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Public support for innovation, intangible investment and productivity growth in the UK market sector

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Public Support for Innovation, Intangible Investment and Productivity Growth in the UK Market Sector*

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Abstract

Pressure on public finances has increased scrutiny of public support for innovation. We examine two particular issues. First, there have been many recent calls for the (relatively new) UK R&D subsidy to be extended to other "research" activities, such as software. Second, argument still rages about the efficacy of direct public spending on R&D via spending on academic research councils, universities, and government undertaken work on civil and military R&D. To evaluate these questions we use data on market sector productivity, R&D and non-R&D intangible assets, and public sector R&D spending. We look for evidence of market sector spillovers from intangible investment and from public R&D. We find (a) no evidence of spillover effects from intangible investment at the market sector level, including from R&D, (b) strong evidence of market sector spillovers from public R&D spend on research councils, and (c) no evidence of market sector spillovers from public spending on civil or defence R&D. Our findings tentatively suggest that for maximum market sector productivity impact government innovation policy should focus on direct spending on research councils.

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Keywords: intangible assets, productivity, R&D, spillovers

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1. INTRODUCTION

In the context of the "New Economy" it is often argued that investment in certain types of capital could have benefits beyond those firms that make the investment. These production spillovers and network effects are most commonly discussed in relation to R&D. Indeed, much innovation policy consists of subsidies to R&D, either directly, via spending on R&D in universities or on defence projects, or indirectly via an R&D tax credit for private R&D spending.[1]

More recently, there has been speculation about possible spillovers from other knowledge assets besides R&D, such as ICT (driven in turn by knowledge transfer and/or network externalities). For example, there have been active suggestions to extend the R&D tax credit to software.[2] At the same time, there is also huge interest in the impact of direct public investment in science and innovation. For example, spending on research councils was tripled between 1999 and 2007, in response to a perceived relatively lower level of such spending in the UK.

In this paper we attempt to answer two questions. Firstly, are there productivity spillovers from intangible investments wider than R&D or do all the benefits of such intangible investment accrue to those firms either producing or using intangible capital? Secondly, are there productivity spillovers to the market sector from direct public sector spend on R&D and if so what spend (research council, civil, defence) is most effective? We believe these questions to be of interest since they shed light on the policy question of whether government should provide support for market sector investment in innovation, by expanding the R&D tax credit to broad range of intangibles for example, or provide direct spending on public R&D e.g. basic research.

There are of course a number of different ways in which these questions can be approached. Our method is in the econometric/growth accounting tradition summarised by, for example Grilliches (1992), and implemented in recent econometric work by, for example Stiroh (2002) (for non-R&D intangible assets) and Guellec and van Pottelsberge (2004) (for public and private R&D in OECD countries).[3] To evaluate whether the R&D tax credit should be widened to a broader range of intangible assets, we gather data on market sector spending on a broad range of intangible assets suggested originally by Corrado, Hulten and Sichel (2006). We incorporate them into the UK National Accounts and adjust value added to reflect the additional investment in the economy when intangible spend is treated as investment rather than, as currently, as an intermediate. We also adjust

[1] A UK R&D tax credit was introduced in 2000 and the tax credit for SME's was significantly enhanced from the 1st August 2008.

[2] In July 2005 a High Court judge ruled that software company BE Studios had claimed £150,000 in R&D tax credits in error because the software development work carried out by the company did not seek to achieve a scientific or technological advance.

[3] Other approaches are set out in, for example, Salter and Martin (2002) who ask industry participants to rate the importance of public research. Mansfield (1981) surveys firm use of basic R&D.

inputs and build intangible asset stocks. We calculate resulting TFP growth using growth accounting methods that assume no excess of social over private returns. This was done in Giorgio Marrano, Haskel and Wallis (2009). We then examine possible spillovers from intangible spending by regressing associated stocks of intangible assets on market sector TFP growth.

To examine possible spillovers from publicly financed R&D to market sector TFP growth we then regress TFP growth on various measures of direct public sector R&D spend including research councils, block grants to universities for research, civil R&D and defence R&D.

Despite the policy importance of these questions, there are comparatively few papers that study them.[4] The part of our work on possible spillovers from a range of intangible assets is very similar in spirit to Stiroh (2002). He did not consider a broad range of intangible assets, but looked for spillovers from ICT hardware and software, finding, on US data, no evidence (namely that measured TFP growth is uncorrelated with all capital inputs, including ICT capital). More recently, O'Mahony and Vecchi (2009) investigate knowledge spillovers from R&D, human capital and advertising finding evidence of spillovers, but only in certain sectors of the economy.

Our work on spillovers from public R&D to the market sector is also similar in spirit to that of Guellec and van Pottelsberge (2001). As they remark, "…there have been very few studies of the effects of public research on productivity". In similar vein the survey paper by Salter and Martin (2002) reports 9 estimates of the rates of return to publicly funded R&D, all of which concern agriculture.[5] Guellec and van Pottelsberge (2004) construct market sector TFP growth for 16 OECD economies and using an error correction model find the (long run) elasticity of public sector R&D (measured by R&D preformed in government labs and universities) of 0.17. They also find that this impact is positively affected by the share of universities (contrary to government labs) in research and negatively affected by the share of defence in public R&D budgets. Note that Park (1995) in his international study finds no effect of public R&D once private R&D is controlled for.

Whilst our methods are not new, to the best of our knowledge, we are the first paper to use improved data to examine these issues. This may matter for the following reasons. First, previous macroeconomic work that typically regressed the standard measure of TFP growth on R&D did not adjust TFP growth for the capitalisation of knowledge assets nor allow for the impact of other knowledge assets besides R&D. This potentially affects the measured rates of return due to measurement error and omitted variable bias. Second, since other work has not collected data on a

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[4] The majority of studies investigate spillover effects at the industry or firm level and mostly focus on R&D intensive sectors. There is much less evidence on the presence and impact of spillovers at the market sector or whole economy level; one such is Guellec and van Pottelsberge (2002, 2004).

[5] They are (author, subject and rate of return): Griliches (1958) Hybrid corn 20–40%, Peterson (1967) Poultry 21–25%, Schmitz-Seckler (1970) Tomato harvester 37–46%, Griliches (1968) Agricultural research 35–40%, Evenson (1968) Agricultural research 28–47%, Davis (1979) Agricultural research 37%, Evenson (1979)

broad range of knowledge assets, it simply does not have the data to examine if subsidies should be extended beyond R&D. Third, there are very few papers even using other data sets on this area for the UK.

Our main findings are as follows. First we find no evidence of spillover effects from intangible investment, including R&D. Second, we find quite strong evidence of market sector productivity benefits from public R&D spend on research councils. Third, find no evidence of market sector spillovers from spending on civil or defence R&D. Our findings tentatively suggest that for maximum macroeconomic impact government innovation policy should focus on direct spending on research councils.

The remainder of this paper is as follows. In the next section, we describe the data used in our empirical analysis and some of its key features. Section 3 outlines the model used in our empirical analysis. Our regression analysis is presented in Section 4. Section 5 discusses the tentative policy implications of our empirical findings and Section 6 concludes.

Agricultural research 45%, Davis and Peterson (1981) Agricultural research 37%, Huffman and Evenson (1993) Agricultural research 43–67%.

