What is the relationship between public and private investment in science, research and innovation?

A report commissioned by the Department for Business, Innovation and Skills

April 2015

Economic Insight

CONTENTS

1. Executive Summary

Drawing on a combination of existing literature, econometric analysis, and qualitative interviews, this report details our findings of the relationship between public and private investment in R&D.

The main implications of our findings are that:

(i) BIS may be understating the level of additionality that occurs from public funding of research. Our analysis suggests that an extra ***£1 of public funding will give rise to an increase in private funding of between £1.13 and £1.60***, whereas BIS currently use an estimate of £0.85.

(ii) ***Holding the science budget for resource spending constant in cash terms has given rise to an estimated additional £1.2bn of private sector investment*** that would not have occurred if the budget had been cut in line with other government departments.

(iii) Based on certain assumptions, we estimate that an extra ***£1 of public expenditure on HEI research leads to an additional £0.29 of private funding of HEI research and £1.07 of research conducted elsewhere***.

1.1. Context

We have been asked by the Department for Business, Innovation and Skills (BIS) to conduct a study into the relationship between public and private investment into science, research and innovation. The aims of this project are to categorise and measure the different types of leverage achieved in the UK and analyse the conditions under which leverage can be increased.

In order to meet the objectives of this project we identified three key questions to answer:

- ***What is the ratio of public to private investment in science, research and innovation?***
- ***How much private investment is caused by public investment?***
- ***What can be done to increase the amount of private sector investment?***

In order to arrive at the answers presented in this report we: conducted a literature review of over 40 theoretical, empirical and policy related papers; undertook econometric analysis of data from a variety of sources; and conducted interviews with 21 individuals involved with research that has received both public and private funding.

In this report we distinguish between two different measures of leverage:

- The ***private sector percentage*** is the proportion of total R&D expenditure that is funded by the private sector.
- ***Additionality*** is the amount of private sector funding that arises as a result of public sector funding, and that otherwise would not have occurred.

In referring to leverage, it is therefore important to clearly distinguish between the relative amount invested by the private sector, and the additional private sector investment that arises as a result of public investment.

1.2. Implications of findings

The main implications of our findings are as follows.

- BIS may be understating the level of additionality that occurs from public funding of research. Our analysis suggests that an extra ***£1 of public funding will give rise to an increase in private funding of between £1.13 and £1.60***. Whereas, we understand that BIS currently use an estimate of £0.85 – and may therefore be materially underestimating the effect of changes in public expenditure on R&D.
- ***Holding the science budget for resource spending constant in cash terms has given rise to an estimated additional £1.2bn*** of private sector investment that would not have occurred if the budget had been cut in line with other government departments.
- The results are consistent with the public investment in research conducted within HEIs giving rise to significant spillover effects outside of HEIs. We estimate that an extra ***£1 of public expenditure on HEI research leads to £0.29 of private funding of HEI research and £1.07 of research conducted elsewhere***.

1.3. Summary of findings

In relation to the three key research questions, our main findings are:

- At a national level the private sector percentage was 70% in 2012.[1] This is based on the definition of the public sector comprising of funding from the UK government, Research Councils, Higher Education Funding Councils and Higher Education. The private sector is defined as comprising funding from UK businesses, UK charities and overseas. The equivalent private sector percentage for research conducted within UK higher education institutions was 35% in 2012/13.[2]
- The results of our econometric analysis are ***consistent with a crowding-in effect*** of public expenditure on R&D. We estimate that a 1% increase in public expenditure on R&D will lead to between a 0.48% and 0.68% increase in private expenditure on R&D. This is equivalent to a £1 increase in public expenditure leading to a £1.13 to £1.60 increase in private expenditure – or a mid-point of £1.36.
- The overarching finding from the interviews we conducted is that the key factor determining the extent of leverage is the existence, longevity and quality of the personal relationships supporting the public and private sector collaborations. We make a number of suggestions regarding further research that might reveal opportunities for policy-led increases in leverage.

In the following sections we discuss our main findings with respect to the key research questions in more detail.

[1] *Source: EI analysis of ONS GERD data*

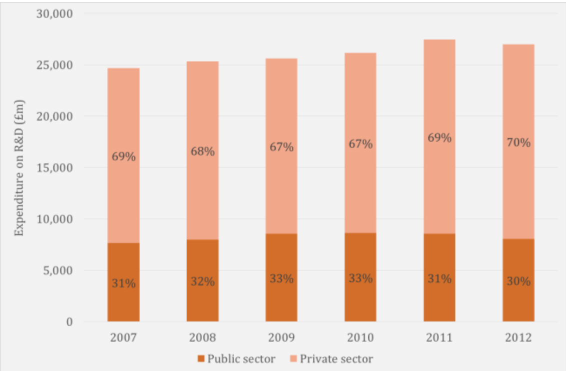
[2] *Source: EI analysis of HESA data*

1.3.1. What is the ratio of public to private investment?

As noted above, the proportion of all R&D conducted within the UK funded by the private sector – the private sector percentage – stood at 70% in 2012 (the latest available time period at the time of writing).[3] [4]

As shown in the following chart, the private sector percentage marginally increased in the period 2009 to 2012.

Figure 1. Private sector percentage at the UK national level over time

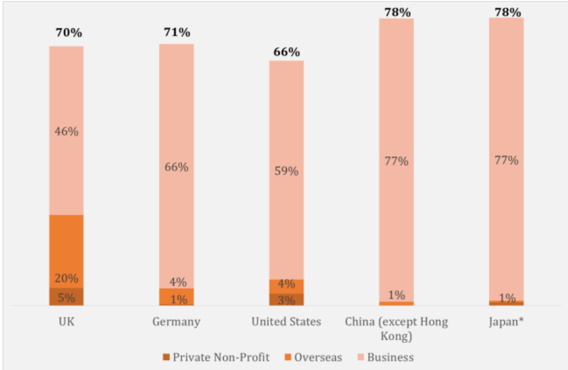


Source: EI analysis of ONS GERD data

We compare similarly to peer countries in relation to our private sector percentage. For example, the US's stood at 66% and Germany's at 71% in 2012.

A significantly higher proportion of the UK's R&D funding comes from overseas compared with peer countries. The chart below shows that 20% of R&D funding in the UK comes from abroad, whereas only 4% of the US's and Germany's comes from foreign sources.

Figure 2. Private sector percentage source comparison with peers (2012)

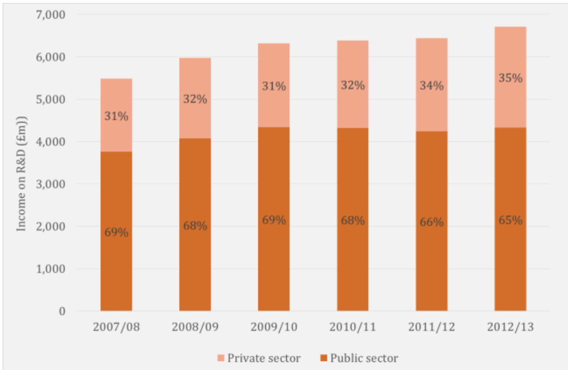


*Source: EI analysis of Eurostat data, *2011 figure where 2012 not available*

We also find that the private sector percentage differs considerably depending on where research is conducted. Research conducted within businesses and charities is primarily funded by the private sector, whereas research conducted with government, Research Councils and HEIs is predominantly funded by the public sector.

The private sector percentage for research conducted in HEIs was 35% in 2012/13. Similarly to the UK national level, the private sector percentage has increased steadily since 2009/10, as shown in the following chart.

Figure 3. Private sector percentage at the UK institutional (within HEIs) level over time



Source: EI analysis of HESA data

There are considerable differences between institutions. Within the top 20 HEIs with respect to total research income, the private sector percentage

3 *Note that since the completion of the analysis in this report, the ONS has published 2013 data. These data show that the public and private sector percentage remains unchanged from 2012 at 30% and 70% respectively. We would not, therefore, expect this new data to materially change the results of our analysis.*

4 *For clarity, 'private' includes expenditure by businesses, non-profit organisations (such as charities) and overseas (which includes some non-UK government expenditure).*

ranged from 58% (University of Oxford) to 39% (University of Warwick) in 2012/13.

Whilst the private sector percentage can tell us relatively how much funding is coming from the private sector, it does not tell us how private funding will change as a result of changes in public funding.

1.3.2. How much private investment is caused by public investment?

There are sound theoretical reasons why greater public investment could either increase or decrease private investment.

- Public funding of research could generate positive spillover effects that induce the private sector to spend more on R&D. For example, basic research funded by the public sector could lead the private sector to invest more in related applied research. Therefore, public expenditure would ***crowd-in*** private expenditure.
- On the other hand, public funding of research could ***crowd-out*** private investment. Public funding could simply be a substitute for private funding, or it could lower the rate of returns to private investment.

Previous empirical studies tend to find positive estimates of additionality i.e. public funding crowds-in private funding. There are however some examples of where evidence has been found that is consistent with crowding-out.

There are two main measures of additionality in the existing literature:

- The ***£ increase in private investment*** arising from a ***£1 increase in public investment***.
- The ***coefficient of additionality*** which measures the percentage increase in private investment arising from a 1% increase in public investment.

The academic literature tends to focus on the latter measure – partly because it is comparable across studies and not linked to a specific currency unit. A relatively broad range of additionality estimates arise from these past studies – typically ranging from 0 to 1. That is, a 1% increase in public expenditure gives rise to an increase in private expenditure of between 0% and 1%. As illustrated by the discussion below, a figure of below 1 can still imply a significant quantity of private investment in £ terms.

These past studies measure the effect of public expenditure in different cases and understandably give different results, although they are broadly consistent with a crowding-in effect. Some studies look at the totality of R&D, whilst others look at specific industries. Furthermore, they relate to a variety of countries, although many are from the US. Our own empirical analysis helps fill a research gap because it focuses on the UK and uses up-to-date data.

Our quantitative analysis is divided into two main categories, macro and micro analysis, as set out in the subsections below.

Macro analysis

Macro analysis looks at additionality at the national level and its main advantage is that it can capture all the spillover effects within the UK. Spillover effects of publicly funded research can occur solely within industry, and even within an industry that isn't obviously connected with the original field of research. Using data at the aggregate national level is a way to capture all of the possible spillover effects. One disadvantage of using national data, however, is that there is only a limited number of data points available and this could limit the robustness of our results.

- Our primary macro analysis uses ONS data and finds a coefficient of additionality of between 0.48 and 0.68 – giving a mid-point of 0.58. That is, a 1% increase in public expenditure leads to a 0.58% increase in private expenditure.
- At the 2012 funding levels of £8.1bn and £19.0bn from the public and private sectors respectively, this is equivalent to a ***£1 increase in public expenditure giving rise to a £1.36 increase in private expenditure***.[5] Using the range of coefficients of additionality above gives a range of £ effects of £1.13 to £1.60.
- We also conducted similar analysis using Eurostat data that covers 15 countries. This analysis is broadly consistent with that of the ONS data, and finds a coefficient of additionality of between 0.49 and 0.58.

In addition to exploring the relationship between total public and total private expenditure, we have also constructed disaggregated models in which we look at the effect of public expenditure on different types of private funding, and the effect of different types of public funding.

- We find evidence of R&D expenditure arising from businesses to be more sensitive to public expenditure than charity or overseas funding. Our analysis of ONS data suggests that business funding is the most sensitive, whereas the Eurostat analysis

[5] *A 1% increase in public funding is equal to (£8.1bn * 1%) £81m. A 0.58% increase in private funding is equal to (£19.0bn * 0.58%) £110m. Therefore a £1 increase in public funding is equivalent to a £1.36 increase in private funding (£110m / £8.1m)*

suggests that overseas funding is more sensitive. These different results could be due to differences in the way countries operate, or different ways of measuring R&D spend. Specifically, we know that the recording of charity spend is not consistent across countries.

- We also investigate whether additionality differs by the source of public funding, although the results are inconclusive. Our ONS analysis does not find a statistically significant difference between what is primarily the BIS budget and other government expenditure. Eurostat analysis finds evidence of government (including, for the UK, RCs and HEFCs) expenditure to be more effective at attracting private investment than HE expenditure. However differences between how countries finance HE might make these results less meaningful.

