2014, Section A5.2).

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[51] In particular, it controls for unobserved firm heterogeneity (unobserved or unobservable enterprise specific influences that do not change over time).

7.2 Methodology

7.2.1 Data Sources

The data set used for this analysis combines three principal sources. The Annual Respondents Database (ARD) is the critical firm-level dataset which gives production statistics for the estimation of TFP and LP. The UK Innovation Survey (UKIS – which is the UK version of the CIS) provides information on firm-level innovation related activities. The other major variables, including R&D, exposure to R&D spillovers, shares of high and medium skill hours, education purchases from education sector and exposure to education purchase spillovers, are at sector level. These other variables come from a variety of sources described earlier in the Report.

The general period of study is between 2000 and 2009, but separate panel datasets are generated for the pre- and post-crisis periods, in order to investigate how the downturn from 2008 affects firm performance. Firms are categorised into 33 sectors, excluding the public sector (for which CIS data are not available). There have been changes in the Standard Industry Classification (SIC) over the period in question and, as a consequence, SIC92, SIC03 and SIC07 have been mapped to the first statistical classification of economic activities in the European Community (NACE1).

7.2.2 Econometric modelling of the impact of spillovers

Regression analysis is carried out on the impact of own-R&D, exposure to R&D spillovers, own-educational purchases and exposure to educational spillovers on firms' productivity performance. Productivity is measured in terms of labour productivity (LP) or total factor productivity (TFP) (Bosworth, *et al*. 2014, Technical Annex, Section 5). Pooled cross-sectional and panel data analysis are used to investigate how firm level and sector level innovation variables influence productivity. The general regression form is as follows:

Ln(productivity) = f[Ln(employment), Ln(real capital stock), Ln(own enterprise R&D), Ln(own-sector R&D spillovers), Ln(supplier R&D spillovers), skillshare, Ln(own-purchases from education sector), Ln(supplier-purchases from education spillovers); training; innovation (product, process and new to market product innovation] (4)

variable definitions are provided in Table 17. "Productivity" in equation 6 can refer to either labour productivity or total factor productivity. The independent variables include both sector and firm level factors. Employment, real capital stock and own-enterprise R&D (intramural and extramural) are constructed at the firm level from either ARD or UKCIS data. Two further variables, training and innovation, also at the firm level are drawn from the UKIS. Innovation distinguishes between new product or process innovation, or whether they have introduced a product which is new to the market. These innovation activity variables are binary with yes or no answers and are all at the firm level.

Table 17: Variables used in the Regression of the Impact of Spillovers on Productivity

Dependent variables:	**Variable name[a]**	**Level**	**Data source**
Ln Labour productivity	LP	Firm level	ARD
Ln Total factor productivity	TFP	Firm level	ARD
Independent variables:			
Ln total employment	emp	Firm level	ARD
Ln Real capital stock	capital	Firm level	ARD
Ln own-sector R&D spillovers	R&DSECSPILL	Sector level	CE/Eurostat/OECD
Ln supplying sectors R&D spillovers	R&DSPILL	Sector level	CE/Eurostat/OECD/WIOD
Share of high skill hours	H_HS	Sector level	SEA-WIOD
Share of medium skill hours	H_MS	Sector level	SEA-WIOD
Share of low skill hours	H_LS	Sector level	SEA-WIOD
Ln own-sector Education purchase spillovers	EDUPURCHSECSPILL	Sector level	WIOD
Ln supplying sector Education purchase spillovers	EDUPURCHSPILL	Sector level	CE/Eurostat/OECD/WIOD
Firm’s internal R&D spending	intr&d	Firm level	UKIS
Firm’s external R&D spending	extr&d	Firm level	UKIS
Firm’s training spending	training	Firm level	UKIS
Sector dummies	SECTOR	Firm level	ARD
Year dummies	year	Firm level	ARD

Note: a) variables at sector levels have been given names in capital letters, variables at firm levels have names in small letters.

The R&D sector spillover data are constructed using CE, Eurostat and OECD data; exposure to technological spillovers is represented by own-sector R&D; R&D spillovers through the supply chain is constructed from the R&D sector spillover data run through the WIOD I-O matrices; "skill share" refers to sector level shares of low, medium and high skill hours, which are drawn from the WIOD SEA data; educational purchases by the firm's own sector, drawn from the I-O matrices in WIOD; and exposure to education purchase spillovers through the supply chain are calculated by running the sectoral educational purchases through WIOD's I-O matrices (see Sections 3 and 4 above).

The same variables are used in both the LP and TFP regressions, equation (4), for comparison purposes. Table 17 lists the variables entering the models in detail.

7.3 Results

7.3.1 The impact of exposure to spillovers on labour productivity

The labour productivity of UK enterprises is calculated as the ratio of the real gross value added over the number in employment, based on data from the ARD. The estimated (natural log of) LP is regressed on R&D, R&D spillovers and the other skill and innovation related variables listed in Table 17 in log linear form (see equations 6 and 7). Both cross-sectional and panel data analyses are used. Pooled cross-sectional and random effect panel analyses are first conducted based on the assumption that the relationships between the independent variables are the same across firms. Interaction terms between R&D variables at sector level and sector dummies are introduced later to relax this assumption – they allow the impact of R&D variables to vary across sectors.

The pooled cross-sectional analysis assumes that firms in the sample are independent of each other, and the regression shows how the variations in the independent variables affect the firms' labour productivity. The panel data analysis looks at how changes in the independent variables of a firm lead to changes in its labour productivity. The panel data analysis controls for unobserved, firm-specific effects.[52] Year dummies and sector dummies are also included to control for the changes in labour productivity across years and across sectors. The dataset is composed of the years 2000/01, 2004, 2006 and 2008, because these are the years available in the UKIS/CIS. There are 446,867 firms in the panel dataset. The results of the estimation are provided in Table 18.

The coefficients on the employment and real capital stock are consistent with constant returns to scale.[53] Before the interaction terms are included, the pooled cross-sectional and random effect analyses (Models 1 and 2 of Table 18) give similar results that, in the main, are consistent with our hypothesis. The impacts of sector level R&D spending (technological spillovers) and R&D spillovers (through the supply chain) are significant and positive implying that firms benefit both from more R&D spending in their own sector and R&D spending in the sectors they trade with. The coefficients on the technological spillovers are considerably smaller than the coefficients on R&D spillovers through the supply chain.

[52] E.g. unobserved heterogeneity. Robust errors are used to control for heteroskedasticity.
[53] E.g. (1-0.252)+0.232≈1. However, compared to other production function studies, the values perhaps over-estimate labour's share and under-estimate capital's share.