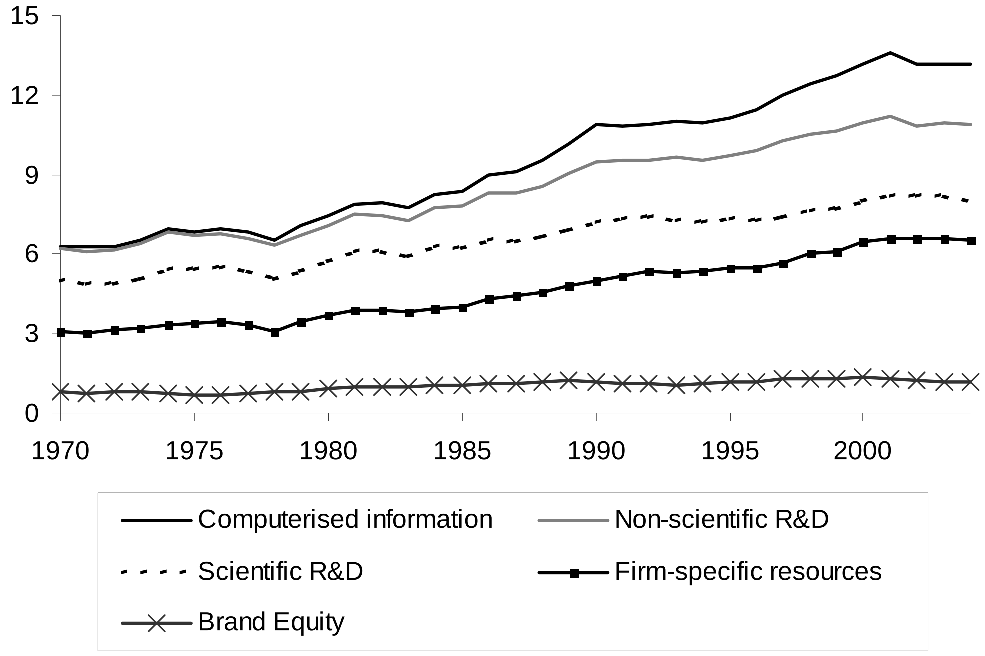
2. INTANGIBLE INVESTMENT AND R&D SPENDING

This section describes the data used in our empirical analysis and some of its key features.

2.1. Market sector TFP and spending on intangible assets

We use data on market sector spending on intangible assets from Giorgio Marrano, Haskel and Wallis (2009), which follows the method in Corrado, Hulten and Sichel (2005,6). We identify three main intangible asset classes. Firstly, computerised information (mainly software), secondly, innovative property (mainly scientific and non-scientific R&D) and finally firm-specific resources (company spending on reputation, human and organisational capital). We also use TFP data and capital stocks data from the same study. Figure 1 shows intangible investment as a percentage of market sector output. For details see Giorgio Marrano, Haskel and Wallis (2009).

FIGURE 1
INTANGIBLE INVESTMENT (percentage of output)



Source: Giorgio Marrano, Haskel and Wallis (2009)

Notes: The figure shows the time series for intangible investment for the aggregated categories as a share of output. Output is market sector gross value added (GVA) adjusted to include all intangibles. It is a cumulative graph so that that top line shows the share of total intangible investment in intangible-adjusted market sector GVA. The lowest line shows the share of brand equity and the line above that shows the share of brand equity plus the firm-specific resources. Thus the gap between the lines is the share of each category of investment. Brand Equity includes advertising and market research. Firm-specific resources includes firm specific human capital and organisational structure. Scientific R&D includes scientific R&D and mineral exploration. Non-scientific R&D includes copyright and licences costs, new product development costs in the financial industry, new architectural and engineering design and R&D in social science and humanities. Computerised information is basically software.

In section 4.2, where we look at spillovers from public R&D, we start by using TFP from Giorgio Marrano, Haskel and Wallis (2009). We then go on to use updated estimates from Haskel et al (2009), as this gives us three extra years with which to test our hypothesis of diminishing returns.

2.2 Government spending on R&D

We use data on government spending on R&D published annually by the Department for Business Innovation and Skills (BIS) as part of science engineering and technology (SET) statistics.[6] The dataset includes full details of publicly funded expenditure on science, engineering and technology for the financial years 1986-87 up until 2005-06. In particular, we consider tables 2.1 and 3.1, entitled "Net government expenditure on SET by departments in cash" and "Net government expenditure on R&D by departments in cash".

Data is available on expenditure on SET and on R&D. SET is a broad term used to describe all publicly funded expenditure on knowledge capital. All SET expenditure is attributed to one of six "primary purposes" which are (a) ppA, General support for Research - all basic and applied R&D which advances knowledge plus support for postgraduate studentships; (b) ppB, Government services - R&D relevant to any aspect of Government service provision (including defence). (c) ppC, Policy support – R&D which Government funds to inform policy (excluding ppB & ppD) and for monitoring developments of significance for the welfare of the population; (d) ppD, Technology support - applied R&D that advances technology underpinning the UK economy (excluding defence, but including strategic as well as applied research; and pre-competitive research under schemes such as LINK); (e) ppE, Technology transfer - activities that encourage the exploitation of knowledge in a different place to its origin and (f) ppF, Taught course awards - includes awards for Masters degrees but not for PhDs, which are included in ppA. R&D spending is a subset of SET spending, being the sum of expenditure on ppA, ppB, ppC and ppD. R&D is in fact over 95 per cent of SET spending and follows almost the same trend, so we use R&D spend here. We also thought it appropriate to exclude taught masters degrees.

Public R&D spend, as well as broken down by these primary purposes, is also broken into administrative units, as shown in Figure 2. The classification available is spending on (a) research councils, (b) defence, (c) civil and (d) Higher Education Funding Council (HEFC). In 1986, the first year of the data, R&D spend was dominated by defence, at over £2bn (at current prices). Civil, at

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[6] All these data are in an extremely useful spreadsheet entitled "SET statistics: science, engineering and technology indicators", reached through a link in the "Related Documents" section of the SET statistics page of the website www.dius.gov.uk/science/science_funding/set_stats. We thank Martin Kenchatt from BIS for help with these data. The previous draft of this paper used a download in November 2009, this uses an updated sheet posted in December 2009. The data are identical aside from the most recent years, which were planned spending and are now realised.

around £1bn was next, and HEFC and research councils were third and fourth. By the end of the period, interestingly, research councils had grown to over £3.5bn, with defence rising somewhat HEFC and civil spending also rose steadily.

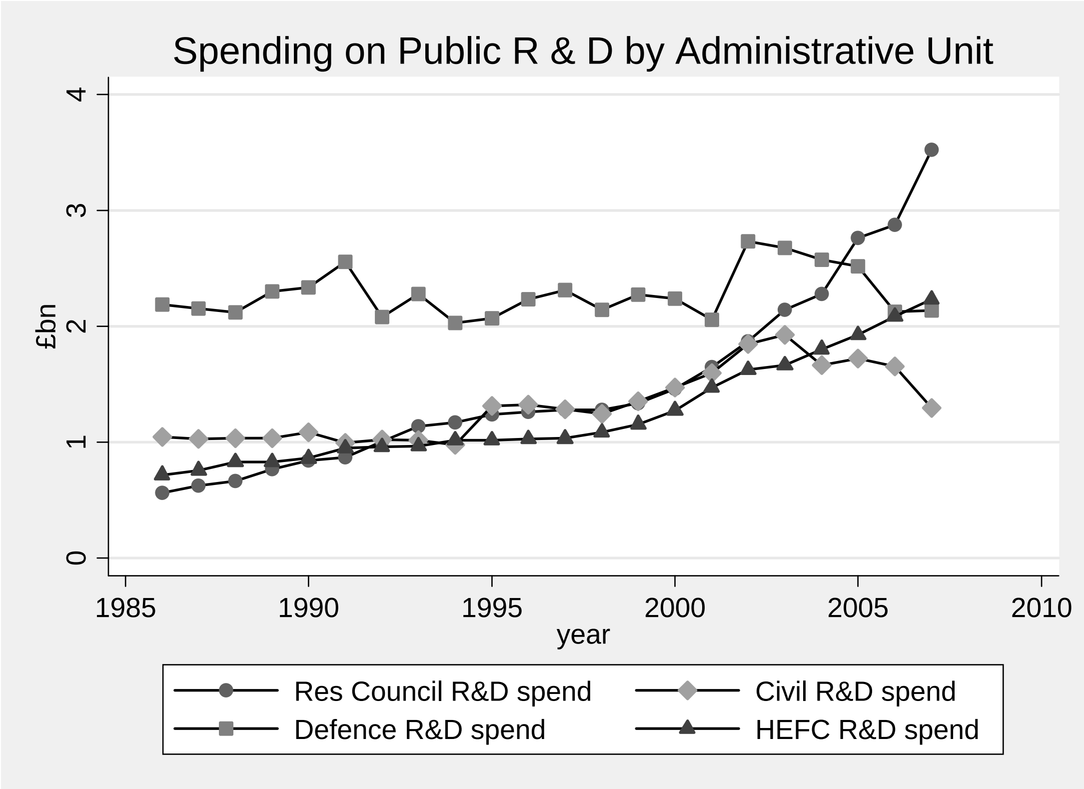
There are number of measurement issues here. First, the HEFC is intended to capture the notion that some fraction of normal spending on higher education institutions is supposed to support research. According to the SET data notes, before 1992, estimates of such spending were based on an assumed fraction of time devoted to research applied to the overall higher education spend figure. After 1994, this was changed and a new method is now based on a splitting of a university's government income into that for research, that for teaching and other. Research spending is now counted as research income and one third of postgraduate teaching income (see notes to the SET data). The discontinuity precludes, say the compliers of the data, comparing data past 1993. Whilst we shall include this HEFC series, we may be mismeasuring this source of spending and we do not measure at all the impact of funded research done by universities in time outside of Research Council grants and this allocation of HEFC time.[7]