The results of our macro analysis imply that by holding the science budget for resource spending constant at £4.6bn, rather than decreasing it by 19% as was planned for other government departments, an additional £1.2bn of private investment has arisen.[6]

The macro analysis of ONS data in section 4.4 and Annex B of this report has been subject to two academic peer reviews. The reviewers suggested that we should undertake further robustness tests that were not reported in section 4.4 and Annex B (relating to the treatment of non-stationary variables, endogenous variables and lag structure). We undertook the tests – either as part of the original analysis or following the peer review process. We reported to BIS the results of the tests, which show that our analysis passes them and is robust.

Micro analysis

Our micro analysis utilises data from HESA, the Higher Education Business and Community Interaction (HEBCI) survey, and the Medical Research Council (MRC). The main advantage of using such datasets is that they allow us to analyse different parts of the R&D sector, and can provide insights as to how spillover effects manifest themselves.

A limiting factor of the micro analysis, however, is that it does not capture all of the spillover effects arising from public expenditure and as such measures a different effect compared to the macro analysis.

That is, our analysis of HESA data estimates the effect of increased public expenditure on research conducted in HEIs on private expenditure on research conducted in HEIs. It therefore does not take into consideration spillover effects that arise purely in the private sector.[7]

- In this context, we find a coefficient of additionality of between 0.25 and 0.81 – giving a mid-point of 0.53. That is, a 1% increase in public expenditure on research performed in HEIs leads to a 0.53% increase in private expenditure on research performed in HEIs.
- At the 2012/13 funding levels of £4.3bn and £2.4bn from the public and private sector respectively, this is equivalent to a ***£1 increase in public funding of research performed in HEIs giving rise to an increase in private funding of research performed in HEIs of £0.29***. Using the range of coefficients of additionality above gives a range of £ effects of £0.15 to £0.45.
- Our analysis also suggests that funding of research conducted in HEIs from overseas sources is more sensitive to public funding, compared to that from UK business or charities. This could suggest that further public funding aimed at facilitating overseas[8] investment would generate more private investment than funding aimed at UK businesses or charities. Notably, the UK already attracts a relatively high proportion of overseas investment.
- In an extension to the main HESA analysis, we investigate whether additionality differs by subject area. The analysis suggests that 'engineering & technology', and 'medicine, dentistry & health' have the highest levels of additionality. That is, these two areas are likely to see the greatest percentage increase in private funding if public funding is increased by 1%. However, results are sensitive to the exact specification used and we therefore cannot say with certainty the rank order of subjects in terms of additionality.

Our micro analysis also considers in-kind contributions and further funding.

- Analysis of further funding data from MRC reinforces our beliefs about how research projects are related and how spillover effects arise. Our analysis shows that a substantial proportion of research projects receive further funding to carry out new, but related, research. Furthermore, this further research can take many years to arise.
- Data from HEBCI suggests that in-kind contributions from public and private sources add an additional 2% to the value of HEIs' monetary

[6] *See section 4.10.1 for calculations.*

[7] *For clarity, this includes all public funding streams going to HEIs, not just quality-related (QR) funding.*

[8] *Overseas includes some funding by non-UK governments.*

research income. In-kind contributions would affect the estimated coefficients of additionality if:

- (a) the value of in-kind contributions are not already captured in the estimates of public and private expenditure; and
- (b) private in-kind contributions are more or less sensitive to public expenditure than private cash contributions.

» Based on the discussion in section 4.9.3 of this report, it is not clear cut whether the above conditions hold in practice. Therefore, there is not a strong basis in the data to adjust the above estimates of additionality upwards or downwards.

Comparison of results and implied spillovers

The table below compares the mid-points of the estimates of additionality from both our macro and micro analysis (i.e. the latter is the analysis of the HESA data).

Table 1. Results of macro and micro analysis (mid-points)

	Macro	Micro
Coefficient of additionality	0.58	0.53
£1 increase in public funding gives rise to an increase in private funding of...	£1.36	£0.29

When comparing the results of the macro and micro analysis is should be kept in mind that they are estimating different effects. The macro analysis estimates the effect of total public sector investment on total private sector investment. The main micro analysis estimates the effect of public funding of HEI-conducted research on private funding of HEI-conducted research.

Although the coefficient of additionality is similar across the two pieces, the £ effect is significantly different. An interpretation of the difference is that there are significant spillover effects not being captured by the micro analysis. That is, if an increase in public funding of research conducted within HEIs led to £1.36 in additional private funding in total (i.e. within HEIs and outside), this would imply that there would be (£1.36 - £0.29) £1.07 spillover effects arising outside of HEIs.[9]

Conclusions from quantitative analysis

Our own quantitative analysis is consistent with that of previous studies. Specifically, our analysis suggests that public funding of R&D crowds-in private investment. We understand that BIS typically uses the estimate of £1 of public funding giving rise to £0.85 of private funding. Our analysis is broadly consistent with this, and suggests that it may be conservative. There is an inherent degree of uncertainty within our estimates of additionality and this should be taken into consideration whenever assessing the impact of a policy change.

1.3.3. What can be done to increase the amount of private sector investment?

We conducted telephone and face-to-face interviews with 21 individuals involved in R&D from various research institutions, funding bodies and industry. In particular, we explored the factors that help (or hinder) leverage in practice.

The overarching message from the interviews, consistent with previous research in this area, is that the key factor determining the extent of leverage is the existence, longevity and quality of the personal relationships supporting the public and private sector collaborations. Many of the interviews focused on the conditions and circumstances leading to a successful collaboration including: (a) initiating and maintaining commercial relationships; and (b) agreeing commercial terms and conditions.

One could conclude from this that there is little a policy maker can do to increase the extent of leverage for a given level of public investment as it rests largely on factors outside of its control (i.e. the formation of personal relationships). Indeed, none of the interviewees suggested that a 'silver bullet' had been overlooked. However, although there may not be a 'silver bullet', our interviews point to various areas where further research might reveal opportunities for policy-led increases in leverage.

In particular, the questions raised by our interviews include:

» Whether anything can and should be done to increase the prevalence of strategic alliances?

» Whether REF has positively or negatively influenced individuals moving between industry and academia?

» What are the 'best' ways of recognising the research interests of different industry partners, in a multi-funding partner environment?

[9] *See section 4.10.4 for further discussion.*

- Is there a way of helping partners reach agreeable terms and conditions faster / more cost effectively?
- Are there ways of encouraging more SMEs into collaborative research in a way that would benefit the research?
- Is there a difference between the social and other sciences in terms of the opportunities to initiate collaborations?

1.4. Recommendations

Based on the research conducted for this report we make a number of recommendations and suggestions for further research. These recommendations include suggestions for how leverage could be better measured and monitored in future.

Specifically, as will become apparent in this report, leverage differs significantly across different parts of the R&D sector and is inherently difficult to estimate. The purpose for which leverage measurements are needed should therefore be carefully considered before any changes are made.

However, here we make a number of recommendations as to how leverage could be better measured and monitored.

- In relation to in-kind contributions, the ONS could adapt their BERD survey to include the measurement of expenditure by the firm on R&D that is conducted within HEIs. At present, externally funded research conducted within HEIs is reported by the HEIs. Including it within the BERD survey would provide another estimate of in-kind contributions.
- Whilst the HEBCI survey records in-kind contributions from non-academic partners, there is not a strict distinction between public and private funders of collaborative research. To give an estimate of the value of private in-kind contributions to research conducted within HEIs, such a distinction could be made in the data collection. Furthermore, additional guidance could be given in terms of how in-kind contributions should be valued in the HEBCI survey.
- We understand that the recording of RC funding, and particularly the outcomes of it, has changed significantly in the last several years with the use of the online system Researchfish. In order to conduct a more detailed analysis of the relationship between RC and private sector funding, and of further funding, this data collection should be continued to allow a more complete data set to build up for future analysis. Particularly, it may give insights as to the characteristics of awards that best attract further funding from the private sector.

1.5. Structure of this report

The remainder of this report contains the following sections.

- ***Analytical framework*** provides a definition of leverage, the theory of public and private investment in R&D, and a framework for considering different types of leverage.
- ***What is the ratio of public to private investment in R&D?*** – addresses our first research question through analysis of various datasets.
- ***How much private investment is caused by public investment?*** – estimates additionality using econometric approaches.
- ***What can be done to increase the amount of private sector investment?*** – gives the results of our qualitative interviews with individuals connected to research funded by both the public and private sectors.
- ***Recommendations and further research*** discusses how the findings of this report could be used and what further research may be worthwhile.
- ***Annexes*** contain a number of additional chapters with supporting evidence.

1.6. Acknowledgements

We are grateful for the time and openness of the individuals that participated in this study, including: officials at BIS; the 21 individuals involved with research that receives both public and private funding; and the excellent individuals who organised the meetings for us.

2. Analytical Framework

This section sets out the analytical framework that we have used throughout this project.

Specifically, this section:

(i) Identifies two key variables of relevance to leverage: the ***private sector percentage***; and the ***coefficient of additionality***.

(ii) Discusses the ***economic theory*** behind why private and public sector organisations invest in R&D and explains why the two are linked.

2.1. What is leverage?

For the purpose of this study we define leverage as a description of the relationship between the amount of private sector investment in R&D and the amount of public sector investment in R&D. We see two variables of relevance to leverage:

- The ***private sector percentage*** is the proportion of the total amount of expenditure on R&D that is funded by the private sector.
- ***Additionality*** is the amount of private sector funding that arises as a result of public sector funding, and that otherwise would not have occurred.

The private sector percentage is useful for understanding the relative size of funding from the two sectors. This may give an indication of the 'importance' of different sources, or give an indication of where additional private sector investment could be attracted to. Additionality, on the other hand, estimates how private funding will react to public funding and could be used for the purpose of policy design, impact assessments, or cost-benefit analyses.

It is important to set out specific definitions at this early stage because the language and metrics used by academic papers, researchers and policy makers differs. We therefore set out the definitions that we will use to ensure that we are making like-for-like comparisons, and the findings of this study can be properly compared to other research. We now discuss the two specific terms set out above in more detail.

2.1.1. Private sector percentage

The private sector percentage is simply an expression of the amount of private sector funding compared to the total. For example, if £100 of public sector funds are invested and £100 of private sector funds are invested, the private sector percentage is 50%. By definition, the private sector percentage must lie between 0% and 100%.

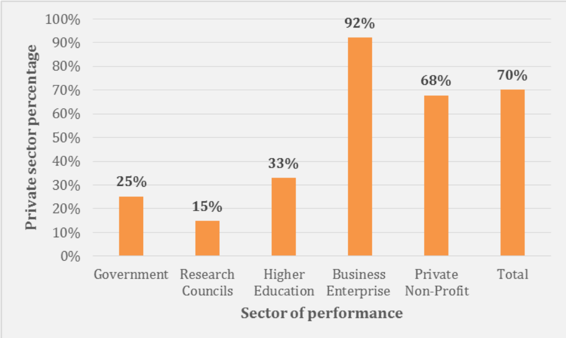
It is also possible to express the amount of private sector investment as a proportion of the amount invested by the public sector.

The private sector percentage can be calculated and expressed at a variety of different levels of aggregation. At a national level, the private sector percentage takes into account all investment in R&D. The gross expenditure on R&D (GERD) in the UK in 2012 was £27bn, of which £19bn was from the private sector[10] – this gives a private sector percentage of 70%.

Lower levels of aggregation include the institutional level, the scheme level (e.g. UKRPIF[11]), and the individual research project level.

The private sector percentage could also be specified for the area in which the research is performed. For example, research performed in private businesses is much more heavily funded by the private sector than the public sector. As is demonstrated by the following chart, 92% of research performed in businesses is funded by the private sector, whereas 33% of research performed in Higher Education is funded by the private sector.