Table 18: The impact of exposure to spillovers on labour productivity, 2000-2008[a]

	Pooled cross sectional	**Panel without interactions.**	**Panel with interactions**
	Model (1)	Model (2)	Model (3)
Ln employment	-0.252**	-0.257**	-0.254**
Ln capital	0.232**	0.233**	0.232**
LN R&DSECSPILL	0.088‡	0.114**	0.174
LNR&DSPILL	0.599**	0.557**	1.586
LNH_MS	-0.995[b]	-0.442	-2.212
LNH_LS	-4.658[b]**	-3.216*	-1.363
LNEDUPURCH	-0.106	-0.08	-0.043
LNEDUPURCHSPILL	-0.407‡	-0.402*	-0.693*
product innovation	0.097**	0.062**	0.062**
process innovation	-0.011	-0.018	-0.02
new to market innovation	0.011	0.033‡	0.032‡
internal R&D spending	0.066**	0.036*	0.036*
external R&D spending	0.047*	0.031	0.036‡
training	0.056**	0.041*	0.041**
2004 (base 2000)	-0.094	-0.036	0.231
2006 (base 2000)	0.046	0.078	0.457‡
2008 (base 2000)	0.024	0.031	0.396
constant	-0.967**	-1.699**	-6.514
SECTOR DUMMIES	√	√	√
SECTOR*LNR&DSECSPILL			√
SECTOR*LNR&DSPILL			√

Notes: variables in small letters are firm level, variables in capital letters are sector level; significance: ** 1%, *5%, ‡10%; a) variable names are given in Table 15; b) base group is high skill hours.

A higher proportion of low skill hours in the firm's own sector tends to significantly lower the firms' labour productivity and there is a clear ranking, with labour productivity falling as the proportions of high decrease and medium increase and as medium decrease and low skill hours increase. Education purchases of the firm's own sector do not seem to have much influence on labour productivity, but education purchases amongst the supplying sectors have a significant negative impact on firm performance at the 10 per cent level or higher – in the latter case, a similar result was found in Section 5.3.1. Again, it is not clear why this unexpected negative sign occurs.

Product innovation, as well as spending on internal R&D and on training are all associated with higher labour productivity, as shown in Models 1 and 2. New to market product innovation also has a marginally positive impact on labour productivity in Model 2. So far, the impacts of R&D variables have been consistent with our expectation based on the assumption that they affect firms in different sectors in the same manner. Again there is evidence that the coefficient on own-R&D is smaller than that of the R&D-spillover. The present results suggest the smallest coefficient is probably associated with own-external R&D spending, followed by own-internal R&D, and then technological spillovers (own-sector R&D), with the largest coefficient associated with R&D spillovers along the supply chain.

Model 3 tests the validity of the assumption that R&D affects different firms in different sectors in the same manner. The inclusion of interaction terms between R&D variables and sector dummies take up the significant impacts of the sector and supply chain R&D variables (final column of Table 15), indicating different impacts of R&D variables on LP across sectors (while the significance of other independent variables are almost the same). To give more details, Figure 16 and Figure 17 provide a comparison of the interaction effects across the sectors, where the base sector is Chemicals and Chemical Products. The largest significant impact of R&D on LP in Figure 16 is in the Coke, Refined Petroleum and Nuclear Fuel sector (0.923), while the smallest significant R&D coefficient is in Other Non-metallic Minerals (-1.359). Other coefficients that are greater or smaller respectively are not significantly different from zero.

The impact of R&D spillovers also changes by sector. Figure 17 gives the details, again taking Chemicals and Chemical Products as the base sector. The largest significant R&D spillover effect is, again, in Coke, Refined Petroleum and Nuclear Fuel (8.88), while the smallest significant coefficient is in Rubber and Plastics (-2.084). Other coefficients smaller than -2.084 are not significant.

The change in results from Models 1 and 2 to Model 3 and the significance of the interaction terms point to the conclusion that, although R&D and R&D spillovers have significant positive impacts on firms' labour productivity on average, they affect firms in different sectors in different ways. They tend to be more important and influencial in high-tech sectors, and less so in primary sectors.

After controlling for all the other variables, the increase in LP is not significant over the years; only 2006 has a marginally significant coefficient compared to 2000 in Model 3. The innovation related activities, both at firm and sector levels, can significantly increase the labour productivity of firms.