Second, since these date are spending one might worry that there is some double counting with private sector spending, if some of that private spending is funded by the government sector. This in practice is small.[8] In 2007, funding of R&D performed in the private sector was £1.1bn, which is 7 per cent of the total. Of that, £890m was for defence spending and £168m was civil. Similarly, total funding by research councils on R&D was £3.2bn, of which £269m was carried out by business enterprise.

[7] For more on the UK research funding system see e.g. HEFCE (2010). Much of the HEFCE funding in this data is quality related (QR) funding, allocated to universities by the RAE. Along with research grant money this is known as the dual-support system. As noted in the text, there is also 1/3rd of postgraduate fees counted. We should note that we have no data on other research funding for universities from charities and EU grants. In 2007-8 this accounted for respectively, 15 per cent and 6 per cent of research income at UK Higher Education Institutions (HEFCE, 2010, page 15).

[8] See www.statistics.gov.uk/pdfdir/berd0109.pdf for these data.

FIGURE 2
PUBLIC R&D BY ADMINISTRATIVE UNIT



Notes: HEFCE (Higher Education Funding Council) spend is that part of university funding designated for research purposes. For method of calculation, see text.

International comparisons of such spending broken down at this level are not available, but the OECD do publish comparisons of Higher Education Expenditure on R&D (HERD) funding (as a proportion of GDP). In terms of the more detailed UK data here, HERD is essentially the sum of spending on HEFCE and research councils. Such comparisons are set out in Table 1 where we see that in 1986 UK HERD stood at 0.34 per cent of GDP giving a ranking of 9th out of the countries show. By 1996 the UK's rank had dropped to 16th as other countries increased their HERD relative to GDP while the UK HERD remained quite stable. By 2006 the UK had regained its rank of 9th (joint 9th with Norway) as HERD increased to 0.46 per cent of GDP.

TABLE 1
HERD AS A PERCENTAGE OF GDP, SELECTED OECD COUNTRIES

Country	**1986**	**Rank**	**1996**	**Rank**	**2006**	**Rank**
Sweden	0.81	1	0.75	1	0.77	1
Canada	0.34	9	0.44	6	0.69	2
Switzerland	0.35	7	0.65	2	0.68	3
Finland	0.34	9	0.46	5	0.65	4
Denmark	0.3	14	0.4	11	0.64	5
Austria	0.42	4	0.53	4	0.59	6
Australia	0.32	12	0.42	8	0.52	7
Netherlands	0.46	3	0.57	3	0.47	8
Norway	0.35	7	0.43	7	0.46	9
United Kingdom	**0.34**	**9**	**0.36**	**16**	**0.46**	**9**
Japan	0.54	2	0.41	9	0.43	11
Belgium	0.29	15	0.38	14	0.42	12
New Zealand	0.17	20	0.4	11	0.41	13
Germany	0.38	5	0.41	9	0.41	13
France	0.32	12	0.38	14	0.4	15
Total OECD	0.29	15	0.34	17	0.39	16
United States	0.26	17	0.31	18	0.36	17
Ireland	0.18	19	0.26	19	0.34	18
Italy	0.22	18	0.26	19	0.34	18
Spain	0.11	21	0.26	19	0.33	20
Korea	n/a	-	0.23	22	0.32	21
Portugal	0.11	21	0.22	24	0.32	21
Turkey	n/a	-	0.21	25	0.3	23
Greece	0.05	23	0.23	22	0.27	24
Japan	0.36	6	0.39	13	0.26	25

Source: OECD Main Science and Technology Indicators, 2009.

Notes: Countries are ordered by their 2006 rank. Data for the years shown is missing for some countries. To ensure a consistent UK ranking over time and on a decent panel of countries when there is a missing year the following year is taken. If this is also not available the previous year is taken. Countries where neither was available have been dropped.

We can further analyse the four broad spending categories. Since the research councils will be a particular focus Table 2 shows the distribution of spending between different research councils for particular years. The final three columns show that the largest shares of spend go to “science”; that is medical and engineering based research councils. So for example, in 2005-6, 20 per cent of spend went to the EPSRC (Engineering and Physical Sciences Research Council), 18 per cent to the OSI (essentially the Royal Society), 15 per cent to the MRC (Medical Research Council), 13 per cent to the Natural Environment Research Council and 12 per cent to BBSRC (the Biotechnology and Biological Sciences Research Council) and 12 per cent to the PPARC (Particle Physics and Astronomy Research Council), a grand total of 82 per cent.

TABLE 2
GOVERNMENT R&D SPENDING BY RESEARCH COUNCIL

Science Budget	**1995-96**	**2000-01**	**2005-06**	**1995-96**	**2000-01**	**2005-06**
	£m	£m	£m	% of total	% of total	% of total
OSI - DTI	25	73	503	2.0	5.0	18.2
BBSRC	173	211	320	14.0	14.4	11.6
ESRC	55	64	116	4.5	4.4	4.2
MRC	275	315	416	22.2	21.6	15.1
NERC	156	170	363	12.6	11.6	13.1
EPSRC	345	395	553	27.8	27.1	20.0
PPARC	202	205	334	16.3	14.0	12.1
CCLRC	-	2	84	0.0	0.1	3.0
AHRC	-	-	58	0.0	0.0	2.1
Pensions/Other	8	24	15	0.6	1.7	0.5
TOTAL	1,239	1,459	2,763	100.0	100.0	100.0