Figure 4. Private sector percentage by sector of performance (2012)



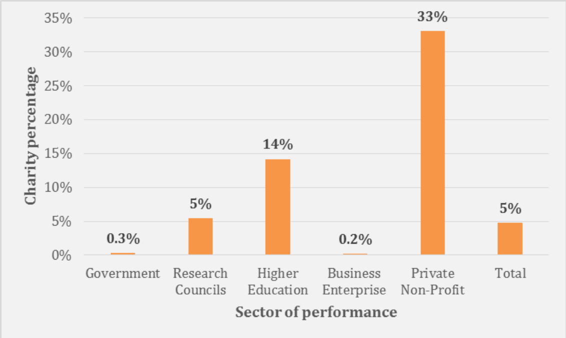
Source: EI analysis of ONS GERD data

Similarly, the percentage can also be computed by the source of private sector investment. For example, one may see a potential to increase the amount of investment from charities that UK R&D could receive, and as such a 'charity percentage' would be a metric of interest. Again, this could be calculated for different categories of where the research is performed. As shown in the following chart, 14% of research conducted in Higher Education is funded by charities, whereas only 0.2% of research in businesses is funded by charities.

10 Source: ONS GERD

11 *The UK Research Partnership Investment Fund (UKRPIF) is a HEFCE led initiative designed to support investment in higher education research facilities*

Figure 5. Charity percentage by sector of performance



Source: EI analysis of ONS GERD data

As is apparent from the charts above, the private sector percentage differs across cuts. Although it is not surprising that different areas of performance receive different amounts of private funding, such comparisons yield a number of questions, including:

- Why do some areas receive more private funding than others?
- Are some areas not taking full advantage of the private funding that they could receive?
- What characteristics are consistent with a high private sector percentage?
- What is driving the differences in percentages of, for example, charity funding?

These are some of the questions that we aim to answer with this study. In particular, one of the reasons that different areas of research receive different levels of private funding may be the level of public sector funding for that area. Furthermore, different types of public funding, such as QR funding or matched funding, may affect the level of private funding that is received.

2.1.2. Additionality

The private sector percentage relates to the level of private sector funding that was achieved. It does not, however, say anything about what would have happened if there was no public sector investment, or indeed what the ***effect of public sector funding is on private sector funding***. Our second variable of relevance to leverage, additionality, describes the causal relationship between public and private sector funding.

As set out in the Green Book[12], additionality should represent the 'net' effect. As such, additionality could be either positive or negative. That is:

- Public sector funding could 'crowd-out' private sector funding. This occurs when an increase in public funding, all else equal, results in a reduction in private sector funding. Public and private sector funding are in effect substitutes. If public and private investment are perfect substitutes, a £1 increase in public funding will lead to a £1 reduction in private funding.
- Public sector funding could 'crowd-in' private sector funding i.e. an increase in public funding, all else equal, increases the level of private sector funding i.e. they are complementary. If public and private funding are perfect complements there will be a one-for-one increase in private expenditure with a rise in public expenditure. If public and private funding are perfect complements, a £1 increase in public funding will lead to a £1 increase in private funding.

Additionality is likely to differ considerably across different levels of aggregation (e.g. national or HEI level) and different areas of research.

Furthermore, additionality may occur across different areas of research or different schemes. Public expenditure in, for example, mathematics could lead to new findings and techniques that could then be utilised in, say, computer science – and increased private funding in that area.

Relatedly, public funds may be used to invest in existing research areas, or used to create new areas of research – both of which can result in additionality. For example, EPSRC is investing in quantum technologies. This is a relatively new area of research that currently doesn't have much private investment, however in the future could represent a significant growth area for the private sector.

The effects of public sector investment could be thought of as 'direct' and 'indirect'. A direct effect at the project level could be that public funding is matched by private funding. The matched private funding will only be equal to additionality if that investment would not have occurred otherwise. If the private funding would have been used for another research project then it is not additional.

An indirect effect of public sector investment could be an increase of private funding for other similar projects – in essence a knock-on effect. Again, this private funding is only equal to additionality when it would not have been spent on research without the public investment.

As we discuss later, econometric regression techniques are used to estimate the level of

[12] *HMT's Green Book sets out how policy appraisal and evaluation should be carried out.*

additionality that is associated with public investment in R&D. This type of analysis can give rise to two different measures of additionality:

- The first measure gives the change in private expenditure given a £1 increase in public expenditure.
- The second measure gives the percentage change in private investment given a 1% increase in public expenditure. It is calculated from the regression coefficient on the public expenditure variable. A coefficient of 0.5 means that a 1% increase in public expenditure leads to a 0.5% increase in private expenditure. The coefficient of additionality is also referred to as the elasticity of private sector investment with respect to public sector investment.

An illustration of how these two measures and the private sector percentage relate is given in the section below.

2.1.3. Relationship between private sector percentage and additionality

There is a relationship between the private sector percentage and additionality. Where funding of a project is entirely additional (i.e. it otherwise would not have occurred) and there are no knock-on effects (such as additional funding of other projects), additionality and the private sector percentage will be equal. However, as will become apparent through the discussion of crowding-in and crowding-out, there are many reasons to think that additionality and the private sector percentage will not be the same.

When the coefficient of additionality is above 1 (a 1% increase in public expenditure increases private expenditure by more than 1%) increasing public expenditure will increase the private sector percentage. Whereas, if the coefficient of additionality is below 1 (a 1% increase in public expenditure increases private expenditure by less than 1%) increasing public expenditure will decrease the private sector percentage.

Table 2, at the bottom of this page, illustrates this relationship. The first row of the table is analogous to the current level of funding in the UK in that the private sector percentage is 70%. The second and third columns show an increase in public sector expenditure of 10% and potential effects this could have on private sector expenditure, and the associated measures of leverage.

This relationship is further summarised in the figure below, which assumes that no other factors have changed that would affect private expenditure.

Figure 6. Relationship between private sector percentage and additionality

Coefficient of additionality	Effect on £ amount of private investment	Effect on private sector percentage
<0	-	-
[0,1]	+	-
>1	+	+

As is demonstrated, it can be the case that public sector investment increases the £ value of private investment, but the private sector percentage falls. This occurs when the coefficient of additionality is between zero and one. In the context of trying to increase the level of private sector investment, this is a positive situation despite the fall in the private sector percentage.

2.1.4. Usage of leverage measurements

Measures of leverage, as presented above, can be used for a number of reasons. These can include:

- ***Demonstrating the overall impact of public funding.*** As we discuss later, there are theoretical reasons why public expenditure on R&D may increase or decrease the level of private expenditure on R&D. As such, to ensure the efficient allocation of public resources, measurements of leverage can be used as evidence as to whether 'crowding-in' or 'crowding-out' occurs.
- ***Estimating how the amount of private funding will change given a change in public funding.*** Closely related to the above, measures of leverage

Table 2. Illustration of measures of additionality

Public expenditure	Private expenditure	Coefficient of additionality	£ increase from £1 increase in public funding	Private sector percentage
£30	£70	-	-	70.0%
£33	£73	0.43	£1.00	68.9%
£33	£78	1.14	£2.67	70.3%

can be used to assess how the private sector would react to changing levels of public funding.

- ***Estimating the level of private funding that a scheme might attract.*** For planning purposes, it may be desirable to estimate how much private funding a particular scheme may attract.

The precise measure of leverage to use will depend very much on the purpose for which it is needed. Taking one of the examples from above, if one was estimating at a national level what the impact of increasing (or decreasing) public funding would be, a measure of additionality would be most appropriate. This is because it would give an estimate of private funding that would occur only as a result of the change in public funding. It would take account of all spillover effects, such as increased investment by firms unconnected to the original area of public research.

If one was estimating the level of private funding that a new public investment scheme would attract, a measure of the private sector percentage may be appropriate for this. This would only be the case if one was interested in solely establishing the amount of private sector funding that the scheme would receive, and not the spillover effects that would arise outside of the scheme. Using the private sector percentage would not take account of, for example:

- increased expenditure by private sector organisations that are not funding the scheme; and
- potentially reduced expenditure, on other research projects, by the private sector organisations that are funding the scheme i.e. substitution effects.

However, if one wanted to consider the 'net' increase in private sector funding as a result of a particular scheme, a measure of additionality would be more appropriate here as well. This would take account of the wider implications of public expenditure on private expenditure.

Any use of measurements of leverage should, to avoid confusion, be accompanied by a description of precisely what is being estimated (e.g. additionality or the level of private funds that will be attracted by the scheme) and how it is being estimated.

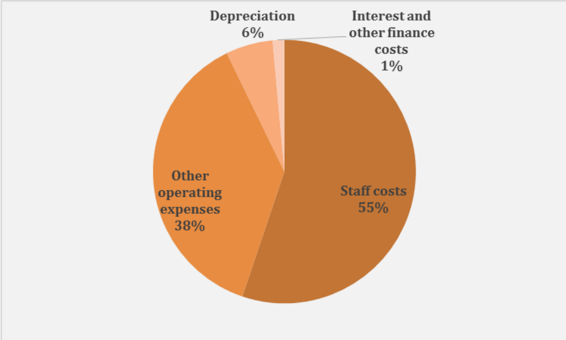
2.1.5. Definition of investment

Further to the definitions set out above, we also define what is meant by 'investment' in R&D. We classify all expenditure on R&D as an investment into future productivity. This includes both capital expenditure, for example on buildings and equipment, and ongoing costs, such as wages.

Labour is typically considered easier to adjust than capital. Capital requires an upfront investment in order to earn a future return and as such cannot be adjusted easily depending on performance. In the context of research though, labour is the key upfront investment and investors have to commit to funding it to generate a future return. For these reasons, we consider both capital and ongoing costs, such as wages, as investments.

The chart below shows that, for HEIs, the vast majority of expenditure is on ongoing costs (staff and operating expenditure) and only a small proportion is on physical capital (as measured by depreciation). Although this includes teaching and research, it gives an indication or the relative magnitudes of capital expenditure compared to wages and other ongoing costs.

Figure 7. Expenditure of UK HEIs 2013/13



Source: HESA

In later sections we discuss the source of the measures used for the level of both public and private investment, and what is and is not included in them. We now turn to why, in principle, there is a relationship between public and private investment in R&D.

2.2. Why is there a relationship between public and private funding?

In this section we explore the theory behind why public and private sector entities invest in R&D, and why a relationship exists between them. This informed the choice of variables that we used as controls when measuring additionality (as discussed in section 4.4.2 and 4.6.2). We start by looking at the reason for public expenditure on R&D.

2.2.1. Why does the public sector invest in R&D?

Businesses invest in R&D, just like any other asset, to earn a return. The public sector, however, invests for different reasons. Haskel et al. (2014) identified two concepts relevant to the justification of public sector investment in R&D:

- spillover effects resulting in firms not being able to realise the full benefit of their investment and therefore underinvesting; and
- 'system failures' resulting in diminished knowledge flows from pure to applied research.

The first concept, and the central theory behind government intervention in R&D, is based on the premise of 'incomplete private appropriability', as identified by Arrow (1962) and Nelson (1959). R&D brings with it certain spillover benefits that the individual who made the investment cannot realise. As the social benefit outweighs the private benefit, a market failure will arise through the underinvestment in R&D.

The degree of spillover benefits can differ significantly between 'pure' and 'applied' research (see for example Diamond (1998) and Hughes and Martin (2012)). Applied research often has direct commercial benefits that can be captured by the investor. Pure research, on the other hand, provides the building blocks on which future, often unknown, applied research can be conducted and a private sector organisation that invests in it cannot fully appropriate the benefits. As such, pure research often attracts higher levels of government support.

There are two main policy measures that can be taken to address the underinvestment in R&D. Firstly, government could fund the research directly themselves (for example, through universities or contracting private firms). Secondly, policy measures could be taken to incentivise private investment. We explore the motivations for private entities to invest in R&D in detail in the section below.

The second concept – system failures – builds on the principle of spillover effects. As pure and applied research serve very different purposes and are often performed by different people, there may be 'system failures' that mean that knowledge does not flow from pure to applied research as efficiently as it could. Cohen and Levinthal (1989 and 1990) defined the concept of 'absorptive capacity' which relates to a firm's ability to access, understand and apply the results of research carried out elsewhere. In other words, a lack of absorptive capacity will result in 'system failures'.

So that society can fully benefit from pure research, there is a rationale for further public investment in R&D to ensure that firms have the relevant absorptive capacity. This issue is also discussed in Hughes and Martin (2012) and Hughes and Kitson (2012).