Figure 16: The impact of R&D Expenditure on Labour Productivity, by Sector

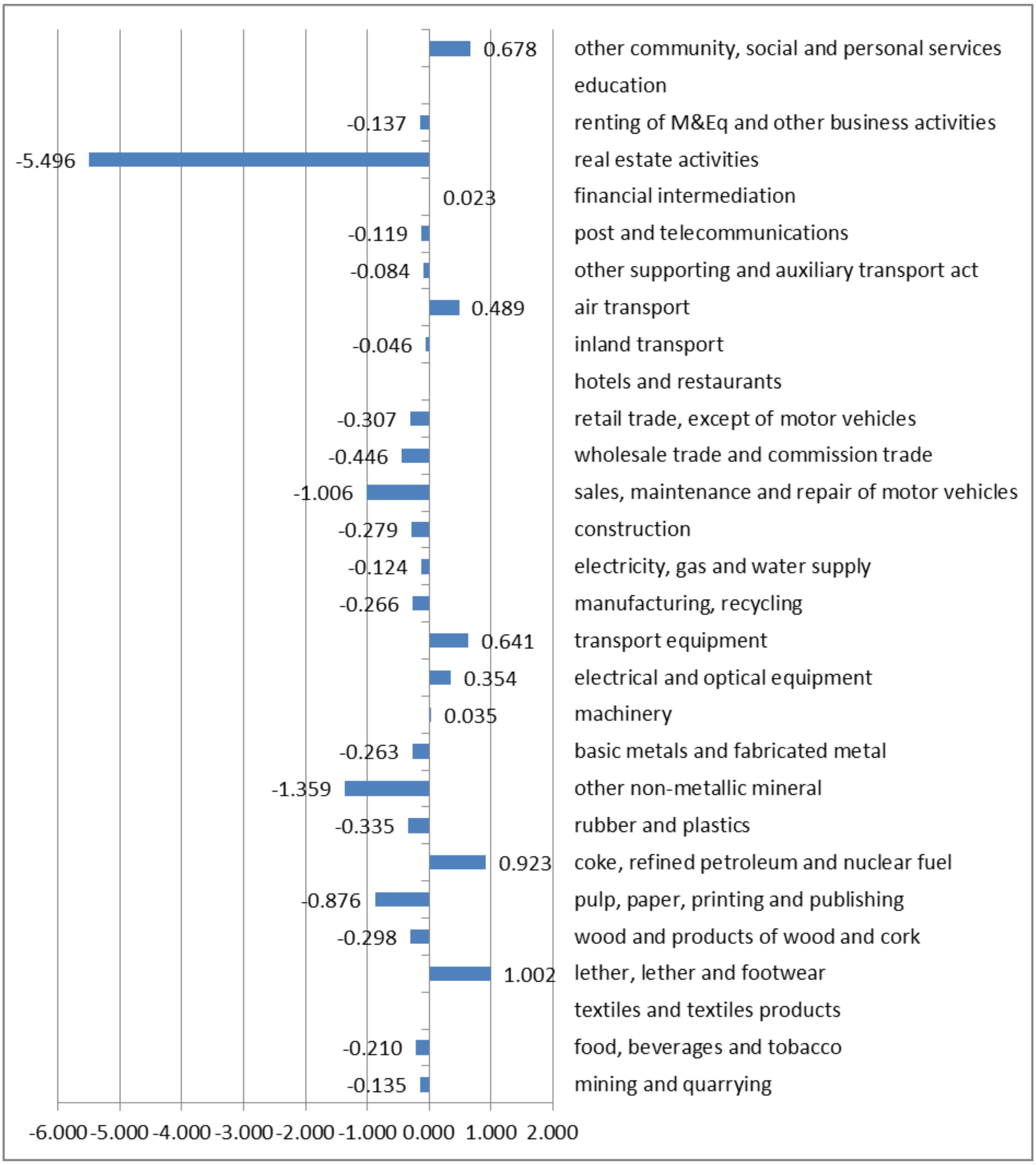
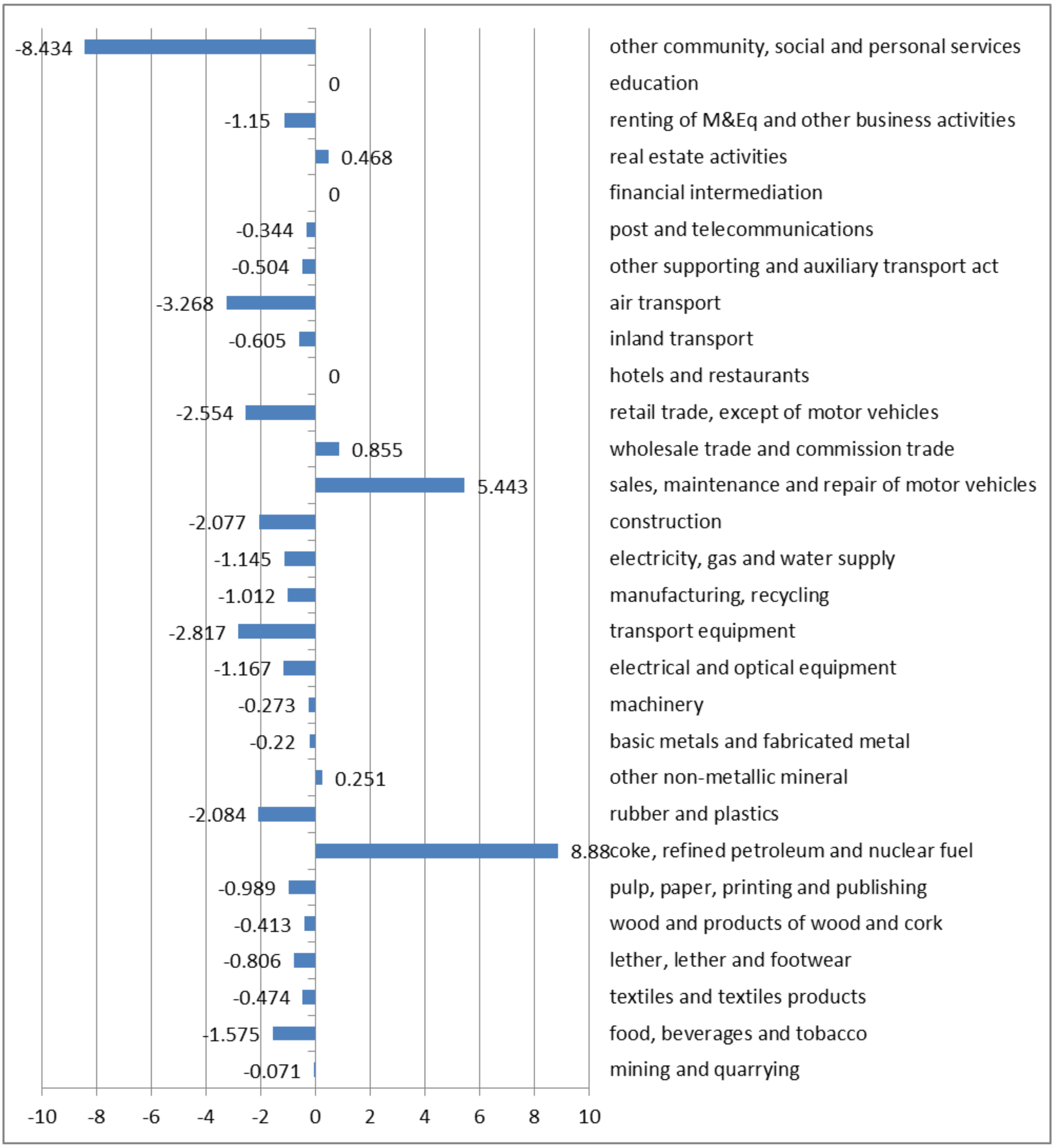


Figure 17: The impact of Exposure to R&D spillovers on Labour Productivity, by sector



7.3.2 The impact of exposure to spillovers on total factor productivity

This section reports on the impact of exposure to spillovers on total factor productivity within the UK. Growth accounting methods are used to estimate the rate of growth in TFP and to calculate the relative contribution of TFP, labour and capital growth on output growth. See Technical Annex 5 for a discussion of how TFP is calculated.

The TFP of UK firms fluctuated from 2000 to 2009, with a large fall from 2008 to 2009. The 2008 recession affects estimates of the linkage between R&D spending and R&D spillovers and enterprise performance and, hence, the period from 2000 to 2007 is analysed separately from that of 2008 to 2009. The two-year balanced panel for the years 2000 and 2007 includes 7,897 firms, and the corresponding 2008-2009 balanced panel includes 12,686 firms.

From 2000 to 2007, most of the private sector had an increased TFP (24 out of 33 sectors). The largest TFP decrease is found in Mining and Quarrying (-1.205[54], e.g. approximately 30 per cent); the largest increase is in the Education sector (0.614). However, during the economic crisis, most of the sectors experienced a significant decline in TFP (25 out of 33 sectors), with only eight sectors showing an increase in TFP over this period. This is consistent with what happened to real GVA in the UK economy – during the recession, 28 out of 33 sectors reported a decline in real GVA.

Education is one of the very few sectors that maintained positive TFP growth (0.253) through 2008 to 2009, but with a smaller magnitude compared to the previous years. Chemicals and Chemical Products actually performed better during the crisis than in the pre-crisis period. It had negative TFP growth during 2000-2007, but positive growth afterwards. Financial Intermediation also appears to exhibit the same pattern, but this may not be accurate due to the poor quality of data and the inconsistent classification of firms in this sector in the ARD over the years (see Technical Annex, Section 5). The average TFP growth across all sectors, calculated as a natural log ratio of 2007 over 2000 was around 0.141 (e.g. about 15.1 per cent), and around -0.119 during 2008 and 2009 (a fall of just over 11 per cent).