Source: BIS SET statistics, table 3.1

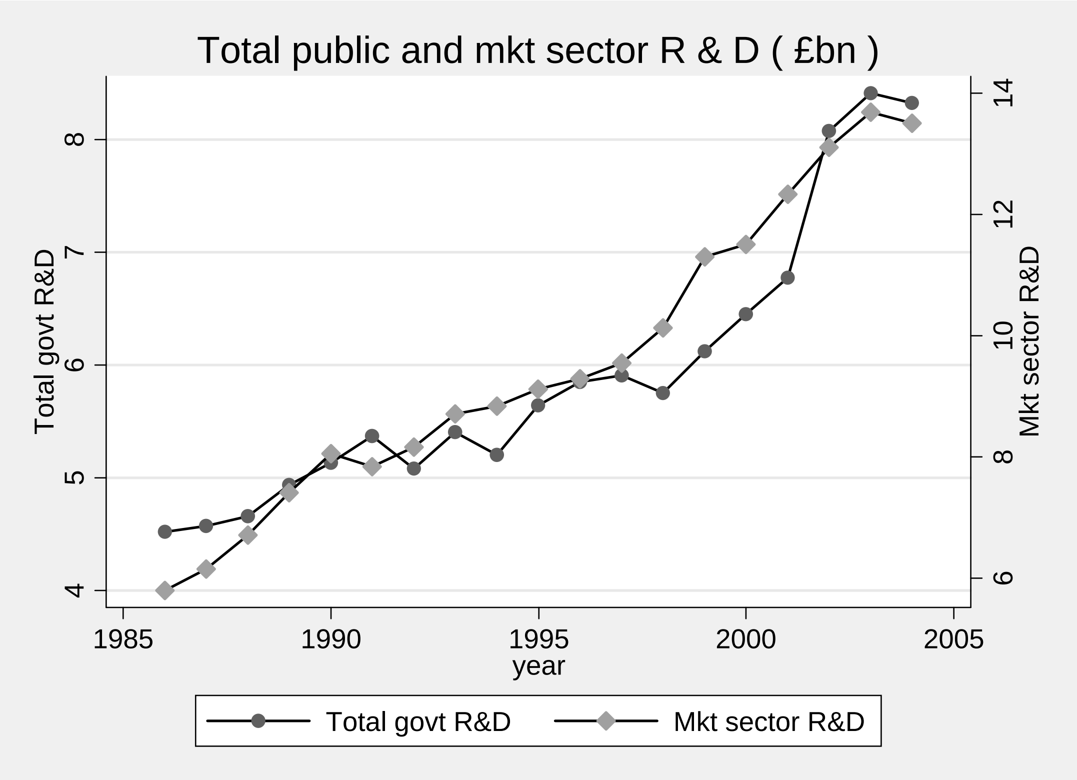
Notes: CCLRC is Council for the Central Laboratory of the Research Councils. The data for OSI-DTI are as follows: OSI expenditure is mostly in support of the Royal Society and the Royal Academy of Engineering, which before 1992-93 had been included in DFE (now DES), and includes over the CSR, SR2000 and SR2002 plan periods the funds for Joint Infrastructure Fund, Science Research Investment Fund, CCLRC for Diamond, OSI Initiatives, Foresight LINK Awards and other science programmes not yet allocated to the Research Councils. Arts and Humanities Research Council (AHRC): Biotechnology and Biological Sciences Research Council (BBSRC): Council for the Central Laboratory of the Research Councils (CCLRC): Engineering and Physical Sciences Research Council (EPSRC): Economic and Social Research Council (ESRC): Medical Research Council (MRC): Natural Environment Research Council (Nerc); Particle Physics and Astronomy Research Council (PPARC).

We turn now to civil and defence R&D spending. The provided data (not shown here for space) reveals that in 2005/06, over 36 per cent of total civil and defence R&D spending went to the Department of Health (DH) (of which most is the National Health Service), over 15 per cent to DFID and just under 12 per cent to DEFRA. How might that affect our results? The majority of health sector output is non-market sector and that bit that is part of the market sector is thought to be poorly measured. Output of agriculture is in our data, but as land is not measured in the UK National Accounts as a productive factor TFP growth is likely poorly estimated in our data for agriculture. We can assume that most DFID spending goes abroad. Thus around 63 per cent of civil spending likely goes to sectors that are not directly measured in our data.

2.3. Some simple analysis: the relation between private and public R&D

Figure 3 shows the relation between private R&D and public R&D spend, which appears to be positive. This appears to support the findings in David, Hall and Toole (2000), who tentatively conclude that public R&D is a complement to private sector R&D rather than a substitute, see also Salter et al (2000).

FIGURE 3
PRIVATE AND PUBLIC R&D SPEND



Source: BIS, SET statistics, Table 3.1 and Business Enterprise R&D survey (BERD).

2.4. Some simple analysis: the relation between public R&D and market sector TFP growth

Figure 4 sets out the relation between research council spend (as a proportion of GDP) and TFP growth (where TFP growth is smoothed by a three year centred moving average). As the picture shows, research council spend rose in the late 1980s and early 1990s, fell in the mid 1990s and then rose strongly from the late 1990s onwards. TFP growth rose in the early 1990s, fell back in the mid 1990s, rose again until 2004 before slowing down in the last few years of our sample. It is interesting to note the turning points of the relationship. The initial rise in spend was in 1988, and the rise in TFP growth was in 1990. The fall in spend was then in 1993 and the fall in TFP growth in 1994. Finally the rise in spend was in 1999 and the rise in TFP growth was in 2000. A cross plot is shown in Figure 5.

FIGURE 4
MARKET SECTOR TFP GROWTH AND RESEARCH COUNCIL SPENDING

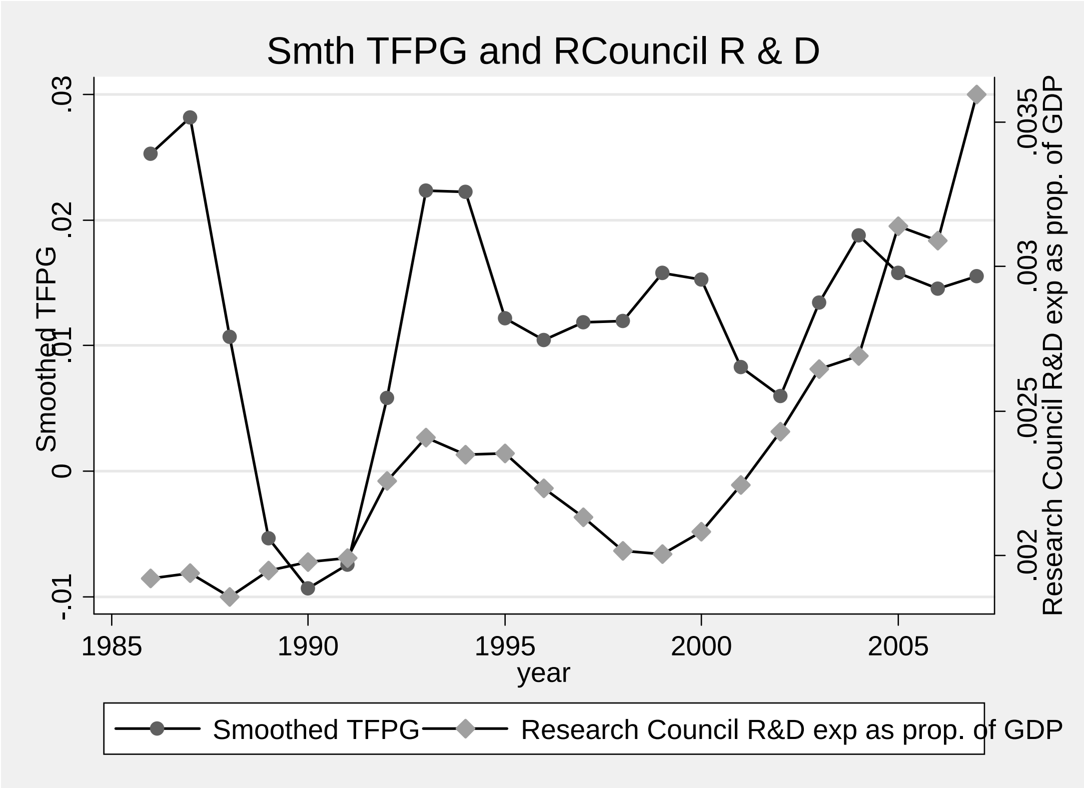
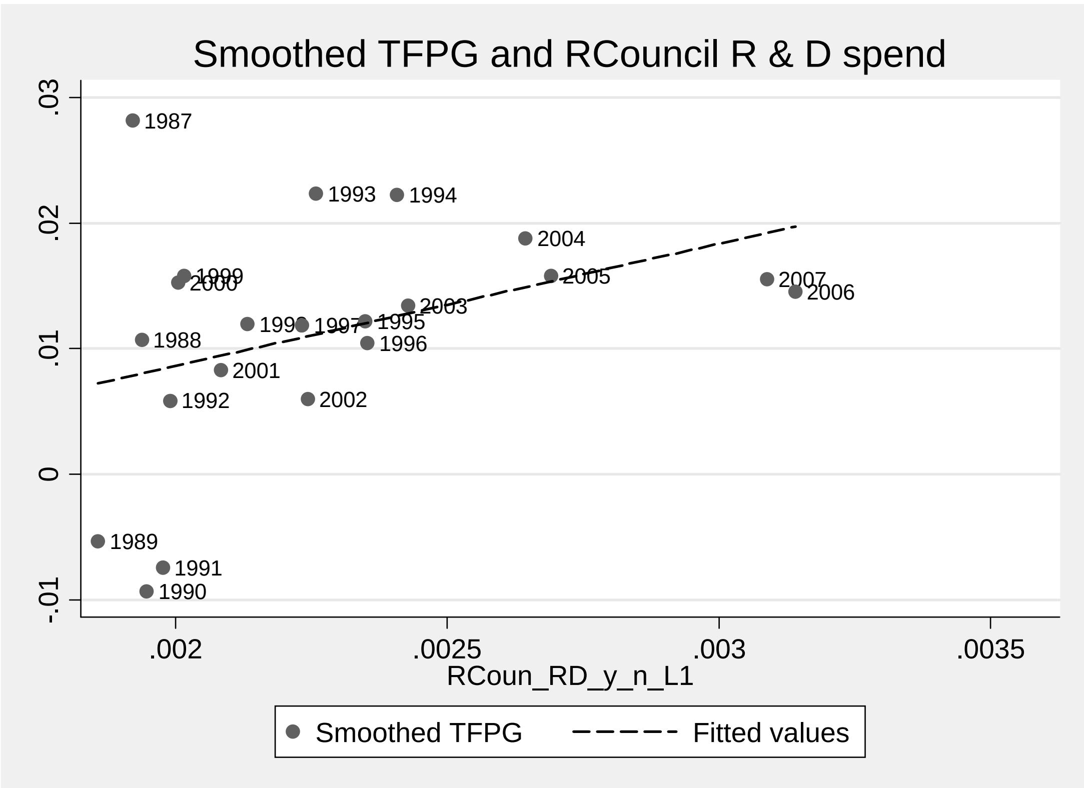