Technology Readiness Levels (TRLs) denote the research stage at which a piece of technology is – ranging from the most basic research to the technology being proved in an operational environment. The European Commission's definitions of TRLs are given in the figure below.

Figure 8. European Commission TRL definitions

TRL 1	basic principles observed
TRL 2	technology concept formulated
TRL 3	experimental proof of concept
TRL 4	technology validated in lab
TRL 5	technology validated in relevant environment
TRL 6	technology demonstrated in relevant environment
TRL 7	system prototype demonstration in operational environment
TRL 8	system complete and qualified
TRL 9	actual system proven in operational environment

Source: European Commission

The transition space between TRLs 4-7 is typically where publicly and privately funded research can interact, and it is here where system failures can arise.

Related to the above discussion, one argument (that is discussed in Haskel et al. (2014)) could be that nations should reduce their investment in pure research as they can benefit from the spillovers of pure research conducted by other countries. However, without domestic understanding of the pure research, the subsequent applied research cannot be conducted. As such, countries cannot simply free ride on the pure research conducted by others and a certain level of public expenditure on R&D is needed.

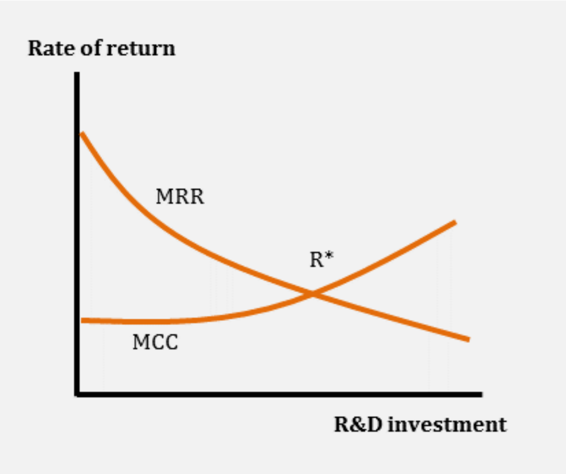
Guellec and van Pottelsberghe de la Potterie (2003) discuss a third reason for government intervention in R&D. They highlight that the returns to R&D can be highly unpredictable and obtaining finance to conduct such research projects may be difficult, particularly for smaller firms. Furthermore, some research may simply be too risky for small firms to invest in because the costs are so great if the research isn't successful.

The essence of the three concepts discussed above is that the public sector intervenes to correct a market failure and, as we discuss later, this could incentivise private entities to invest more. We first discuss how the private sector decides how much to invest in R&D.

2.2.2. How do private businesses decide how much to invest in R&D?

Private firms invest in R&D for profit and will invest so long as the expected revenues outweigh the expected costs. One simple but effective framework for determining the level of investment by an individual firm is attributable to Howe and McFetridge (1976). It postulates that at any given time a firm has a range of potential R&D projects available to it. The firm assesses the expected cost and revenue streams of each project – which can be thought of as giving rise to the internal rate of return. Projects can then be ranked in order of return, which forms the marginal rate of return curve (MRR) shown in the figure below.

Figure 9. A firm's optimal level of R&D investment



Source: Based on Howe and McFetridge (1976)

The marginal cost of capital (MCC) curve is assumed to rise with the level of R&D investment and the optimal level of investment in R&D is given by point R*.

David et al. (2000) identify factors that determine the position of the MRR and MCC curves. They give the following features that will influence the MRR curve:

- The 'technological opportunities' that are present in the firm's market.
- The level of demand for potential products.
- Institutional and other conditions affecting the 'appropriability' of innovation benefits.

Correspondingly, the features that affect the MCC curve are given as:

- Policy measures that affect the private cost of R&D projects such as the tax treatment of that class of investment, R&D subsidies, and government cost-sharing programmes.
- Macroeconomic conditions and expectations affecting the internal cost of funds.
- Bond market conditions affecting the external cost of funds.
- The availability and terms of venture-capital finance and the tax treatment of capital gains.

Becker and Pain (2007) identify five main categories of determinants of business investment in R&D.

- Two principal ***characteristics of the firm or industry*** identified are internal finance and sales. In particular, cash flow (cash from income available to spend on investments) has been found to matter in many firm-level studies. It is commonly argued that, given capital market imperfections, firms are not able to attract (sufficient) external funds to finance investment in R&D. Being financially constrained, they have to rely on internal funds. There is, however, mixed empirical evidence relating to the importance of cash flow – see for example David et al. (2000) and Bhagat and Welch (1995).
  Several arguments have been put forward to support the hypothesis that innovation will increase more than proportionately with respect to firm size, measured either by sales or by market power. These include economies of scale in R&D technology, more efficient implementation, higher returns from R&D and greater ability to secure finance for risky projects given capital market imperfections.
- ***Product market competition*** may have two distinct relationships with R&D expenditures. A lack of competition may weaken incentives for R&D, as firms may already be able to generate excessive returns through market power. Alternatively, a lack of competition (measured through concentration ratios, for example) may indicate that firms invest heavily in R&D in order to gain a competitive advantage and protect their market share.
- As discussed extensively in this report, ***public policy*** can influence private investment in R&D. Policies could include the direct funding of research projects performed in business, beneficial tax policy, and investment in other research that has spillover effects for private business.
- A large body of evidence indicates that firms' ***resource endowment and location*** are important determinants of the pattern of R&D across countries, regions and industries. For example, Furman et al. (2002), Adams et al. (2003) and Kanwar and Evenson (2003) all highlight human capital, measured either in terms of years of education or in terms of the number of scientists and engineers, as a positive determinant of the level of expenditure on innovative activities.
- ***Other determinants of private R&D*** is a residual category that includes factors such as overseas investment in R&D and the spillovers that it can bring with it. As discussed previously, the inward investment from one firm may have a positive influence on the decisions of others to invest in the same country.

Some of the factors described above are relatively easy to quantify and include in a statistical model. For example, bond yields can be used as a measure of the cost of finance, and measures of the marginal rate of tax are easily available. Other factors, such as the 'technical opportunities' available, and the level of demand for potential products are much harder to measure because they are not directly observed and depend on expectations at a point in time. For these reasons, one needs to use other variables to proxy for them.

2.2.3. How do charities decide how much to invest in R&D?

The literature underpinning the analytical framework set out in section 2.2.2 above was developed under the assumption that a firm's primary objective is to maximise profits. However, we note that non-profit organisations, including charities, spent around £1.3 billion (4.7%) on R&D activities in the UK in 2012. Given the noticeable contribution that non-profit organisations make to R&D in the UK combined with the fact that they are likely to have primary objectives other than profit maximisation, in this section we consider the usefulness / applicability of our framework to non-profit organisations.

Our overall conclusion is that while non-profit organisations may have different objectives to profit-maximising firms, we would expect their ability and willingness to invest in R&D to be influenced by similar factors – such as the cost of undertaking R&D and the demand for the outputs facilitated by R&D.

The rest of this section is split into three parts:

- The first part sets out who is included in our definition of 'charities', to provide further context.
- The second part briefly summarises what the existing literature says about: (a) the objectives of non-profit organisations; and (b) how these objectives could influence their investment decisions in a manner that is different to profit-maximising organisations.
- The third part sets out the implications of the above for our analytical framework and analysis.

Who are the charities?

Before discussing the difference between the way in which businesses and charities make investment decisions, we first consider who the charities are that invest in research. The ONS states:

"The private non-profit sector includes registered charities and trusts. Those performing R&D in this sector specialise mainly in health and medical research. Some of the largest of these are based in the UK. This sector includes, for example, a number of cancer charities that carry out extensive research into types of cancer prevention, from drug development to clinical trials."

For the purpose of this report we use 'charities' to refer to all non-profit organisations.

Main (2013) gives a quantification of the scale of charity investment that is from medical research charities. It references a report by the UK Clinical Research Collaboration which estimates that 85% of charitable expenditure on research in the UK is on medical research.[13]

Objectives and investment decisions of charities

The existing literature suggests that charities could have a wide range of objectives, such as:

- Maximising output – see James (1983) and Gassler (1987) and (1997).
- Budget maximisation – see Tullock (1966) and Niskanen (1971).
- Services maximisation – see Ben-Ner (1983).
- Income maximisation – see James (1981) and (1983), and Harris (1979).
- Social welfare maximisation – see Weisbrod(1974) and (1977)
- Quantity quality trade-offs – see Hansmann (1980), Easley and O'Hara (1983), and Bays (1983).

We think that there is a useful distinction between:

- the different ***objectives*** that non-profit organisation have compared to profit-maximising firms; and
- the ***factors*** that influence the amount and type of investment in R&D they undertake.

That is, the literature highlights that even if organisations have different objectives, they may nevertheless respond to similar economic factors when making investment decisions.

For example, take a charity which has as its objective maximising 'social output' subject to the budget it has available for doing so. One would expect the level of output it can produce to be influenced by the input costs it faces (which may be the same as a profit maximising firm). One would also expect it to make trade-offs between different inputs into R&D based on

[13] *This estimate is calculated by comparing the GERD data for health-related research to the total spend by medical research charities. The Association of Medical Research Charities (AMRC) represents 126 members which invested £1.1bn in research in 2011.*

their relative costs and relative effectiveness (which could apply to where in the world R&D is carried out). Equally, its budget is likely to be determined (in part) by the amount of disposable income available to donors, in a way analogous to the demand for products and services supplied by firms.

Implications for our analytical framework and empirical analysis

As discussed in the previous section, profit maximising firms invest in R&D up to the point at which marginal cost equals marginal revenue. Once marginal cost is higher than marginal revenue, firms will be better off either not spending the money, or spending it elsewhere. There are good reasons to believe that this framework also applies to charities, too.

Firstly, as mentioned above, even though their objectives may differ from profit maximising firms, they still face the same input costs/ output demand. Although some differences may emerge in terms of the type of R&D activities undertaken if there is a difference between those that deliver marginal revenue versus those that help meet non-profit objectives, the overall framework still applies.

Take again a charity which has the objective of maximising 'social output'. Whether it maximises revenue or its objective, the only factors it can actively influence are its input costs and/ or output demand. So, in order to achieve more 'social output' it will have to either pay researchers less, or pursue activities that increase its donations/ funding, for instance through increased publicity, or more fund-raising events. Having reduced its costs/ maximised its revenue – all else equal – it will then be able to provide more 'social output'. So, although the motivations for the charities' actions and investment decisions may be different to profit-maximising firms' ones, the mechanisms with which they can achieve their ultimate objective are essentially the same ones.

Therefore, if the factors influencing charities' investment decisions are similar to the ones affecting private companies' R&D investment decisions, we will have to control for similar factors in our empirical analysis, when measuring additionality.

As part of our empirical analysis, when considering the effect of public funding on private funding, we believe that changes in charities' objectives that would alter their spending on R&D have not occurred, and that they are uncorrelated with government spending, hence allowing us to estimate additionality for the charitable sector.

2.2.4. How can public funding affect private investment?

As discussed previously, public investment in R&D could have a positive effect on private sector investment in R&D (crowding-in), it could have a negative effect (crowding-out), or it could have no effect at all. In this section we discuss why crowding-in and crowding-out occurs.

Crowding-in

Starting with crowding-in, there are many mechanisms through which public investment in R&D could lead to additional levels of private sector investment in R&D. Guellec and van Pottelsberghe de la Potterie (2003) classify three types of policy instrument that governments can use to support private investment in R&D: (i) publicly performed research (government or university); (ii) government funding of business-performed R&D; and (iii) fiscal incentives.

(i) Publicly performed research (government or university)

As noted in section 2.2.1 above, publicly performed research can overcome the issues of underinvestment directly and is used particularly for pure research.

(ii) Government funding of business-performed R&D

David et al. (2000) lists four channels through which government funded business-performed R&D could crowd-in private R&D:

- public R&D contracts could increase the efficiency of the firm's R&D by lowering common costs or increasing 'absorptive capacity';
- public R&D contracts may improve the chances for success on the firm's other projects;
- public R&D contracts could signal future demand; and
- public R&D contracts could allow firms to overcome fixed R&D startup costs i.e. 'pump-priming'.