An initial regression on the level of TFP was run on a balanced panel of 15,720 firms between 2000 and 2009 (a 10 year panel) to explore what factors might be related to the TFP. However, none of the variables included in the random effects panel model have significant coefficients and the results are not reported here. Unlike the sector results in Section 5.3.2 current TFP growth does not appear to depend on the current investment in R&D and innovations at either firm or sector level. Subsequent regressions are performed to test how these variables affect TFP growth.

TFP growth is regressed on the same set of independent variables as in the labour productivity regression (see Section 7.3.1). The 2000-2007 TFP growth is regressed on the values of the independent variables at 2006, to be consistent with CIS 2006, and the

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[54] These coefficients represent the natural log of TFP growth and can only be sensibly translated into actual growth rates if they are sufficiently close to zero. Where they are not (as in the case of education below), no attempt is made to calculate actual growth rates.

2008-2009 TFP growth is regressed on the independent variables at 2008, again, to match CIS 2008. Two cross-sectional regressions are carried out on TFP growth in these two periods and, then, the two periods are combined to form a two-period panel dataset for a random effects panel analysis. The regression results are presented in Table 19. Models 4 and 5 are the cross-sectional outputs, and Model 6 is the panel output. Sector dummies are included in all the three models, and a year dummy is included in Model 6 to capture the change over time.

Table 19: Impact of Exposure to Spillovers on TFP growth

TFP growth	TFPG00-07	TFPG08-09	Panel of TFPG08-09 and TFPG 00-07
	Model (4)	**Model (5)**	**Model (6)**
employment	-0.043	-0.343**	3.563*
capital	-0.059	-0.127**	-12.409**
R&D	0.026	0.074**	0.028
R&DSPILL	-0.233	-1.245**	0.620
H_MS	-1.219‡	0.095	-0.543
H_HS	-0.676*	-0.439**	0.174
EDUPURCH	0.106*	0.324**	2.552**
EDUPURCHSPILL	0.065	1.380**	1.564*
constant	1.717	-2.642	91.792
sector dummies	√	√	√
Year	n/a	n/a	√

Note: variables in small letter names are at firm level, variables in capital letters are at sector level; Significance:** 1%, * 5%, ‡10%

The three models all point to the same conclusion. The firm level factors, such as firms' own R&D spending (both internal and external), training spending, process and product innovation activities, and innovation resulting in a new to market product launch, do not have any significant impact on firms' TFP growth (thus, they are not presented in the results table). It appears to be that certain sector level variables significantly affect the TFP growth of individual firms.

The impact of the sectoral level factors also affect TFP growth differently pre- and during the crisis. From 2000 to 2007, only education purchases from the Education sector is a significant (at the five per cent level) and positive influence on firms' TFP growth. Shares of higher and medium skill hours have unexpected negative coefficients. During 2008-2009, TFP growth is significantly related to changes in R&D and R&D spillovers, but the latter has an unexpected negative sign. Education purchases and exposure to educational spillovers continue to influence TFP growth, but now the coefficients are not only positive, but significant at the one per cent level. This model suggests that the marginal effects of exposure to educational spillovers are much larger than the effects of own-educational purchases (however, this is not the case in the other two regressions).

When the two data periods are pooled together and a random panel data analysis is carried out (controlling for unobserved firm heterogeneity), only education purchases and education spillovers exhibit a consistent strong and significant positive influence.

The R&D variables no longer have any significant effect on TFP growth.

Coefficients of sector dummies and year dummies tell a very similar story as found from the previous descriptive analysis. The largest TFP growth occurs in the Education sector and the smallest growth/largest decline is in Mining and Quarrying. TFP growth is significantly larger in 2000-2007 than 2008-2009. An inclusion of size as an extra independent variable also shows some significant effects. Medium and large firms tend to have higher TFP growth on average than smaller firms.

8. Conclusions on Spillovers and Policy Issues

This section provides the main conclusions of the study. It focuses on why "rent" or "embodied" spillovers are potentially important to economic performance and technological change. It outlines the main hypotheses tested as part of the investigation. The discussion then turns to the results of the "static" models, followed by the results of the dynamic models. Finally, the concluding section focuses on the results from a policy perspective.

8.1 A new view of "rent spillovers"

The traditional empirical economic approach to identifying spillovers does not focus on the supply chain, but primarily on technological or spatial distances, where firms and other organisations that are closer to one another are more likely to experience spillovers from one-another. Indeed, Griliches' argument that benefits experienced by a buyer from a supplier are simply a price index measurement problem may have put economists off exploring the role of the supply chain. The present study argues that there seems to be much more going on along the supply chain than the inability of suppliers to appropriate all of the benefits of their innovation.

It is quite easy to argue why supply chain spillovers are not just a measurement problem when the discussion turns to whether innovation in one sector results in subsequent innovation in other sectors. It is not feasible for an initial innovator to appropriate all of the future benefits of the innovations that it may give rise to amongst enterprises that it supplies. In this case, the initial innovator is less likely to know what further innovations will be spawned or what they will be worth to subsequent innovators. This makes it very difficult for them to appropriate the benefits of future innovations.

It has long been realised that absolute appropriability by the first innovator of the benefits of all subsequent innovations is not a desirable outcome – such a system would remove all incentives for subsequent innovations. Hence, even where laws provide incentives to inventors and innovators, these attempt to avoid appropriation of the benefits of subsequent innovations. For example, a patent monopoly comes at the cost of having to disclose the invention to the public and the exclusive right to the invention is restricted for a maximum period of 20 years.

The broader management literature gives a clear indication that the supply chain may be important. This literature is littered with examples of the role of the supply chain in both the development and transfer of new knowledge. This literature, however, tends to take a "linear" view that extends from suppliers (e.g. car component makers) to eventual buyer (e.g. a car assembly company), with knowledge flows taking place in one or other or both directions. Conceptualising it in an input-output framework, where there are direct and indirect flows that influence, albeit to different extents, all parts of the matrix, gives the supply chain idea a dynamism that suggests it might be a source of endogenous growth.

The management view also tends to focus on cooperation and collaboration along the supply chain and, thereby, the importance of networks. While such cooperation and collaboration are clearly an important part of the story, they are unlikely to be the whole story. The present Report argues that many independent innovations in other sectors produce an opportunity or need for innovation down the supply chain. This may occur as existing suppliers innovate or as innovations take place elsewhere, which change the direction and magnitude of flows within the input-output matrix.