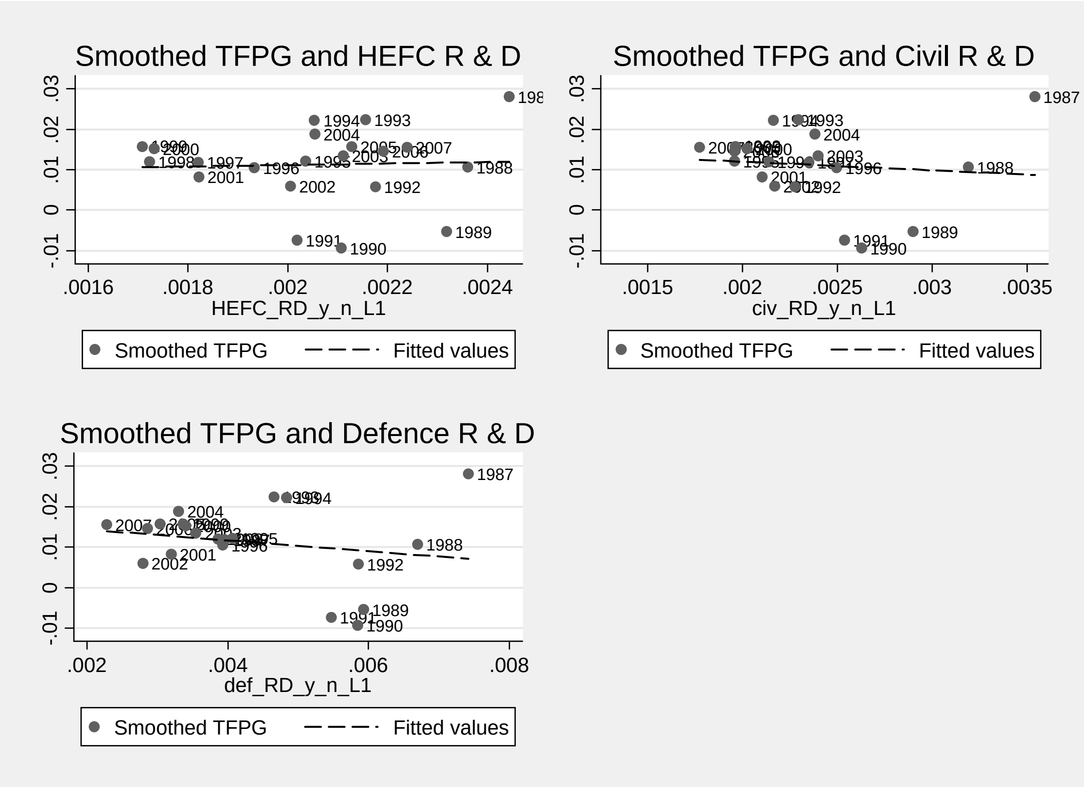
FIGURE 5
SMOOTHED MARKET SECTOR TFP GROWTH AND RESEARCH COUNCIL SPENDING



Notes: spending is as a proportion of market sector value added, lagged one year..

Figure 5 includes a simple fitted value line. This shows an upward sloping relationship between research council spending and TFP growth. This is the correlation that we investigate more formally below. There are of course a number of issues that we shall have to explore such as other factors, reverse causation etc. but before doing this we show the other data by showing the cross plots with the other spending categories, HEFC, civil and defence R&D. As can be seen from Figure 6 the relationship is much less clear and for civil and defence R&D the line of best fit is actually slightly downwards sloping.

FIGURE 6
SMOOTHED MARKET SECTOR TFP GROWTH AND PUBLIC R&D



Notes: spending is as a proportion of market sector value added, lagged one year.

3. MODEL

3.1. Model

Consider the following model;

$$Y_t = A_t F(L_t, K_t, N_t^{PRIV}, N_t^{PUB}) \tag{1}$$

where Y_t , L_t and K_t are output, labour input and tangible capital input respectively. N_t^{PRIV} is intangible capital. N_t^{PUB} is freely available public R&D, so it has an output elasticity but cannot be seen in factor prices. It might include knowledge elsewhere in the world. A_t is any increase in output not accounted for by the increase in the factors of production (in this case labour, tangible capital, intangible capital and the stock of public R&D).

Denoting ε as an output elasticity we can write, for, say a translog form of (1)

$$\Delta \ln Y_t = \Delta \ln A_t + \sum_{X=L,K,N^{PRIV}} \varepsilon_X \Delta \ln X + \varepsilon_{N^{PUB}} \Delta \ln N_t^{PUB} \tag{2}$$

where X denotes the first three inputs in F in (1). To convert this into something estimable we then make the following assumptions. First,

$$\Delta \ln A_t = a_o + v_t \tag{3}$$

where v is an iid error. Second, we assume the ε terms are factor shares plus a term to account for either deviations from perfect competition or spillovers due to that factor

$$\varepsilon_X = s_X + d_X \ \forall X \tag{4}$$

where s_X is the share in Y of spending on factor X. Third, observed TFP growth is defined as

$$\Delta \ln TFP_t \equiv \Delta \ln Y_t - \sum_{X=L,K,N^{PRIV}} s_X \Delta \ln X \tag{5}$$

Fourth, turning to the $\varepsilon_{NPUB}\Delta\ln N^{PUB}$ term in (2). Consider ε_{NPUB}. If public knowledge is freely available, $\varepsilon_{NPUB}>0$, but cannot be seen in factor share. Thus we must determine it econometrically in this framework or by case studies. Our main assumption is that $\Delta \ln N^{PUB}$ is driven by public sector R&D i.e. knowledge made publicly available by the public sector. At a zero depreciation rate of such knowledge it is standard to write $\varepsilon\Delta \ln N^{PUB} = \alpha(R^{PUB}/Y)_{t-1}$ where α is the rate of return on such knowledge spend, R^{PUB} public sector spending on R&D, Y is GDP and it is conventional to lag this ratio. In addition, $\Delta \ln N^{PUB}$ might include knowledge elsewhere in the world, knowledge on the internet etc, all of which we capture in Z. Thus we write

$$\varepsilon_{N^{PUB}} \Delta \ln N_t^{PUB} = \alpha_1 \left(\frac{R^{PUB}}{Y} \right)_{t-1} + \alpha_2 Z_t \tag{6}$$

All this gives us

$$\Delta \ln TFP_t = \alpha_1 \left(\frac{R^{PUB}}{Y} \right)_{t-1} + \alpha_2 Z_t + \sum_{X=L,K,N^{PRIV}} d_X \Delta \ln X + v_t \tag{7}$$

Which has the following intuition. Measured TFP growth will be driven by freely available knowledge, summarised in the first two terms, the influence of spillovers or departures from perfect competition, in the penultimate term, plus any residual mismeasurement captured here by v_t. With a limited number of observations our central empirical exercise is to test for spillovers and network effects from intangible capital and then to look for market sector productivity benefits from the public stock of knowledge.