In relation to the first point above, publicly funded projects could take on an element of shared costs that are required for other research projects. For example, public funding could be used partially to pay for research facilities that are needed for multiple projects – but without the publicly funded project there would simply not be enough demand to justify investment in them.

Additionally, and related to the second channel, staff may learn from publicly funded projects that enable them to better access and understand research, and make other projects possible or less costly.

The third channel above relates to how government spending could signal future demand. There are a number of ways in which this could affect firms' expected revenues. Firstly, government spending in an area of research could simply signal that there will be further government demand for related research or products. Secondly, government spending could signal that the government is committed to making a particular area of research a success. In the event that private funding is not adequate to fully conduct some research, the government could be perceived as willing to help out – and thus increasing the chances of success. Thirdly, decisions made regarding public spending may be seen as particularly well informed, or made by those who are particularly knowledgeable in a sector. The decision to invest in an area may therefore be regarded as a strong signal of future success.

These first three channels have the effect of shifting out the MRR curve – that is, they either increase expected revenues or decrease the expected costs.

The fourth channel makes the financing of research easier by covering the costs of the initial, and most risky, research required for further research and product development. This fourth channel lowers the opportunity cost of capital and shifts the MCC curve out to the right.

(iii) Fiscal incentives

The third type of policy instrument that government can use to encourage private investment in R&D is fiscal incentives i.e. tax breaks. These have the effect of lowering the costs of conducting research and pushing the MCC curve down. However, such policy options do not involve direct government expenditure on R&D and are therefore not considered as driving crowding-in or crowding-out. We see tax incentives as beyond the scope of this project. However, the tax regime is an important driver of the level of private investment in R&D and, as Guellec and van Pottelsberghe de la Potterie (2003) point out, when analysing the effect of public funding of research one also has to take into account the tax regime to isolate the effect.

Crowding-out

Despite the evidence presented above of the potential benefits and crowding-in effect of public expenditure on R&D, in theory, public expenditure could also lead to a reduction in the amount private sector organisations invest.

As with crowding-in, crowding-out can arise due to various reasons. Publicly funded R&D may simply substitute for some amount of investment (if not on a one-for-one basis) that would occur by private firms anyway. If there is a piece of research that is commercially viable, but is publicly funded, a private entity is less likely to conduct the same research.

Public funding of research performed in businesses may also lower the expected return of other private entities also investing in that area. The firms receiving public funds could be well positioned to enter the final product market with significant first-mover advantages. Non-contract receivers might be further discouraged from undertaking their own R&D by the anticipation that the government procurement agency in question would have an incentive to disseminate cost-saving and quality-enhancing innovations, as a means of enabling entry and greater competition in the end-product market. When viewed from the latter perspective, 'dual-use' programmes of government procurement of R&D-intensive goods take on the appearance of a two-edged sword.[14]

As we will discuss later, the existing literature highlights that one effect of public expenditure on R&D may be to increase the wage of researchers. Such an increase in cost would reduce the level of investment in R&D by private firms, all else equal.

2.2.5. What is the net effect of public investment in R&D in principle?

This question has been examined analytically by David and Hall (1999). Their basic proposition is that: whenever the market supply of R&D inputs is less than infinitely elastic, as is likely to be the case in the short-run, increased public sector demands for those resources must displace private R&D spending, unless it gives rise to spillovers that also raise the aggregate private derived demand for R&D inputs. Put simply, if public spending increases R&D costs, and does not affect underlying private demand for R&D, public expenditure will crowd-out private expenditure.

The net effect will therefore depend on:

- ***The elasticity of labour supply***. The more inelastic labour supply is the more likely crowding-out is to occur.
- ***The rate at which private marginal returns to R&D change with public R&D***. If private demand for R&D does not increase with public R&D, crowding-out is more likely to occur.

Without being able to fully specify both the magnitude of the elasticity of labour supply and the shift in schedules due to spillover effects, it is not possible to determine the net effect of public expenditure on R&D, as per the framework set out in Figure 6. The purpose of econometric analysis, which we discuss

[14] *See Branscomb and Parker (1993) for more discussion on 'dual-use' programmes*

later, is to hold these factors constant to help isolate the impact of government spending.

2.3. Conclusions

In this section we have identified two variables of relevance to leverage – the private sector percentage and additionality. We have recognised that different types of research may attract different degrees of leverage, and that there are important distinctions between industry and charity funders. Additionally, it is critical that any discussions of metrics of leverage are clear with regards to how measurements have been computed and how they are being applied.

The net effect of public funding, whether there is crowding-in or crowding-out, is ambiguous from a theoretical perspective. We do know, however, that the net effect will turn on the elasticity of supply of labour and the rate at which private marginal returns to R&D change with public R&D.

In the next section we present our findings with respect to the private sector percentage.

3. What is the ratio of public to private investment in R&D?

This section answers our first research question.

The main findings from this section are:

(i) The private sector percentage at the ***UK national level*** has increased over time and stood at ***70%*** in 2012.

(ii) In comparison to its peers, the UK receives a particularly high proportion of R&D funding from ***overseas*** and ***charities***.

(iii) The private sector percentage at the ***UK institutional level*** (within HEIs) stood at ***35%*** in 2012/13.

To answer this first research question we have analysed a variety of different datasets to calculate the private sector percentage across different levels of aggregation. We present these findings in three sections that cover the private sector percentage on a national, international and institutional (within HEI) level.

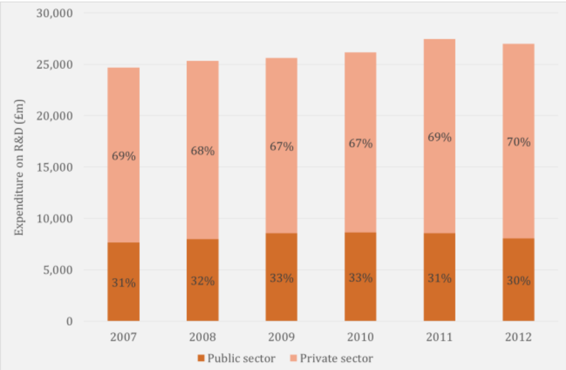
3.1. What is the private sector percentage at a national level?

The private sector percentage at the UK national level stood at 70% in 2012 (the latest available time period from ONS when this analysis was undertaken). That is, of the £27bn of R&D conducted in the UK, £19.0bn was funded by the private sector. We define the public and private sectors as follows:

- » The ***public sector*** includes all UK-government funding, including: higher education funding councils; research councils; higher education; and other government spending.
- » The ***private sector*** includes UK business, UK charity, and overseas funding. We understand the majority of overseas funding is from foreign businesses.

As can be seen in the following chart, the private sector percentage has marginally increased since 2009.

Figure 10. Private sector percentage at the UK national level over time

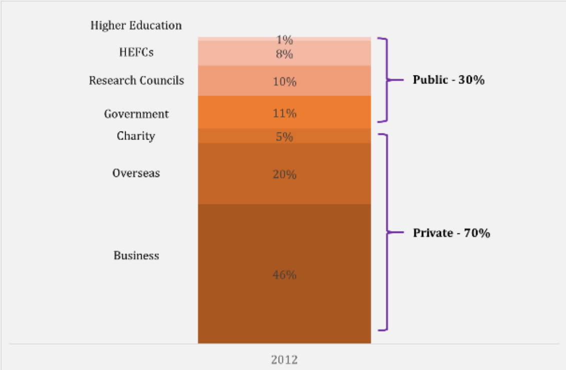


Source: EI analysis of ONS GERD data

Along with the percentage of funding coming from the private sector increasing, the absolute value of funding (in cash terms) has also been increasing. In 2009 the private sector funded £17.1bn of research and this increased to £19.0bn in 2012.

In relation to the source of the private funding, the largest proportion comes from UK businesses, followed by overseas and UK charity, as is illustrated in the following chart. We understand the majority of overseas funding to represent foreign business investment.

Figure 11. Source of GERD (2012)

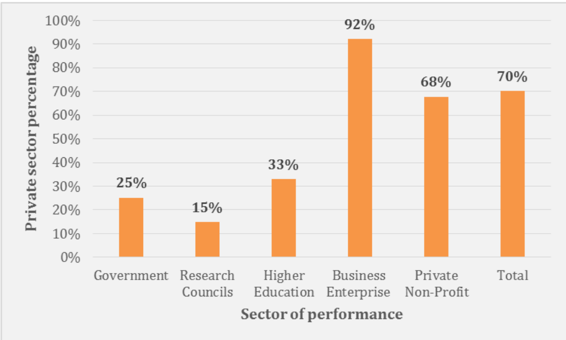


Source: EI analysis of ONS GERD data

In relation to the source of public funding, the largest proportion comes from Research Councils and HEFCs together (mainly funded through BIS).

There are significant differences between who funds research and where it is conducted e.g. businesses may fund research that is conducted in HEIs. As shown earlier, the private sector percentage differs significantly by the sector in which the research is performed.

Figure 12. Private sector percentage by sector of performance (2012)

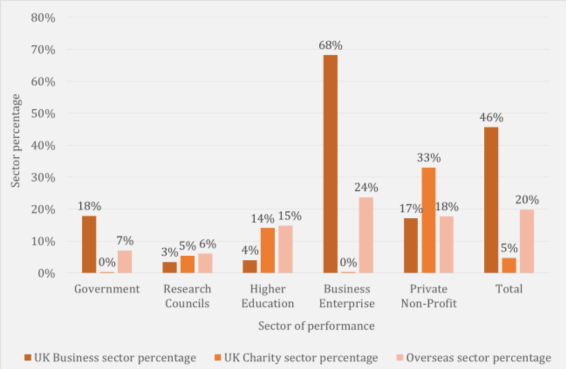


Source: EI analysis of ONS GERD data

Unsurprisingly, businesses have the highest private sector percentage, followed by charities. Based on 2012 ONS data, the private sector percentage in Higher Education is 33%.

In a similar way to the private sector percentage, the business, charity and overseas sector percentages can also be calculated, as are presented in the following chart.

Figure 13. Business, charity and overseas sector percentages (2012)



Source: EI analysis of ONS GERD data

The differences are broadly as one would expect. UK businesses are the biggest funders of research conducted within businesses and charities the biggest funders of research conducted within charities. Charities and overseas sectors fund a similar amount of research that is conducted with Higher Education, which is significantly more than UK businesses. This demonstrates the relative importance of UK charity and overseas funding for HEIs.

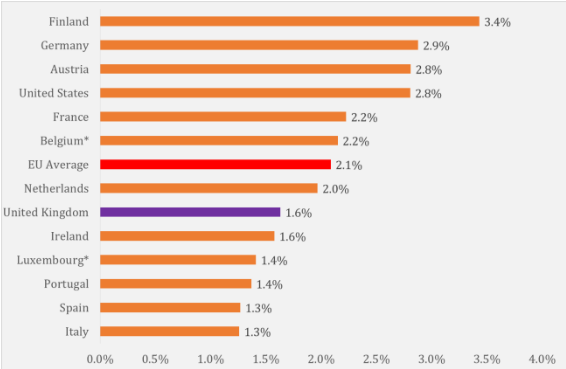
The table at the bottom of this page provides data on the source of funding and area of performance of UK R&D in 2012.

3.2. How does the UK compare internationally?

Total R&D expenditure as percentage of GDP in the UK represented 1.6% in 2012[15]. This is slightly below the EU average at 2.1% and less than some notable peers such as Germany or the US, at 2.9% and 2.8% respectively.

The European Commission, as part of its strategy for economic growth - Europa 2020 – has set a 3% objective for R&D intensity. As can be seen from the figure below, only a handful of Member States are close to that target.