Schumpeter has argued that the reworking of the economic system is a process of creative destruction, in that innovative firms are borne and grow and, as a consequence, those working with the old technologies decline and die. While within a sector this is a kind of "vintage effect" with new technologies entering and old technologies falling off the end, it can also occur between sectors, for example, as new materials emerge as the output of one sector and old materials produced by another sector fall into disuse. In this way, new supply chain patterns emerge in intermediate goods within the input-output matrix, reshaping the whole economic system.

8.2 Spillover hypotheses

The present report investigates two potential groups of spillover effects. The first, which is more static in nature, is where other sectors' expenditures on R&D or education affect the buying sectors' performance (productivity, profit, etc.). The other, which is more dynamic in nature, is where the innovation of the supplying sectors impacts on the future innovation of the buying sector. Both groups of spillover effects have the potential to create sustained endogenous economic growth.

In the "static" case, for example, if exposure to spillovers increases profits, these can be invested in further own-R&D or education, which will affect the future growth of that sector and its spillovers to other sectors. In the "dynamic case, for example, as innovations take place in the products supplied to sector i which, in turn, give rise to innovation in sector i's product, this may also give rise to innovations in the sectors that i supplies. In turn, innovations induced by sector i in other sectors may feedback to sector i, and so on.

The "spillover hypotheses" tested are as follows:

(i) does investment in R&D or educational purchases of suppliers impact on the productivity, profitability or export performance of their buyers ("static" case);

(ii) does innovation amongst suppliers impact on the future innovation of their buyers ("dynamic" case);

(iii) does innovation amongst suppliers impact upon the subsequent creation and destruction of buying firms (which is a potential method of transmission in the "dynamic" case)?

Of course, estimation of models to test these hypotheses give rise to many other results, for example, about the relative effects of own-R&D investments and own-education purchases vis a vis the corresponding magnitudes of their spillover effects.

8.3 Results of the "static" model

8.3.1 Productivity

Labour productivity

The sector level analysis finds that the coefficient on own-R&D takes a small, but significant positive coefficient, suggesting that a one per cent increase in own-R&D is associated with a 0.03 per cent rise in labour productivity. At the mean value added per worker in the UK, over the period 1995 to 2009, of 45,160 Euros (2005 constant prices), the improvement in labour productivity of 0.03 is equivalent to 1,355 Euros per worker per annum.

In the case of R&D spillovers, there is sufficient evidence of the positive effects of exposure to spillovers, with coefficients positive and significant at the five per cent level or higher. While the likely magnitude of the R&D spillover coefficient is less certain, it appears at least as large as the effects of own-R&D and, probably, considerably larger (possibly in the 0.08-0.16 range). Taking 0.08 as the estimated effect, a one per cent increase in spillovers translates into 3,613 Euros per UK worker (based on the mean value added per person of 45,160 Euros, see above).

The results suggest that a one per cent increase in own-educational purchases probably results in a 0.01 to 0.02 per cent rise in labour productivity (about 452-904 Euros per UK worker at the mean value added per employee). The coefficient on exposure to educational spillovers, although highly significant throughout, remains negative. The coefficient estimates suggest that it is the sectors with higher own-educational purchases and higher skill levels are "better off" in terms of higher labour productivity if they purchase their inputs from sectors that purchase less education. In other words, the sectors with higher own-skills and educational purchases are able to add more value to inputs bought from sectors with lower skills and educational purchases, other things being equal.

The results of the UK analysis of labour productivity at the enterprise level are consistent with the sector model findings. All of the UK R&D and R&D spillover coefficients show positive and generally significant coefficients. Again there is evidence that the coefficient on own-R&D is smaller than that of the R&D-spillover. The present results suggest the smallest coefficient is probably associated with own-external R&D spending, followed by own-internal R&D, and then technological spillovers (own-sector R&D), with the largest coefficient associated with R&D spillovers along the supply chain. Educational purchases are insignificant and educational spillovers tend to have a perverse, significant negative sign, similar to the European-wide sector level results discussed in the previous paragraph.

Total factor productivity

In the sector level model, overall own-R&D plays almost no role in these regressions and the same is true for R&D spillovers, until the final regression (which includes all R&D and R&D spillover interaction terms), where the own-R&D coefficient is very close to being significant at the 10 per cent level and the coefficient on R&D spillovers is significant but the opposite sign to that expected. However, taking into account the negative overall R&D spillover coefficient, 38 per cent of all country / sector R&D coefficient combinations are consistent with experiencing a positive effect of R&D spillovers on TFP. Own-education purchases and exposure to education spillovers are both positive and significant at the one per cent level throughout. The coefficients on educational spillovers are much larger than those on own-education, by a factor of four or five. Combining the effects of the coefficient and the mean values of the variables, suggests that the impact of educational spillovers on TFP is just less than twice the order of magnitude of the effect of own-educational expenditures on TFP.

Regressions that allow the impact of educational purchases and educational spillovers on TFP to differ by sector show a wide variation among sectors. The combined coefficient and sector dummy showing the impact of purchases from the education sector is 50 per cent higher in the Education than in Chemicals and Chemical Products (the reference sector) and 34 per cent lower in the Leather sector than in the reference sector. The combined coefficient and dummy values showing the impact of exposure to education spillovers ranges from 34 per cent higher in Other Community and Personal Services relative to Chemicals and Chemical Products to 20 per cent lower for Mining and Quarrying. This shows that the ability to translate exposure to spillovers into higher productivity is not uniform across sectors.

Interestingly, sectors that have relatively high productivity gains from educational purchases do not necessarily have the highest productivity gains from exposure to educational spillovers or *vice versa*. Indeed, there are examples of sectors that, in relative terms benefit most from own-education, but benefit little from educational spillovers and *vice versa*. This could lead to a “free rider” problem as low investing sectors gain at the expense of sectors making significant investments in education and training. It demonstrates the way in which sectors that are not major purchasers of educational outputs are able to improve their performances.

In the UK enterprise level model, none of the firm level factors, such as firms’ own-R&D spending (both internal and external), training, nor any of the innovation activities have a significant impact on firms’ TFP growth. It is only a number of the sector level variables that significantly affect the TFP growth of individual firms. When the data for the whole period are pooled and controlling for firm-specific heterogeneity, only education purchases and education spillovers exhibit a consistent strong and significant positive influence. The R&D variables no longer have any significant effect on TFP growth. If anything, through the analysis, R&D spillovers tend to be negative when they are significant. Thus, the UK enterprise level results for TFP are very similar the sector model results, and the same switch occurs between the importance of R&D and educational spillovers from the labour productivity to the TFP results.

Coefficients of sector dummies and year dummies in the UK enterprise level model tell a very similar story to the descriptive analysis. The largest TFP growth occurs in the Education sector and the smallest growth/largest decline is in Mining and Quarrying. TFP growth is significantly larger in 2000-2007 than 2008-2009. An inclusion of size as an extra independent variable also shows some significant effects. Medium and large firms tend to have higher TFP growth on average than smaller firms.