It is worth noting the different interpretations of the right hand side depending whether $\Delta \ln TFP$ includes intangibles or not. To interpret d_X as excess returns requires computing $\Delta \ln TFP$ with intangibles. To the best of our knowledge this has not been done. Much of the literature on R&D excludes capitalised R&D from $\Delta \ln TFP$, in which case $d_{R\&D}$ is of course both the private and social returns to R&D, as that literature notes.

3.2. Measurement issues

We talked about measurement of public R&D above. Here note that we have measured TFP growth and output (Y) in a way consistent with the inclusion of privately generated knowledge in the production function. i.e. adjustment of the National Accounts and full growth accounting. Most past macro studies do not capitalise R&D into output. Some deal with the issue by subtracting R&D personnel from the employment data and implicitly do not adjust output by only considering the non-knowledge part of output (although in principal one should also adjust capital used in R&D as well).

In practice, this mostly means that a regression of non-output adjusted TFP growth on R&D will estimate both private and social returns.

This approach uses lagged R^{PUB} /Y as a regressor. Guellec and von Pottelsburgh (2001) instead use log changes in the stock of public knowledge, which is equivalent if such public knowledge does not depreciate. The problem with the stock approach is that one has to specify both a depreciation rates and a starting value. Thus we stick to the flow approach for public knowledge here. We report experiments with longer lags in case it is felt that knowledge takes time to disseminate.

We clearly have to capture the different parts of R^{PUB} and the elements of Z above. To do this we have data on R^{PUB} split into research councils, HEFCE, civil and defence and we shall examine these together and separately. We also control for other Z factors by measuring the fraction of the population on the internet and the fraction on broadband, the gap between the US (the frontier country) and the UK to represent possible learning opportunities and foreign spending on government R&D.

4. REGRESSION ANALYSIS/FINDINGS

4.1. Production spillovers and network effects from intangible investment

The table below sets out our estimates of spillovers from market sector intangible investment.

TABLE 3
SPILLOVERS FROM INTANGIBLE INVESTMENT
(Dependent variable: market sector ΔlnTFP, including intangibles, excluding intangibles and smoothed as indicated)

	(1)	(2)	(3)	(4)	(5)	(6)
	TFP growth including intangibles	TFP growth including intangibles	TFP growth including intangibles	TFP growth excluding intangibles	TFP growth excluding intangibles	TFP growth including intangibles
VARIABLES		smoothed	smoothed			
DlnH	0.31		0.28	0.079	0.088	1.52
	(1.99)		(2.90)	(0.38)	(0.39)	(2.22)
DlnK(tan)	-0.50	-0.31	-0.13			-0.36
	(-1.66)	(-1.24)	(-0.64)			(-1.46)
DlnK(soft)	-0.19	-0.073	-0.080			-0.030
	(-0.81)	(-0.43)	(-0.49)			(-0.16)
DlnK(ecom)	0.30	0.54	-0.14			0.038
	(0.62)	(1.51)	(-0.38)			(0.072)
DlnK(innovp)	0.33	-0.38				-0.19
	(0.33)	(-0.44)				(-0.27)
DlnK(innovp x RD)			-0.037			
			(-0.074)			
DlnK(R&D)			0.37	0.038		
			(0.75)	(0.13)		
R&D/Y (t-1)					0.65	
					(0.19)	
DlnL						-1.36
						(-1.71)
Observations	19	19	19	19	19	19
R-squared	0.336	0.246	0.432	0.017	0.019	0.489

Notes: t-values are in parentheses. DlnH is change in log hours worked. DlnK is change in log capital stock of, as indicated, tangibles, software, economic competencies (market sector R&D, design, product development in financial services), economics competencies excluding market sector R&D, market sector R&D, R&D/Y where Y is output including capitalised software and DlnL is change in log labour quality.

Column 1 simply regresses (unsmoothed) Δln*TFP* including intangibles on hours (as a cyclical control) and a split of the inputs into, respectively, tangible capital, then intangible capital, split into software, economic competencies, and innovative property. None of these ΔlnN terms are remotely significant. Column 2 uses smoothed TFP growth (including intangibles) with similar findings. Column 3 breaks out innovative property into scientific R&D and the rest of innovative property. The purpose of this is to see if there is any evidence that the inclusion of R&D in the innovative property term in column 1 obscures possible spillovers from R&D. Again no significant effect. Columns 4 and 5 explore this further with just including the change in the R&D stock and then the (lagged) R&D to output ratio, again neither are significant. Column 6 is the same as column 1 but also includes a labour quality term (that is, the change in hours for occupation/age/gender cells weighted by their wage bill shares). The results do not change significantly.

To check robustness, we also estimated the same equations using further lags of intangible capital stocks (up to 4 lags). Once again we find no significant effects. We also tried instrumental variable (IV) estimation with (1) lagged capital as instruments and (2) US intangible capital data as instruments. The usual overidentifying restrictions tests holds and our main result of no significant spillover effects holds.

What is the interpretation of these results? They suggest no tangible or intangible spillovers from private sector investment at the market sector level. For the tangible and software intangible category, this is in line with results for the US in Stiroh (2002). For the non-R&D intangible categories, these are, to the best of our knowledge, new results. For the R&D intangible category the following is worth noting. First, since R&D is capitalised the private returns are not included in TFP growth. Thus our results do suggest private returns to private sector R&D (around 20 per cent), but no significant social returns.

Our results in columns 1 to 4 differ from other macro level studies. Past literature, such as Guellec and van Pottelsberge (2001), regress traditionally measured TFP growth on R&D. In standard National Accounts aggregates R&D will not have been treated as an asset and so will also not have an associated capital income flow. This means that the relation between R&D and traditionally measured TFP growth will capture both the private return and any spillovers, if they exist. In order to identify spillovers it is necessary to ensure that the private return to R&D is not captured in TFP growth. To do this requires a recalculation of National Accounts aggregates treating R&D as an asset. The data we use does exactly that.

Second, in column 4 and 5 we get closer to previous studies by regressing $\Delta \ln TFP$ without capitalising R&D on R&D. We obtain a positive coefficient, suggesting a private and social return of 65 per cent (column 5), but nothing of statistical significance, suggesting no statistically significant net spillovers from private R&D to the private sector. Our data suggested a private return to R&D of 20 per cent.

The following points are worth noting. First, 85 per cent of private sector R&D is concentrated in manufacturing, which is itself now only 12 per cent of value added. Thus with manufacturing shrinking, it may be extremely hard to find spillover effects from market sector data (note that intangible spending is much more dispersed in manufacturing and services so this argument does not apply). Second, as mentioned above in the public civil spending area, much of the private sector

R&D is in defence and pharmaceuticals, which are hard to measure sectors. Third, and related many of the results on spillovers use industry level data and our economy-wide data may be too crude to capture these effects. All the studies cited in Jones and Williams (2002), for example are industry level, namely Griliches and Lichtenberg (1984b), Terleckyj (1980), Scherer (1982) Griliches (1994) and Sveikauskas (1981). Indeed, in Cameron's (1996) survey of 60 studies of the rate of return to R&D, only one (Grilliches, 1973) is at the total economy level. Indeed the only major recent aggregate study we are aware of is Guellec and van Pottelsberge (2001) but their data runs 1980-98 and covers countries with larger manufacturing sectors.[9]

Finally, note that O'Mahony and Vecchi (2009), who estimate spillover effects from R&D, human capital (skills) and brand equity (advertising) for a large panel of companies across the OECD, find evidence of spillovers from R&D and human capital for R&D intensive sectors but only from human capital for non-R&D companies. When they spilt the sample into manufacturing and non-manufacturing they find evidence of spillovers from R&D and human capital for manufacturing firms but no evidence of spillovers for non-manufacturing firms. They also find no evidence of spillovers among the European countries (UK, Germany, France).