Figure 14. GERD as a percentage of GDP (2012)



*Source: EI analysis of Eurostat data, *2011 figure where 2012 not available*

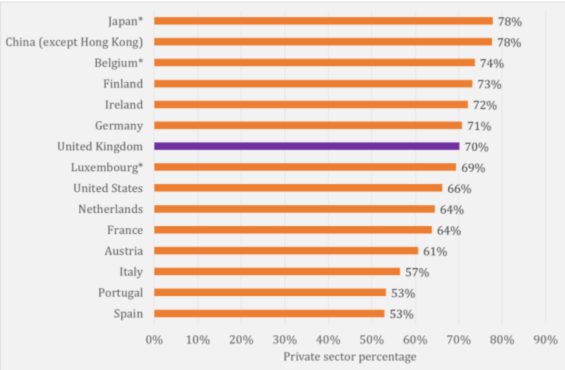
Table 3. Source of funding and area of performance of UK GERD (£m 2012)

Funded by \ Performed in	Government	Research Councils	Higher Education	Business Enterprise	Private Non-profit	**Total**
Government	948	103	406	1,346	67	**2,871**
Research Councils	68	578	1,955	2	85	**2,688**
Higher Education Funding Councils	-	-	2,185	-	-	**2,185**
Higher Education	2	10	284	-	14	**310**
Business Enterprise	243	28	292	11,666	88	**12,317**
Private Non-profit	4	44	1,022	37	170	**1,277**
Overseas	96	49	1,068	4,055	91	**5,358**
Total	**1,360**	**813**	**7,211**	**17,107**	**515**	**27,006**

[15] *The ONS reports a figure of 1.72%, which we understand is calculated using a different measure of GDP*

The UK's private sector percentage compares similarly to a number of close peers. The US's private sector percentage is slightly less, at 66% in 2012, and Germany's is fractionally more at 71% in 2012. Japan and China have the highest private sector percentage out of the peer group that we considered, standing at 78%. The figure below illustrates this along with a collection of other countries.

Figure 15. Private sector percentage across a peer group of countries (2012)



*Source: EI analysis of Eurostat data, *2011 figure where 2012 not available*

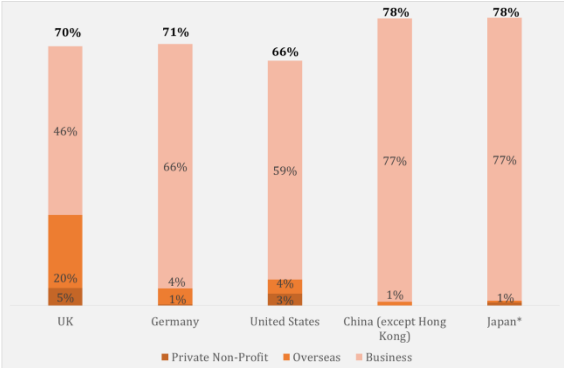
The average private sector percentage of their peer group is 67%, so the UK is above it.

In relation to the breakdown of private sector funding, there are considerable differences across countries. The UK private sector percentage is made up of 20% overseas funding, whereas Germany and the US both receive 4% of R&D funding from abroad. This is illustrated in the figure below. China and Japan receive little (1%) to no funding from abroad, respectively.

A further point of distinction is private funding coming from the charitable sector. In the UK this amounts to 5%, whereas in the peer countries it is below that – Germany and China have no charitable funding, with the US and Japan having very little (3% and 1% respectively). When analysing these data, it should be borne in mind that a country reporting 0% of charitable funding does not necessarily mean that no charitable funding occurs. For example, Germany reports its PNP income as part of Government income, and hence there will be a zero against its charitable funding.

So, although the private-public split is similar across all countries, the constituent parts of the UK's private sector percentage are quite different compared to the other countries.

Figure 16. Private sector percentage source comparison with peers (2012)



*Source: EI analysis of Eurostat data, *2011 figure where 2012 not available*

The UK appears to be successful at securing funding from abroad and from the charitable sector, whereas other countries rely fully on their own businesses for the private sector percentage. As such, the UK appears to have a competitive advantage in attracting overseas and charitable funding.

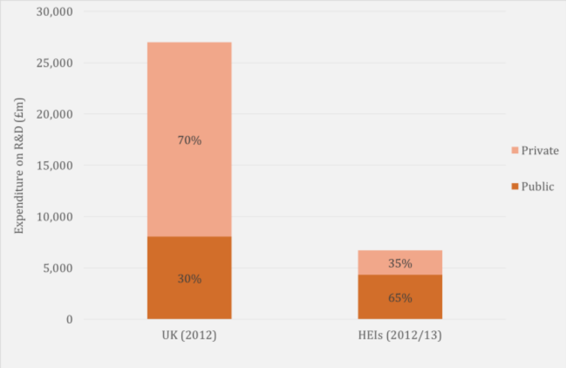
3.3. What is the private sector percentage within HEIs?

In order for the institutional (within HEIs) private sector percentage to align with the national one, we define the public and private sectors as follows:

- The ***public sector*** includes all UK government funding, including: Research Councils, HEFCs, and other government funding.
- The ***private sector*** includes UK business, UK charity, and overseas funding. Overseas funding consists of EU and Non-EU funding, where most EU-related funding is from EU government bodies, and Non-EU funding is mostly from Non-EU business and charity.

The private sector percentage within HEIs for the year 2012/13 stood at 35% - significantly less than the UK as a whole. This within HEIs private sector percentage of 35% is a result of approximately half of UK publicly funded research being conducted within HEIs, but only a small proportion of privately funded research. This is illustrated in the following chart.

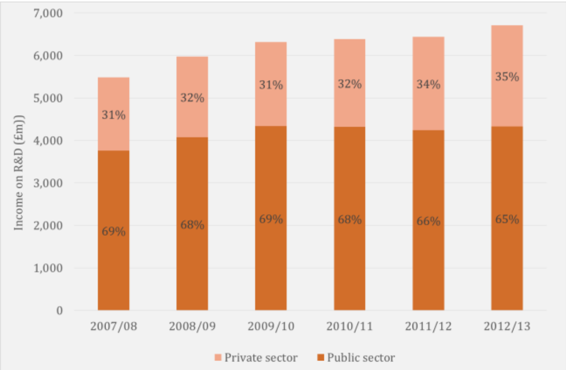
Figure 17. Private sector percentage in UK compared with HEIs



Source: EI analysis of ONS GERD and HESA data

Along with the total UK, the private sector percentage within HEIs has also increased slightly since 2007/08, as can be seen in the chart below.

Figure 18. Private sector percentage at the UK institutional (within HEIs) level over time

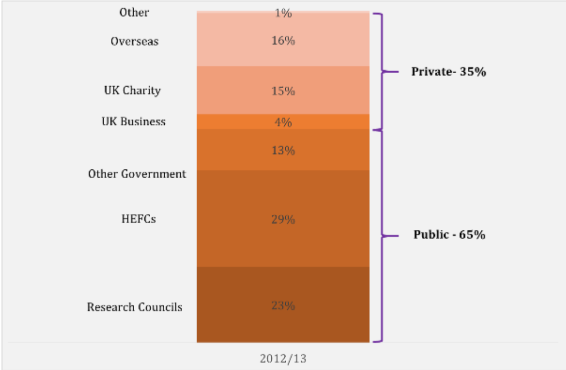


Source: EI analysis of HESA data

Private sector investment in UK HEIs has increased from £1.7bn in 2007/08 to £2.3bn in 2012/13. This amounts to an increase in cash terms of private sector investment.

In relation to the source of private funding of HEIs, the largest contribution comes from overseas[16], closely followed by UK charity and then UK businesses. This is illustrated in the following chart.

Figure 19. Sources of R&D income (2012/13)

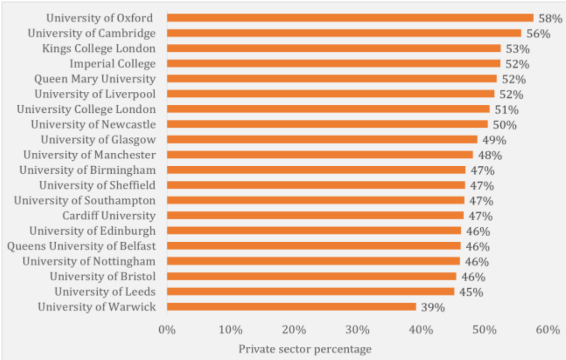


Source: EI analysis of HESA data

The largest proportion of public funding comes from Research Councils and HEFCs together (mainly funded through BIS), followed by other government funding.

Looking at the top 20 HEIs by total research income in the figure below, we see that their private sector percentage lies between 39% and 58%, which is above the overall private sector percentage of 35% (considering all HEIs together). This indicates that although the overall private sector percentage within HEIs is low compared to the total UK level, there is a high variance between HEIs.

Figure 20. Distribution of top 20 HEIs' private sector percentage



Source: EI analysis of HESA data

Just over a fifth of all HEIs have a private sector percentage of 40% or above. 78% of HEIs receive more than 60% of their R&D income from the public sector.

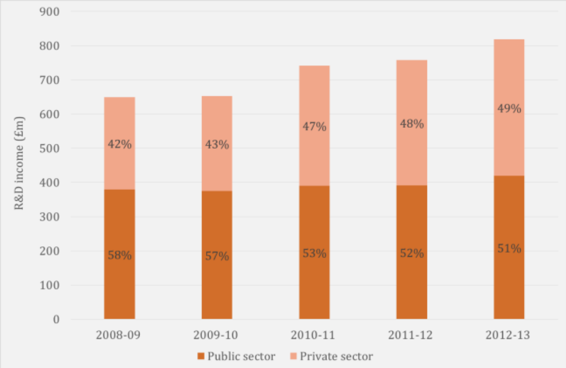
As can be seen in the figure below, the private sector percentage within collaborative funded projects[17] at

[16] *9% of overseas funding is from EU government bodies, the other 5% being split across EU and Non-EU business and charity*

[17] *Collaborative research is academic research which has public sponsorship (grant in aid from a Government or public body) and at least one other external partner. It is undertaken with partners such as research organisations, private business, other HEIs, Government or the third sector, and includes at least one other non-academic organisation*

HEIs is 49% in cash terms, for the period 2012/13. This figure is directly comparable to the private sector percentage of 35% for HEIs as a whole, showing that the private sector contributes proportionately more to collaborative research performed in HEIs compared to all research conducted in HEIs.

Figure 21. Private sector percentage at the UK institutional (within HEIs) level w.r.t. collaborative research over time



Source: EI analysis of HE-BCI data

Nonetheless, the private sector percentage within collaborative research has increased marginally in cash term since 2008/09.

3.4. Conclusions from this section

We draw the following conclusions from this section:

- The private sector percentage within the UK as a whole has increased gradually since 2009, and has also been increasing in cash terms. The current trajectory suggests that this will continue.
- UK and overseas businesses represent the largest proportion of investment into UK R&D. The amount of research that they fund within HEIs, however, is comparatively much smaller.
- The UK compares similarly to its international peers with regards to the private sector percentage, however R&D as a whole represents less of GDP than others.
- In comparison with its peers, the UK appears to be successful in securing funding from overseas and from the charitable sector.
- The private sector percentage within HEIs has marginally increased since 2007/08, also in cash terms. The same applies to the private sector within HEIs relating to collaborative research only since 2008/09.
- Given that so much of the R&D performed in the UK takes place outside of HEIs, one may expect to see significant spillover effects arising here.

Having identified the private sector percentage across a range of different aggregations, we now turn to estimating how much private investment is caused by public investment.

4. How much private investment is caused by public investment?

This section answers our second research question.

The main findings from this section are:

(i) Our macro analysis finds a coefficient of additionality of between 0.48 and 0.68. The mid-point of this range and the current funding levels implies that a ***£1 increase in total public funding will give rise to a £1.36 increase in private funding of R&D***.

(ii) Our main micro analysis finds a coefficient of additionality of between 0.25 and 0.81. Taking the mid-point and the current funding levels implies that a ***£1 increase in public funding of HEI-conducted research will lead to a £0.29 increase in private funding of HEI-conducted research***.

This section of our report presents our quantitative analysis with respect to how the amount of public expenditure affects the amount of private expenditure on R&D. Whilst the previous section addressed the private sector percentage, this section is concerned with additionality. That is, this section presents our estimates of the effect of public sector expenditure on private sector expenditure.