8.3.2 Gross and net profitability

The profitability of the buyers is a key measure of performance which can throw some light on who is appropriating the financial benefits. If the spillovers raise the buyer's profitability, then the buyer has been able to appropriate some of the financial benefits of the innovation. If the buyer experiences improved productivity performance because of the supplier innovation, this suggests that a spillover has taken place, but if the buyer's profitability is unchanged, this suggests the supplier is able to appropriate the full benefits of the spillover.

The initial expectation was that the coefficients on R&D and, possibly, education would be significant negative in the profit per unit of value added equations. Investments in R&D, for example, are generally paid out of gross profits (retained profits). However, in both cases, their coefficients are very small and generally insignificant when regressed on gross profit per unit of value added. The reason for this is probably that sectors that do more R&D or purchase more from the educational sector probably do so on an on-going basis over time. Thus, past investments are being reflected in present profits to a degree that broadly off-sets the magnitude of current investments in R&D and educational inputs. No attempt was made to test whether R&D increases future profits, as there is already an extensive empirical literature confirming this.

The R&D spillover and education spillover coefficients have significant positive values in the gross profit per unit of value added equations in all cases (in the final two equations, the significant coefficients appear on the interaction variables). The likely size of the effect of a one per cent increase in the exposure to R&D spillovers is about 0.10-0.11 per cent, while the size of the effect of education spillovers is between 0.06-0.08 per cent. At the mean value of gross profit per unit of value added of 1.658, a one per cent increase in exposure to R&D spillovers would increase the gross profit per unit of value added to around 1.660 and a one per cent increase in exposure to education spillovers would increase it to about 1.659.

The net profit data are weaker than the gross profit and the associated results are considerably weaker. The coefficients on own-R&D and R&D spillovers are (ignoring equation one) insignificant throughout. Both variables are ejected from the regression on the inclusion of the R&D interaction terms, but a considerable number of the coefficients on the interaction terms are significantly different to zero at the 10 per cent level or higher.

The estimated education expenditure coefficient is significantly positive in two instances, but the associated coefficients are quite small (a one per cent increase in educational expenditure resulting in a 0.02 per cent rise in net profit). However, education spillovers are significant positive throughout at the one per cent level or higher, suggesting that a one per cent increase in exposure to educational spillovers has between 0.05 and 0.09 per cent increase in net profit per unit of value added.

8.3.3 Export performance

R&D has a positive coefficient throughout in the export/gross output function, but is only significant in the final two equations, which include all the dummy and interaction terms. It is also has a significant positive coefficient at the 10 per cent level or higher in all but the final regression in export/import equations. The R&D spillover coefficients tend to take the wrong sign in the export/gross output function and when the R&D spillover coefficient is positive in the export/import function, the coefficients are not significantly different from zero at the 10 per cent level.

The key result is the positive significant coefficient that occurs on the educational spillover variable. This coefficient is consistent in size in each equation, but quite different in scale across the two functions. A one per cent increase in educational spillovers produces a 0.05 to 0.07 per cent rise in exports per unit of output, but a 0.4 to 0.6 per cent rise in exports per unit of imports, which reflects the greater variation in the second measure (and possibly the fact that educational spillovers are export increasing and import saving).

8.3.4 Summary of the static model results

Table 18 shows the impact of skills on performance. Note that the table only covers the main variables and that care should be used in interpreting the outcomes (e.g. the expected sign is not always obvious, as in the case of own-R&D and own-educational expenditures in the profit equations).

Table 20: Summary of the Impact of Skills and Innovation on Productivity, Profits and Trade Performance[55]

	LP (Sector)	LP (Enterprise)	TFP (Sector)	TFP (Enterprise)	Gross Profit (Sector)	Net Profit (Sector)	Export/Output (Sector)	Export/Import (Sector)
Employment	-	-	n/a	-	n/a	n/a	n/a	n/a
Capital Stock	+	+	n/a	-	+	+		
R&D (own)	+	+			(-)		(+)	+
R&D Own-sector Spillovers	n/a	+	n/a	n/a	n/a	n/a	n/a	n/a
R&D I-O Spillovers	+	+			+		(-)	
Med Skill Hours		+	+		-	-		(+)
High Skill Hours	+	+	+	-	+	+	+	+
Education Purchase	+		+	+			+	
Edu Spillovers	-	(-)	+	+	+	+	+	+
Training	na	+	na	n/a	na	na	na	na
Product Innovation	na	+	na	n/a	na	na	na	na
Process Innovation	na		na	n/a	na	na	na	na
New to market innovation	na		na	n/a	na	na	na	na

Notes: n/a – not applicable (no conceptual reason for the variable to be included); na – variable is not available or not sufficiently available to be included in the regression; + positive sign and significant; (+) generally positive sign but not consistently significant; - negate sign and significant; (-) generally negative sign but not consistently significant; shaded cells indicate the coefficient is of the “wrong” sign; empty cells indicate indeterminate sign, generally insignificantly different from zero.

[55] For more details on the information presented in Table 20, see Tables 6 and 7 (labour productivity at sector level), Table 18 (labour productivity at enterprise level), Table 8 (total factor productivity at sector level), Table 19 (total factor productivity at enterprise level), Tables 9 and 10 (profits) and Tables 11 and 12 (trade performance).

The results show that the share of hours worked by highly skilled employees is positively linked to almost all of the measures of productivity, profits and trade performance. Expenditure on training is associated with increased labour productivity at the enterprise level. Purchases of goods and/or services from the Education sector (comprising schools, and further and higher education institutions) increases labour productivity at the sector level, total factor productivity at both the sector and enterprise level, and the ratio of exports to output at the sector level. Exposure to spillovers from education purchases is negatively correlated with labour productivity but positively and significantly correlated with all the other performance variables. Own-R&D spending (and product innovation at the enterprise level) are linked positively to labour productivity and export performance. Exposure to R&D spillovers along the supply chain (R&D I-O Spillovers) is also linked with higher labour productivity and gross profits.

8.4 Results of the dynamic model

8.4.1 Endogenous growth

The principal aim of the dynamic model is to investigate whether the current production of new knowledge depends on past investment in new knowledge (*e.g.* past R&D expenditures) and on other factors such as knowledge flows from outside the firm or sector. The model regresses current innovation activity on past innovation in the same sector and in the supply chain for that sector, controlling for country and sector specific effects and, where appropriate, including time dummies. The country and sector specific effects control for the persistence of innovation (e.g. that sectors with past high levels of innovation are also likely to have current high levels).

In all three areas of innovation investigated, clear evidence was found for significant positive effects of both prior innovation and prior innovation by the supply chain. While the estimated coefficients are somewhat difficult to interpret in their logit form, they nevertheless generally suggest that the effect of prior innovation by the supply chain has at least as large an impact as prior innovation within the same sector, at least for process innovation and new to market innovation (where the coefficients are 0.269 and 0.284, for process, and 0.338 and 0.396, for new to market innovation). In the case of product innovation, however, the spillover coefficient is approximately half the value of own-innovation coefficient (0.402 compared with 0.210).