[9] Specifically, Guellec and van Pottelsburgh (2004), using macro data for OECD economies do find a significant effect of R&D/Y on TFP growth pooling across all countries, 1981-98. However, using their data set provided with the paper a regression just for the UK of TFP growth on business R&D/Y (and Δlog employment) returns a coefficient of 2.11 (t=0.85). So our results are consistent with this.

4.2. Spillovers from public R&D

We next consider spillovers from public sector R&D.

TABLE 4
SPILLOVERS FROM PUBLIC R&D
(Dependent variable, market sector TFP growth)

VARIABLES	(1) TFP growth including intangibles	(2) TFP growth including intangibles	(3) TFP growth including intangibles	(4) TFP growth including intangibles	(5) TFP growth including intangibles	(6) TFP growth including intangibles
(Res+HEF+Civ+Def)/Y (t-1)	-1.82 (-1.09)					
Res Coun R&D/Y (t-1)		30.1 (3.38)	35.4 (4.00)	23.6 (3.06)		
HEFC/Y (t-1)		9.66 (0.68)				
Civil/Y (t-1)		-3.99 (-0.38)				
Defence/Y (t-1)		-1.41 (-0.45)				
ln(ALP_US/ALP_UK)				-0.42 (-2.18)		
Foreign Govt R&D/Y				0.14 (1.93)		
Dinternet				0.00036 (0.79)		
Res Coun R&D/Y (t-2)					33.6 (2.77)	
Res Coun R&D/Y (t-3)						24.4 (1.82)
Observations	17	17	17	17	17	16
R-squared	0.083	0.496	0.479	0.709	0.333	0.159

Notes: t-values are in parentheses. Variables are R&D spending by Research Councils, HEFCE (that part of university support that is apportioned to research in universities), Civil and Defence. Foreign Govt is the Publicly funded R&D/Y ratio in the non-UK G7 countries, weighted by PPP incomes per head. Ln(ALP_US/ALP_UK) is the log of labour productivity in the US relative to the UK, from OECD. Dintenet is the change in the share of UK households connected to the internet. TFP growth is smoothed, using TFP data that includes private spending on intangibles, from Giorgio Marrano, Haskel and Wallis (2009). The subscripts t-1, t-2 and t-3 indicate lags of one, two and three years. Years are 1988-2004, except last column which is 1989-2004, since the research councils data starts in 1986.

As we have seen, public sector R&D is broken into a number of categories. In column 1 we regress TFP growth on the sum of all categories and find no statistically significant effect. Column 2 enters the breakdown: research council, HEFCE, civil and defence. Even though they are rather collinear, there is no significant effect from the HEFCE, Civil of Defence. Column 3 shows the results of regressing TFP growth on research council spending alone. The estimated coefficient is very high, suggesting a very large spillover from this spending to market sector TFP growth and the coefficient is significant.[10]

Column 4 then adds in other Z variables that might help explain TFP growth. They are, respectively, productivity levels of US relative to the UK, on the basis that gap with leader shows potentially knowledge stock to obtain, foreign government R&D/GDP weighted by relative GDP. Dinternet is change in fraction of consumers with an internet connection, which grew very sharply over the late 1990s. When adding these additional explanatory variables the effect of research council spending remains.[11]

Finally we were concerned that the impact of research council spending might take longer then one year and so columns 5 and 6 present estimates with research council spending lagged by two and three periods. As can be seen our results are robust to increasing the number of lags. .

We carried out a number of other checks. First, we also added all the DlnK terms in table 3 to column 3 of table 4, but the none of them were significant. Second, we added to DlnK(R&D), the stock of market sector R&D and market sector R&D/Y (lagged) but neither were significant, whereas the Research Council/Y(t-1) term remained so. Third, we experimented with the proportion of households on broadband and different measures of the international gap, such as relative TFP, but the Research Council/Y(t-1) term remained significant. Fourth, we experimented with different TFP growth measures, unsmoothed and the EUKLEMS market sector TFP growth measure from the EUKLEMS data, but, again this did not affect the significance of the Research Council/Y(t-1) term.

One might of course worry about reverse causation in the above results. We have no natural experiment in our data, although it would hard to devise one: the experiment of variation in support across different geographical areas for example, does not work here since knowledge flows across borders. Our lagged results are, we believe of note. It is of course possible that reverse causation is at work, namely that increased private sector TFP growth endogenously caused government to raise public sector TFP growth, but with our lags of two and three years, it would have to be that the anticipation of increased TFP growth in two or three years time would have to raise TFP growth now.

Finally, we wanted to investigate further the high estimated marginal effect of Research Council/Y(t-1). A natural hypothesis is that this marginal effect is large since funding was comparatively low over most of the period. The most natural way to examine this is to include the most recent years since 2004 since this is the very large rise in spending (see Figure 2). To do this we

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[10] Individual regressions of the other components of public R&D gives similar results to column 2. That is, other components of public R&D spending, entered separately, are not found to have a significant effect on market sector TFP growth.

[11] We also tried, without affecting the sign or statistical significance of the research council coefficient terms for unions (coverage and density), adding non-linear effects of research council spend and public capital stock (buildings, transport). We then broke the research council term into those parts consistently available, that is spend by the MRC, SERC/EPSRC and ESRC, but these were too collinear to obtain any well specified results.

have had to update our TFP growth calculations which we have done in Haskel et al (2009) (note that the latest revision by the ONS of calculating financial services, a volatile and important sector, makes the updating a large task). The results are set out in Table 5

TABLE 5
MARGINAL EFFECTS OF RESEARCH COUNCIL SPENDING
(Dependent variable, market sector TFP growth)

VARIABLES	(1) TFP growth including intangibles 1988-2004	(2) TFP growth including intangibles 1988-2005	(3) TFP growth including intangibles 1988-2006	(4) TFP growth including intangibles 1988-2007
Res Coun R&D/Y (t-1)	27.2	23.3	15.0	12.7
	(3.36)	(3.28)	(2.33)	(2.63)
Observations	17	18	19	20
R-squared	0.398	0.382	0.284	0.272

Which presents estimates of the spillover effect from research council spending for 4 different time periods. Column 1 uses the original time period, but using the new TFP data to 2007. We obtain a similar significant result, but with a somewhat smaller coefficient. The main point however is shown in row 1: as we extend the time period during which Research council spending is very rapidly expanding, the marginal effect falls, being 12.7 when including the most recent period.

4.3. Discussion of results

First, given current pressure on public finances there is clearly a need to focus Government support for innovation in areas where the impact is likely to be largest. We believe our findings point in a specific direction for Government innovation support. Our results tentatively suggest that government innovation policy should focus on direct spending on innovation, specifically funding for research councils, rather than through tax incentives to firms.

Second, we do find a high rate of return on research council spending, although diminishing strongly, consistent with the idea that for much of the period public support for this research has been comparatively low. It is worth noting that the UK science base is also usually found to be world class (see e.g. Bruneel, D’Eeste, Neely and Salter, 2009) in a number of dimensions, and given that the research supported by research councils is freely available and likely to be basic science, the spillover effects should be very high. Note that private R&D is reported from the BERD to be around 33 per cent basic and 66 per cent applied, and one might expect few spillovers from applied work, that is, putting a particular idea into productive form. There is some support for high university spillovers;

Guellec and van Pottelsberge (2004) find a positive impact of public sector R&D (measured by R&D performed in government labs and universities) on market sector TFP growth. They also find that this impact is positively affected by the share of universities (contrary to government labs) in research and negatively affected by the share of defence in public R&D budgets.