This section is divided into the following subsections:

» ***Overview of approach to estimating additionality*** sets out the different pieces of analysis that we have conducted and how they are related to each other.
» ***Existing estimates of additionality*** presents a literature review of previous empirical studies that have estimated additionality.
» ***Analytical benefits and challenges*** discusses the pros and cons of the different analyses.
» ***Results from ONS data analysis*** presents our primary macro analysis using the ONS data.
» ***Results from Eurostat data analysis*** presents our macro analysis of the Eurostat data, which acts as a cross-check to the ONS analysis.
» ***Results from HESA data micro analysis*** presents primary micro analysis which is based on HESA data.
» ***Results from HESA academic subjects extension analysis*** presents further micro analysis, which is an extension to the HESA analysis above.
» ***Further funding*** sets out the analysis that we have conducted on MRC data.
» ***In-kind contributions*** analyses data from HEBCI and makes recommendations with respect to estimating in-kind contributions.
» ***Applying the estimated coefficients of additionality*** discusses how the results should be used to estimate the £ effect of policy changes.

Further details of our analysis are given in the appendixes, and referenced within the sections below.

4.1. Overview of approach to estimating additionality

To estimate additionality we have used econometric regression techniques to establish the relationship between public and private sector investment. Our method is consistent with previous empirical studies, as set out in section 4.2. Our analysis adds to the existing base because we: (i) focus on the UK; and (ii) use the most up-to-date data.

The datasets we have used cover the funding of UK R&D at various different levels of aggregations and we make the high-level distinction between two types of analysis that we have conducted:

» ***Macro analysis*** utilise datasets that represent the UK at the national level – the entity under consideration is the UK. The main advantage is that all spillover effects with the UK will be captured in the data. As such, estimates of additionality will represent the effect of public expenditure on all private expenditure within the UK. Our macro analysis is based on ONS and Eurostat data.
» ***Micro analysis***, on the other hand, assesses additionality at the HEI or award level. We estimate the effect of public expenditure on an HEI, for example, on the amount of private funding that it receives. Not all spillover effects are captured, such as changes in spending by businesses on research conducted in businesses. The main advantages of micro analysis is that it considers a more granular level and more data is available to produce robust findings. Our micro analysis is based on HESA, HEBCI and MRC data.

Depending on the dataset we 'correlate' public spending with private spending across years/ countries/ HEIs/ funding awards to estimate additionality. Specifically:

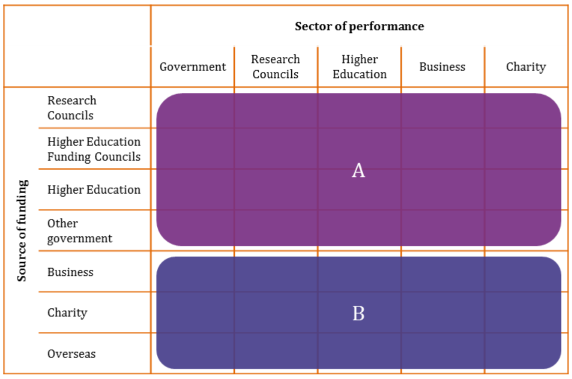
» ***ONS*** data provides information at the UK level on the gross expenditure on R&D (GERD) across multiple years. We use the differences across years to estimate additionality.
» ***Eurostat*** data provides information similar to the ONS but across multiple countries and years. We use the differences across countries and years to estimate additionality.
» ***HESA*** data provides information on the funding of research that is conducted within HEIs. We use differences across years and HEIs to estimate additionality. We also investigate the differences in additionality between academic subjects.
» ***MRC*** data provides information on further funding that holders of MRC awards have received. We use differences across awards to estimate additionality.
» ***HEBCI*** data provides information on the income of HEIs from business and community interactions. We use differences across institutions to estimate additionality. Furthermore, the data gives us an indication of the relative size and importance of in-kind contributions.

After presenting the results of our literature review on previous empirical studies, we present the results of our analysis in five main sections. The relationships between these five pieces of analysis can be considered using diagrams as presented below. As will be seen, the different pieces of analysis are estimating different effects and we would naturally expect different estimates to arise.

ONS data analysis

The diagram below illustrates the source and area of performance of all R&D conducted within the UK. Our ONS data analysis estimates the effect of all publicly funded R&D on all privately funded R&D. This is illustrated as the effect of funding that falls into area A on funding that falls into area B.

Figure 22. Illustration of macro analysis



In addition to the effects at this highest level, within our macro analysis we also consider the effects of subcategories of A on subcategories on B – still, the entity under consideration is the UK.

Eurostat data analysis

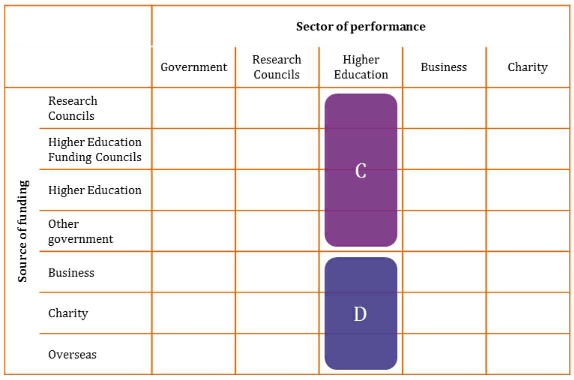
The Eurostat data analysis that we conduct is similar to the ONS analysis but here we have the additional dimension of multiple countries. Instead of basing estimates solely on variations over time, the Eurostat data allows to utilise variations over countries as well. The effect we estimate using the Eurostat data is the same as illustrated in Figure 22.

We have conducted this additional analysis to act as a cross-check to the results of the ONS analysis. The Eurostat data contains significantly more observations and alleviates some of the concern around the small sample size from the ONS dataset.

HESA data analysis

This analysis looks at the effect of public expenditure on research performed within an HEI on the private expenditure performed within an HEI. As is illustrated in the following chart, this analysis will only capture the spillover effects that arise within research performed in HEIs.

Figure 23. Illustration of main micro analysis



Private expenditure outside of area D that is induced because of expenditure in area C will not be accounted for.

Furthermore, this analysis is conducted at the level of the individual HEI and spillover effects between institutions will not be captured. For example, increased public spend on one institution that arises in greater private spend on another institution will not be captured. Such an effect could be experienced if, for example, publicly funded basic research in one institution results in a private sector organisation increasing their spend on related applied research in another institution.

In an extension to the main HESA analysis we also investigate whether additionality differs by subject area.

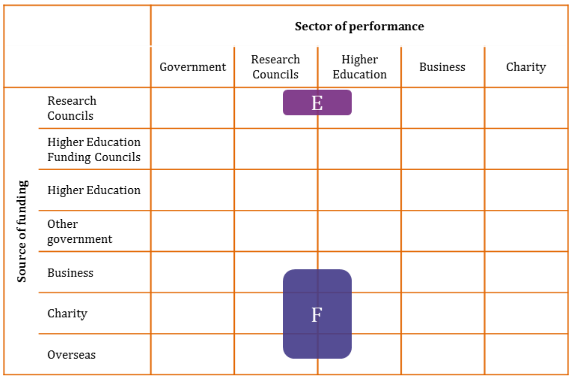
We have also conducted two further pieces of micro analysis that are presented in separate sections, as per below.

Further funding

Further funding occurs where additional money is received to conduct new but related research. MRC has provided data on funded awards/programmes and the associated further funding reported to MRC through Researchfish.[18] The effect we estimate is illustrated in the diagram below but the data we have used does not align exactly. Specifically, our measure of area E may include some funding from the private sector, however we understand this to be a small proportion.

[18] *https://www.researchfish.com/*

Figure 24. Illustration of further funding analysis



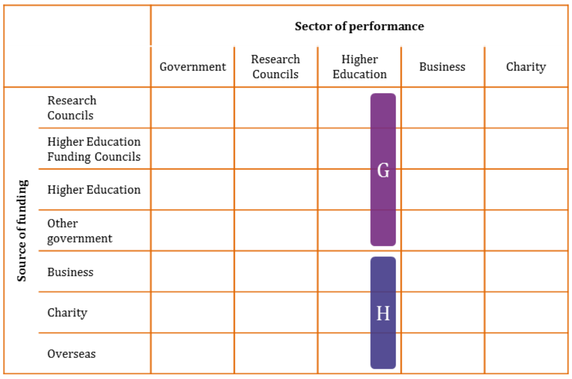
We also note that the analysis is conducted only on MRC funding active on or after 1st April 2006. As such, the results may not be applicable to awards managed by other research councils. Nonetheless, our analysis could in theory be replicated using data from other research councils and a number of extensions are suggested.

In-kind contributions

The analysis discussed above uses data on the cash funding of research. It does not take into account in-kind contributions that can add value to monetary funding. We have used HEBCI to estimate the value of such contributions and the effect public funding has on their size.

This analysis is represented in the following diagram.

Figure 25. Illustration of in-kind contribution analysis



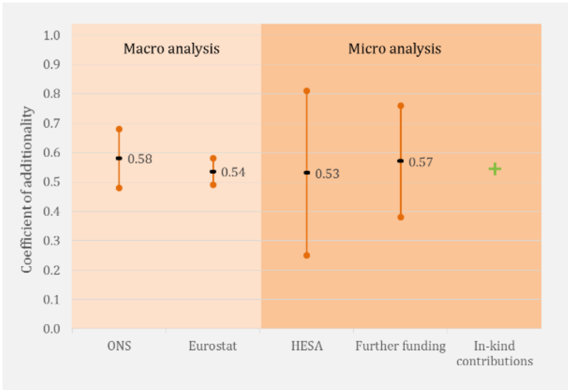
It should be reiterated that this analysis captures value that is not reflected in the other analyses – the value from in-kind contributions.

Summary of estimates of the coefficient of additionality

The following chart presents the estimates of the coefficient of additionality from the five pieces of analysis described above. The table overleaf also includes a summary of the different effects we have found with regard to the type of private funding and the source of public funding.

As can be seen, for four of the pieces of analysis we present a range for the coefficient of additionality, along with the mid-point. For in-kind contributions, we find evidence suggestive of a positive coefficient, but the analysis is not comprehensive enough to give an estimate.

Figure 26. Estimates of the coefficient of additionality



As discussed above, each of the pieces of analysis estimates a coefficient of additionality at a different level of aggregation. ONS analysis, for example, estimates the effect of total public expenditure on total private expenditure. HESA analysis estimates the effect of public expenditure on R&D conducted within HEIs on the amount of private expenditure on R&D conducted in HEIs. For this reason, the estimates from the different pieces of analysis are not directly comparable with each other.

In section 4.10 we discuss how the estimates of the coefficient of additionality should be applied to give the £ effect of a change in public expenditure. Before turning to the results of our own analysis, we first present empirical estimates from previous studies and discuss the analytical benefits and challenges of our approach.

Table 4. Summary of estimates of the coefficient of additionality

	Analysis	Estimate of	Coefficient of additionality	Most reactive type of private funding	Effect of types of public funding
Macro analysis	ONS	The effect of total public sector expenditure on R&D, on total private sector expenditure on R&D. Illustrated as the effect of A on B in Figure 22.	0.48 – 0.68 (0.58 mid-point)	1. Business 2. Overseas 3. Charity	No difference found
	Eurostat	As above, i.e. the effect of total public sector expenditure on R&D, on total private sector expenditure on R&D. Illustrated as the effect of A on B in Figure 22.	0.49 – 0.58 (0.54 mid-point)	1. Overseas =2. Business and Charity	Government, rather than HE, funding more effective
Micro analysis	HESA	The effect of public sector expenditure on R&D conducted within HEIs, on private sector expenditure on R&D conducted within HEIs. Illustrated as the effect of C on D in Figure 23.	0.25 – 0.81 (0.53 mid-point)	1. Overseas =2. Business and Charity	No difference found
	Further funding	The effect of Research Council funding on the amount of further funding received from the private sector on awards that receive further funding. Illustrated as the effect of E on F in Figure 24.	0.38 – 0.78 (0.57 mid-point)	-	-
	In-kind contributions	The effect of public expenditure on collaborative research conducted within HEIs, on the value of in-kind contributions from private sector partners. Illustrated as the effect of H on H in Figure 25.	Evidence suggests positive coefficient	-	-

4.2. Existing estimates of additionality

The relationship between public and private investment in R&D has been subject to many empirical academic studies, starting with Blank and Stigler (1957). The majority of papers estimate a coefficient of additionality and we use this metric to compare between the results in the papers.