In order to illustrate the importance of this finding, the conclusions concentrate on product innovation and product innovation spillovers, although similar results are also found for process innovation and new to market product launch (and their associated spillovers).

For instance, the initial effect of own-product innovation is to increase product innovation two years ahead. A one percentage point increase own-product innovation (an increase from 26 to 27 per cent of firms at the mean), leads to a 0.49 percentage point increase in the proportion of firms undergoing product innovation two years later. This implies that a one per cent increase own-product innovation, leads to a 0.32 per cent increase in the proportion of firms carrying out product innovation two years later.

Exposure to product innovation spillovers has a similar, although slightly smaller impact. A one percentage point rise in suppliers undergoing product innovation (18 to 19 per cent at the mean) leads to a 0.35 percentage point increase in the proportion of firms undergoing product innovation as a result of exposure to spillovers from the suppliers. This implies that a one per cent increase in supplier product innovation leads to a 0.14 per cent increase in the proportion of firms undergoing product innovation two years later as a result of exposure to spillovers.

It is not possible to simply sum the two together – as the change in product innovation itself determines the change in spillovers. Using the mean values of own-product innovation and product spillovers, it is possible to suggest that, on average a one percentage point rise in own-product innovation is associated with a 0.7 percentage point rise in spillovers (not a one percentage point rise). Thus, raising prior own-product innovation by one percentage point raises product innovation spillovers by 0.67 of one percentage point, which, when combined, raise subsequent product innovation by 0.73 of a percentage point (0.49 from prior own-innovation and 0.23 from prior product innovation spillovers).

If it can be assumed that the innovative activity stimulated two years on also produces further innovation activity four years on (and so on), then the effects of the initial innovation cumulate over time – as each round of innovation creates a new subsequent round. While the effects of each round of innovation on the next round become smaller and smaller with the passage of time, nevertheless, they are long-lived (with the marginal effects of the initial product innovation only falling to about 10 per cent, ten years after the initial innovation – the shortest lived of the three forms of innovation). The cumulative effect of product innovation and its associated spillovers is over two times the size of the effect after two years, about the same in the case of process innovation and its spillovers, while the final outcome for new to market product launch is about three times the effect after two years.

The size of the cumulative effects are critically dependent on the assumption that the coefficient values on past innovation remain constant over time. This assumption means the size of the effect of past innovation declines geometically at the margin over time. In practice long-lived effects are likely only to be associated with ground-breaking and widely used technologies, so-called "general purpose technologies" (which generally exhibit different phases of technological development). The majority of run of the mill innovations are likely to be much shorter lived, with marginal effects declining more rapidly over time. Nevertheless, the potential cumulative nature of the innovation process may give some insights about endogenous growth.

8.4.2 Creative destruction

Creative destruction is a process by which better products make older ones obsolete. Schumpeter saw this as taking place through the establishment and growth of innovatory firms and the decline and death of enterprises based on obsolete technologies. This suggests there may be a link between past innovation and firm birth rates, death rates and the amount of demographic upheaval in the population of firms ("churn"), as well as firm survival rates. The last of these variables is the weakest as it is difficult to synchronise the period the survival rate covers with the timing of innovation.

Two sets of regressions are undertaken, involving each of the four enterprise demographic variables: the first relates to the largely pre-recession period ending in 2007 and 2008; and the other is more heavily influenced by the recession and ends in 2009 and 2010. Each of the three innovation variables outlined in 8.4.1 are included as explanatory variables, from as many of the Community Innovations Surveys as possible. In practice, the effects of the recession accentuate the effects of earlier innovation, rather than cloud them.

The principal feature of the 2007/2008 results is that almost the only role played by the own-innovation variables is that of own-product innovation. There is reasonably compelling evidence that the 2006 values of this variable have positive and significant effects on the rates of enterprise births, deaths and churn. This result is consistent with creative destruction, with higher levels of own product innovation raising both the birth and death rates of enterprises and, thereby, the level of churn in the economy.

The majority of the influences on firm demographics in 2007 and 2008, however, come from the innovation spillover variables, where there are some interesting and largely consistent results. Where they are significant (almost all coefficients are significant in either 2004 or 2006), product innovation spillovers have a negative effect on births, deaths and churn, and a positive effect on survival. The opposite is true for process innovation spillovers, which have a positive effect on births, deaths and churn, and a negative effect on survival.

The results for 2009 and 2010 demographics suggest that the effects of innovation and innovation spillovers on births and deaths can be long-lasting. Consistent with the earlier results, the own-product innovation variable for 2006 is the most important of the own-innovation variables, with the 2008 version of this variable insignificantly different from zero at the 10 per cent level or higher throughout. Combining the 2004 and 2006 effects, consistent with creative destruction, the coefficients are positive and significant for births, deaths and churn, with consistent negative survival coefficients for 2009 (insignificant) and 2010.

The other feature consistent with the 2007 and 2008 results is the relative lack of a role for own-innovation vis a vis innovation spillovers. As in the earlier results, combining the effects of 2004 and 2006, product innovation spillovers significantly lower the rates of birth, death and churn, raising the survival rate (only significant in 2009). The exposure to process innovation spillovers from 2004 and 2006 has significant positive coefficients for births, deaths and churn and significant negative coefficients on the survival rates.

8.4.3 Summary of the dynamic model results

Table 21 summarises the links between past innovation and its associated spillovers and both subsequent innovation and subsequent firm demographics. As with Table 20, some care needs to be taken in interpreting the results (e.g. the period covered by the five year survival rate is not always entirely consistent with those of the birth, death and churn rates). In addition, while Table 21 reports the main variables of interest, they are not the only ones in the regressions.

As shown by the shaded cells in the first three columns of results, the principal relationships are that,

- prior product innovation and exposure to product innovation spillovers are positively correlated with subsequent product innovation;
- prior process innovation and exposure to process innovation spillovers are positively correlated with subsequent process innovation;
- prior new to market innovation and exposure to new to market innovation spillovers are positively correlated with subsequent new to market innovation.

While these are the principal linkages, there are others which cross over innovation type which are also significant. These relationships between prior and subsequent innovation may be a source of endogenous growth.

Table 21: Summary of the Link between Innovation and Business Demographics[56]

Prior: / Subsequent:	Product Innovation	Process Innovation	New to market Innovation	Birth Rate	Death Rate	Churn	5 Year Survival Rate
Product Innovation	+	+	+	+	+	+	(-)
Process Innovation	+	+					
New to market innovation	+	(+)	+		(-)		(-)
Product Innovation Spillovers	+	(+)	-	-	-	(-)	(+)
Process Innovation Spillovers		+		(+)	+	+	-
New to market innovation Spillovers			+	(+)	+		(+)[a]

Notes: + positive sign and significant; (+) generally positive sign but not consistently significant; - negate sign and significant; (-) generally negative sign but not consistently significant; shaded cells indicate the strongest results; a) "wrong" sign.