Third, turning to Civil and Defence R&D, as discussed above, the lack of spillover effects here could reflect a true lack of spillovers, due e.g. to secrecy in defence R&D, or could be a result of measurement problems, such as mismeasurement of health output or defence being too small to pick up in our market sector data. In addition, social reasons for investing in defence are likely not well picked up by market sector output per person. All this suggests that more forensic work is required to better understand just what such R&D data consists of and what projects it is likely spent on.

Finally, consider our findings of no spillovers from market sector intangible investment. The existing literature on such spillovers has only looked at R&D (on which there is a large literature) and on spillovers from software (e.g. Stiroh, 2002, who looks for spillovers from hardware and software combined). Stiroh (2002) finds no spillovers from software. The aggregate studies on R&D typically find no effect, although the disaggregated studies do find such an effect. Our aggregate finding does not imply that there are not spillover effects at the industry or firm level but that these do not appear to be significant in a macroeconomic sense. This has implications for measures such as the R&D tax credit. Firstly, our results suggest that the R&D tax credit should not be expanded to cover a broader range of intangible assets. Secondly, our results suggest that although the R&D tax credit is likely to have a beneficial impact on specific sectors of the economy, due to the industry level spillovers evident in past literature, there appears to be no evidence of market sector level spillovers. For the UK this is likely to be due to the small size of R&D intensive sectors, concentrated in manufacturing, relative to the entire market sector.

5. CONCLUSION

Using a dataset on market sector productivity, intangible assets and public sector R&D this paper looks for evidence on spillovers from intangible investment and market sector productivity benefits from public R&D. The empirical results suggest no evidence of spillover effects from intangible investment at the market sector level, including R&D. The result for R&D differs from much of the past literature but the majority of that literature focuses on industry or firm level spillovers rather that market sector level. We argue that our finding is more robust than those macroeconomic studies that do exist because we fully re-estimate National Accounts aggregate to take account of the treatment of R&D as a capital asset, thus fully removing from measured TFP private returns to capital.[12]

We find strong evidence of market sector productivity benefits from public spending on research councils with a very high, but diminishing, estimated rate of return. We find no evidence of market sector spillovers from public spending on civil or defence R&D

Taken together these findings tentatively suggest that in a world of constrained fiscal spending government innovation policy should focus on direct spending on innovation, specifically research councils, rather than through tax incentives, such as the R&D tax credit, to firms.[13]

These findings are of course based on a relatively small number of observations. Future work could of course use better data and better measures e.g. of health output in evaluating publicly financed health R&D. But given the paucity of evidence on such an important question, we think the findings here are worth reporting and will hopefully spur more work and better data.

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[12] Although our findings are of course subject to the usual criticisms of data etc. In this case, our data is eerily reminiscent of Griliches (1979) discussion of the difficulties of using time series data to examine the contribution of NASA R&D to the US economy "…we are faced with the fact that at the aggregate level we have only one cycle to work with: a rapid and continuous rise in NASA's R&D expenditures to the mid-1960s and then a more or less continuous decline to the mid-1970s." Our research council data consist of a rise in the early 1990s, a decline in the mid 1990s and a sharp rise again.

[13] Finally, in the 2009 Pre-Budget Report, £600m of cuts were announced to higher education, from which we should be able to use our coefficients to work out the impact on private sector growth. At time of writing, there is no information currently on the impact on research councils. The most detailed information is on how £449 million of cuts will be made to HEFCE in 2010-11, and that such cuts will mainly fall on capital spend and teaching.

REFERENCES

Bruneel, J, Pablo D'Este, Andy Neely and Ammon Salter, (2009), "The Search for Talent and Technology", www.aimresearch.org/index.php?page=the-search-for-talent-and-technology.

Corrado, C., Hulten, C. and Sichel, D. (2005) 'Measuring Capital and Technology: A Expanded Framework,' in C. Corrado, J. Haltiwanger, and D. Sichel (eds), Measuring Capital in the New Economy, National Bureau of Economic Research Studies in Income and Wealth, Vol. 65, 11-45, The University of Chicago Press, 2005.

Corrado, C., Hulten, C. and Sichel, D. (2006). 'Intangible Capital and Economic Growth,' NBER Working Paper, No. 11948.

David, P. A., Hall, B. H. and Toole, A. A. (2000). 'Is public R&D a complement or substitute for private R&D? A review of the econometric evidence', Research Policy, Vol. 29, 497-529.

Geroski, P. A. (1995). 'Do spillovers undermine the incentive to innovate?', in Dowrick S. (ed.), Economic Approaches to Innovation, Edwar Elgar, Aldershot, pp. 76-97.

Giorgio Marrano, M. and Haskel, J. (2006) 'How Much Does the UK Invest in Intangible Assets?' CEPR Discussion Paper, No. 6287.

Giorgio Marrano, M., Haskel, J. and Wallis, G. (2009). 'What Happened to the Knowledge Economy? ICT, Intangible Investment and Britain's Productivity Record Revisited,' Review of Income and Wealth, 55, 3, 686-716.

Griliches, Z. (1979). 'Issues in assessing the contribution of research and development to productivity growth', Bell Journal of Economics, Vol. 10, pp. 92-116.

Griliches, Z. (1992). 'The search for R&D spillovers', Scandinavian Journal of Economics, Vol. 94, pp. 29-48.

Guellec, D. and Van Pottelsberghe de la Potterie, B. (2001). 'The internationalisation of technology analysed with patent data', Research Policy, Vol. 30, pp. 1256-1266.

Guellec, D. and Van Pottelsberge, B. (2002). 'R&D and Productivity Growth: Panel Data Analysis of 16 OCED Countries,' OECD Economic Studies, 33, 103-126.

Guellec, D. and Van Pottelsberghe de la Potterie, B. (2003). 'The impact of public R&D expenditure on business R&D', Economics of Innovation and New Technologies, Vol. 12, pp. 225-244.

Guellec, D. and Van Pottelsberghe de la Potterie, B. (2004). 'From R&D to Productivity Growth", Oxford Bulletin of Economics and Statistics, 66, 3, pp. 353-378.

Haskel, J., Clayton, T., Goodridge, P., Pesole, A. Barnett, D., Chamberlin, G. Jones, R. Khan, K. and Turvey, A. (2009). 'Innovation, knowledge spending and productivity growth in the UK', Interim report for NESTA Innovation Index project, www.nesta.org.uk/library/documents/growth-accounting.pdf

HEFCE (2010). *Securing World-Class Research in UK Universities*, www.hefce.ac.uk/research/funding/resfund/QR.pdf

HM Treasury (2004). *Science & innovation investment framework 2004-2014*, HMT, London, 2004.

Mansfield, E. (1998). ‘Academic research and industrial innovation: an update of empirical findings,’ Research Policy 26, 773–776

OECD (1993). *The Measurement of Scientific and Technological Activities: Standard Practice for Surveys of Research and Experimental Development – Frascati Manual 1993*, OECD, Paris.

O’Mahony, M. and Vecchi, M. (2009). ‘R&D, Knowledge Spillovers and Company Productivity Performance,’ Research Policy, 38, 35-44.

Park, W. (1995). ‘International R&D spillovers and OECD economic growth’, Economic Inquiry, Vol. 33, pp. 571-591.

Poole, E. and Bernard, J. T. (1992). ‘Defence innovation stock and total factor productivity growth’, Canadian Journal of Economics, Vol. 25, pp. 438-452.

Salter, A., D’Este, P., Pavitt, K., Scott, A., Martin, B., Geuna, A., Nighingale, P. and Patel, P. (2000) ‘Talent, Not Technology: The Impact of Publicly Funded Research on Innovation in the UK’ mimeo.

Salter, A, and Martin, B., (2001), “The Economic Benefits of Publically Funded Research: A Critical Review”, Research Policy, 30, pp. 509-532.

Scherer, F.M., 1982. Inter-industry technology flows in the United States. Research Policy 11, 227–246.

Stiroh, K. (2002). ‘Are ICT Spillovers Driving the New Economy?’ Review of Income and Wealth, 48, 1, 33-57.

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