The final four columns of Table 21 summarise the correlations between innovation and business birth, death, churn and survival. The highlighted cells in these four columns provide evidence of "creative destruction". Product innovation increases both the birth and death rates within the sector, as new products displace old products (and thereby increasing "churn" and lowering the firm survival rate), creating both "winners" and "losers" among competing firms in the sector. Interestingly, exposure to product innovation spillovers, seems to favour established firms, leading to drops in the birth, death and churn rates and an increase in the five year survival rates. Exposure to process innovation spillovers and, less precisely, new to market innovation spillovers, appear to have the opposite impact, leading to increases in both the birth rates and death rates and a drop in the survival rates.

8.5 Policy implications

Spillovers are of considerable interest to policy makers because, where they are present, they drive a wedge between the private and socially optimal investments in activities such as R&D and innovation. The economic literature suggests that these are areas of under-investment by private investors because the results of the knowledge production and novel and improved products can be used productively by others, in ways that the resulting benefits cannot be appropriated by the original knowledge producer / product innovator.

[56] For more details on the information presented in Table 21, see Table 13 (innovation and prior innovation) and Tables 15 and 16 (innovation and firm demographics).

The present study provides empirical support for both R&D spillovers and education spillovers along the supply chain, although their roles appear to differ, depending on what measure of economic performance is used. A role is found for R&D and / or educational spillovers in all of the performance measures examined (e.g. various forms of labour productivity, total factor productivity, profitability and export performance). However, it is not clear why R&D spillovers are positive and important in explaining various measures of labour productivity and educational spillovers are positive and important in explaining total factor productivity, but the result appears to be systematic as it occurs in both the Europe-wide sectoral model and the UK enterprise level model.

In general, the coefficients on the R&D, education and innovation spillover variables are larger, often considerably larger, than those on the corresponding own-R&D, own-education and own-innovation variables. Thus, for an equal change in the magnitude of own-innovation and the exposure to innovation spillover, the effect of the innovation spillover will be that much larger. The UK labour productivity results highlight this finding – the smallest positive coefficient was on own-external R&D spending, followed by own-internal R&D, and then technological spillovers (own-sector R&D), with the largest coefficient associated with R&D spillovers along the supply chain.

While the coefficients are an estimate of the marginal effects, it is also worth noting that the overall size of the exposure to spillover differs from that of the corresponding own-innovation. The UK lies third in terms of the overall magnitude of exposure to R&D spillovers in 2009 (21 billion Euros, 2005 prices), but is dwarfed by Germany (60 billion) and, more particularly, France (90 billion). The UK lies second in terms of exposure to educational spillovers in 2009 (28 billion Euros, 2005 prices), considerably lower than Germany (40 billion), but slightly above France (22 billion).

The ratio of exposure to spillovers / own-investment is an indication of the efficiency with which each country's input-output matrix translates own-R&D into exposure to the corresponding spillovers. This ratio differs significantly across countries and over time.[57] In 2009, the ratio of R&D spillovers to own-R&D ranges from 2.5 in France to 0.5 in Turkey. The ratios in 2009 are 1.0 in Germany and the UK and 0.6 in Poland. Between 2000 and 2009, the ratio increased in France (from 1.9 to 2.5), remained constant in Germany (at 1.0), while it declined in the UK (from 1.4 to just below 1.0) and Poland (from 1.2 to 0.6). Countries with high and stable spillover ratios are likely to benefit more from own-R&D and, thereby, the R&D spillovers this creates, than countries with low ratios, other things equal. By 2009, the UK was below average in this respect.

In the UK, the three sectors with the greatest exposure to R&D spillovers in 2009 are the Other Community, Social and Personal Services, Public Administration and Defence, and Financial Intermediation. Exposure in these three UK sectors is 1,300 million Euros (constant 2005 prices) in 2009. The fact that certain sectors are more exposed to spillovers perhaps points to how they are able to sustain productivity growth and performance improvement of their own, without necessarily being important centres of R&D. Unlike technological spillovers (which require some commonality of technology) or spatial spillovers (which require commonality of location), spillovers along the supply chain

[57] A ratio of greater than one indicates that the exposure (e.g. to the weighted sum of supplier R&D) is greater than own-R&D spending, a ratio of less than one indicates that own-R&D spending is higher than exposure.

are able to reach other sectors in other locations that may carry out little or no R&D or educational purchases in their own right.

The countries with the highest levels of purchases from the Education sector (Germany, the UK and France) also saw the highest levels of exposure to educational spillovers.[58] In 2009, the ratio of exposure to spillovers to own-purchases ranges from 2.7 in Belgium to 0.7 in Turkey – very similar to the range of ratios seen in R&D. The UK's ratio in 2009 is 1.3 and, while this is slightly higher than for R&D, is below average across European countries. In the UK, the Real Estate (1,700 million Euros, all 2005 prices), Other Community, Social and Personal Services (1,500 million Euros) and Financial Intermediation (1,300 million Euros) sectors have the highest exposure to spillovers from educational purchases.

Another policy issue is that sectors that have relatively high productivity gains from exposure to the educational purchases of other sectors do not necessarily have high productivity gains from own-educational spillovers. It is possible to find examples of sectors that, in relative terms benefit most from own-education, but benefit little from educational spillovers and *vice versa*. This could lead to a "free rider" problem as low investing sectors gain at the expense of sectors making significant investments in education and training.

Perhaps the most important finding of the study, however, is that there is empirical evidence that suggests not only that previous own-innovation affects subsequent own-innovation, but that previous innovation of supplying sectors affects subsequent own-innovation. While the marginal effect of an innovation declines as it spawns further innovation around the input-output matrix, the cumulative amount of innovation can be large – estimated at around two to three times the initial impact. Again, countries with higher innovation spillover to own-innovation ratios will benefit more from investment in innovation.

The final finding is that empirical evidence has been found of creative destruction, whereby past own-product innovation increases the births and deaths of enterprises and, thereby, the "churn" in the population of firms. While confirmation of Schumpeter's theory is important, the present modelling shows that innovation spillovers are perhaps even more important influences on firm demographics. In particular, product innovation amongst suppliers lowers the birth and death rates of the buying sectors and process innovation amongst suppliers raises the birth and death rates of buyers. These are new empirical findings and their policy implications have yet to be studied.

[58] As in the case of R&D, a ratio of greater than one indicates that the exposure (e.g. to the weighted sum of supplier purchases from the Education sector) is greater than own-education spending, a ratio of less than one indicates that own-education spending is higher than exposure.

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