Two surveys of studies have been conducted that review a large proportion of the empirical papers. We have reviewed these two surveys, some of the interesting papers that appear in them, and some additional papers that are not covered in the studies. The papers that we have explicitly reviewed are summarised in the table at the bottom of this page.

The first wide scale survey of papers was performed by David et al. (2000) and covers papers from 1966 to 1999.

At the 'line of business' and laboratory level, they find elasticities ranging from ***0.06*** to ***0.336***. At the firm level they find both positive and negative elasticities, ranging from ***-0.13*** to ***0.48***. At the national level they find elasticities ranging from ***0.045*** to ***1.04***. We provide a review of some of the papers that give rise to these estimates later in this section.

David et al. (2000) draw the following conclusions from their survey.

- About ***two-thirds*** of studies surveyed provide evidence that public funding is complementary to private financing (i.e. crowding-in occurs), while ***one-third*** point to a substitution between the two sources (i.e. crowding-out).
- Government grants and contracts, and government spending on basic research do not displace private R&D funding except when R&D inputs have inelastic supply. The outcome depends on market demand and supply conditions, which are unobserved most of the time.
- Government R&D and tax incentives stimulate private R&D investments.

More recently, Correa et al. (2013) provide a meta-analysis of 37 papers from 2004-2011. The analysis suggests that public funds do not crowd-out but incentivise firms to revert funds into R&D. Results show that the effect of public investment in R&D is

Table 5. Summary of coefficients of additionality

Paper	Estimated effect	Data used	Coefficient of additionality*
Diamond (1998)	Effect of federal funding of basic research on private finding of basic research.	US macro time series 1953-1993	1.04
Lichtenberg (1987)	Effect of federally funded industrial research on privately funded industrial research.	US macro time series 1956-1983	0.045 (insignificant)
Guellec and van Pottelsberghe de la Potterie (2003)	Effect of publicly performed research on business funded research.	Macro panel data on 17 OECD countries 1981–1996	0.08 for government funding, -0.07 for government research
Haskel et al. (2014)	Effect of QR and RC funding on total external income (including public and private)	HESA and HEBCI data from UK HEIs 2003-2012	0.28**
Becker and Pain (2007)	Effect of government funded research conducted in industry on total industry R&D expenditure.	Panel of 11 UK manufacturing industries 1993-2000	0.18
Görg and Strobl (2007)	Effect of public sector grants to manufacturing firms on the firm's investment in R&D.	Panel of Irish manufacturing firms 1999-2002	Positive for small grants, negative for large

** Coefficient of additionality refers to the percentage change in private expenditure arising from a 1% increase in public expenditure. For example, a coefficient of additionality of 0.5 means that a 1% increase in public funding is associated with a 0.5% increase in private funding*

*** Long-run effect of public income on total external income (includes private and public income). Long-run effect calculated from Exhibit 12 Model 1.3 coefficients: 0.103/(1-0.632) = 0.28.*

predominantly positive and significant. The elasticity estimates range from ***0.166*** to ***0.252***, with reasonable confidence intervals at the 95 percent level.

To structure our own review of papers, and to align with our quantitative work, we look separately at:

- ***National macro studies*** that look at individual national economies and study changes in private sector investment over time.
- ***Cross-country macro studies*** that use datasets that include observations of the same countries over multiple time periods (panel data).
- ***Micro level studies*** that look at specific industries, firms, or HEIs.

4.2.1. National macro studies

Five papers were reviewed by David et al. (2000) that studied the relationship between public and private investment at the national level. All papers found evidence of crowding-in and they report elasticities from two papers.

Lichtenberg (1987) found an elasticity of 0.045, although this is insignificant. The paper estimates regressions of private R&D expenditure on US federal industrial R&D expenditure between 1956 and 1983, controlling for total demand (sales) and in some cases other variables.

Diamond (1998) finds an elasticity of 1.04. He studies the effect of federal funding of basic research on private funding of basic research in the US over 43 years. The paper focuses on basic research defined, by the National Science Board, as: research with the objective "to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind".

As the author notes, the results of this study should be interpreted with caution, however. The high elasticity could be a product of both public and private expenditure being driven by an omitted variable – such as the cost of performing research or potential returns to research. Furthermore, the estimate is in relation to expenditure on basic research, which naturally has a higher elasticity compared to all research expenditure.

Main (2013) quotes an internal BIS paper[19] that relates the level of private expenditure on business enterprise R&D (BERD) to the level of public BERD in the service sector. GDP was used to control for economic factors in regressions based on the growth rates of variables. Including a one year time lag, the results suggest that a 1% increase in public BERD in the services sector leads to an increase in private sector BERD in the services sector of 13.57%. This estimate is very high compared to other studies.

4.2.2. Cross-country macro studies

David et al. (2000) report on two papers that use macro panel datasets. ***Von Tunzelmann and Martin (1998)***, a working paper, undertakes an analysis of R&D time-series for 22 OECD countries over the period 1969–1995. Using the panel data, they fitted a linear model relating the changes in industry-financed R&D to the changes in government-financed R&D, and the previous level of both private and public R&D expenditures, allowing country-specific differences in all the coefficients. In only 7 of the 22 countries did they find that changes in government-funded R&D have any significant impact on changes in industry-funded R&D, with the sign being positive in five of those seven cases.

The other paper, ***Levy (1990)***, uses a sample of nine OECD countries for the period of 1963–1984. He uses a specification that distinguishes among three geographic regions within which it is assumed that there would be strong spillover effects: the US, Europe, and Japan. He regresses national private R&D investment on aggregate public R&D investment in each region, aggregate regional GDP, and individual country dummy variables. Among the nine countries in his panel, Levy finds that five countries exhibit significant overall crowding-in, whereas two countries show significant crowding-out (one of which being the UK). The reasons for the differences remain unexplored.

Guellec and van Pottelsberghe de la Potterie (2003) investigate how publicly performed research, direct funding and fiscal incentives stimulate business-funded R&D across 17 OECD countries. The authors' primary model gives the following short-run (long-run) private R&D elasticities: 0.07 (0.08) for government funding; -0.28 (-0.31) for tax incentives; -0.06 (-0.07) for government research; and there is no impact of university research.

The major results of the study are the following:

- Direct government funding of R&D performed by firms has a positive effect on business financed R&D (except if the funding is targeted towards defence activities).
- Direct funding is more effective when it is stable over time.
- The stimulating effect of government funding varies with respect to its generosity – it increases

[19] *'Investigating leverage amongst public and private R&D investments', Dunn*

up to a certain threshold (about 10% of business R&D) and then decreases beyond.

4.2.3. Micro level studies

David et al. (2000) report the elasticity of five micro level studies giving a range of -0.13 to 0.336. Below we review a number of papers that are more relevant to our work due to being more recent or focussed on the UK.

Haskel et al. (2014) analyse the relationship between 'total external income' and QR and RC funding. They use HESA and HEBCI data for the period 2003 to 2012. Total external income (TEI) is defined as funding from business and community interactions, and includes both public and private funding. Their regression models take the form:

$$ln(TEI_t) = \alpha + \beta ln(TEI_{t-1}) + \gamma ln(QR\&RC_{t-1})$$

It relates the level of total external income in an HEI in 2008-12 to the level of total external income and QR & RC funding achieved in the period before (2003-07). Levels of funding are adjusted for the number of full time equivalent staff. The results suggest that if QR & RC funding would have been 1% higher in the first period, total external income funding would have been 0.10% higher in the second period. As the lagged dependent variable is included as an explanatory variable this should be considered as a short-run effect. The implied long-run effect is 0.28%.

Ulrichsen (2014) investigates the relationship between HEFCE KE funding (through HEIF), and total KE income. He uses HESA, HEBCI and HEFCE data for the period 2005 to 2012. As with Haskel et al. (2014), KE income can include funding from both public and private sectors. His regression models take the general form of:

$$ln(KE\ income_t) = \alpha + \beta ln(KE\ income_{t-1}) + \gamma ln(HEIF_t) + \lambda(controls_{t-1})$$

It relates the level of KE income of a HEI in 2009-2012 to the level of KE funding achieved in the previous period (2005-2008) and the level of HEIF funding in this period (2009-2012). Levels of funding are adjusted for the number of full time equivalent staff. The results imply that a 1% increase in HEIF funding would lead to a 0.3% to 0.37% increase in KE funding. As the lagged dependent variable is included as an explanatory variable this should be considered as a short-run effect. The implied long-run effect is 0.65% to 0.72%.

Görg and Strobl (2007) investigate the relationship between government support for R&D and private expenditure on R&D within the manufacturing sector in Ireland. Their regression included explanatory variables according to the size of the R&D subsidy. Dummy variables were used to denote whether a small (<€12,500), medium (>€12,500, <€55,000), or large (>€55,000) grant was received. Each category had roughly the same amount of firms in it.

The results suggest that, for domestic plants, grant provision at a small or medium scale does not crowd-out private spending, and in the case of small amounts may even create additionality effects. Too large grants, however, may act to finance R&D activity that would have taken place anyway and thus have a crowding-out effect. Their model suggests that a small grant increases a domestic firm's private R&D spending by 26.4%, and a large grant reduces their private R&D spending by 20.4%. In contrast, they find that there is no evidence of such additionality or crowding-out effects for foreign multinationals, regardless of grant amount size.

Becker and Pain (2007) investigate the effect of government funded R&D using a panel of UK manufacturing industries. They estimate that the effect of a 1 percentage point increase in the share of business R&D expenditure funded by the government is an increase in the level of R&D expenditure of 1.1% in the short-run, and 1.8% in the long-run. We calculate these to be roughly equivalent to coefficients of additionality of 0.11 and 0.18, respectively.

4.2.4. Implications for our quantitative analysis

The papers reviewed above have a number of implications for our own quantitative work.

- Firstly, we are not able to form a strong a-priori view as what to expect the coefficient of additionality to be. The papers do generally find a positive relationship between public sector and private sector funding and the estimates tend to be between zero and one. This, however, is a relatively large range.
- Furthermore, the coefficient of additionality can be expected to be different depending on the subject of our analysis. That is, we can expect different results from the macro and micro analysis.
- There is no standard methodological approach, further than the use of regression analysis. There are multiple studies that assess additionality at macro and micro levels. Some studies utilise panel data approaches, and others rely on either cross sectional or temporal comparisons. In the following section we discuss the benefits and challenges that each of our analytical approaches face.

4.3. Analytical benefits and challenges

In this section we briefly discuss the challenges and benefits in relation to the different pieces of econometric analysis that we have conducted. These have been identified through:

- the literature review presented in the section above;
- our understanding of econometric techniques; and
- conducting the actual analysis.

In line with our main analysis packages, we categorise the analytical benefits and challenges in terms of: national macro analysis; cross-country macro analysis; and micro level analysis. Annex A details the benefits and challenges summarised in Table 6, and below we discuss some of the main points.

National macro analysis

The primary advantage of analysing additionality at the macro level is that all spillover effects (within the country) are incorporated in the estimates. For example, if public investment in one area resulted in a change in private investment in another, analysis at low levels of aggregation may not capture these spillovers.

A challenge faced by such macro analysis is controlling for the appropriate drivers of private sector investment – specifically wages. One effect of public expenditure may be an increase in researcher wages, and care needs to be taken as to not attribute increased costs to increases in the amount of private research being funded.

Cross-country macro analysis

National macro datasets have naturally limited numbers of observations, which can limit the analysis and robustness of results. Cross-country macro analysis allows for a greater number of observations to be used. Also, more sophisticated techniques can be used to control for country-specific effects.

However, with more countries in the analysis there may be a greater number of factors that need to be accounted for to explain the variation. The choice of countries to include in the analysis can also influence the results, and it is not always clear which ones should be included.

Micro level analysis

Micro level analyses tend to benefit from even greater numbers of observations, giving the potential for even greater robustness.

Importantly though, we may be more interested at additionality at levels of aggregation less than the national level – for example, within HEIs. Micro analysis can also provide insight as to how and where spillover effects manifest.

Micro analysis can suffer from selection bias, though. Factors that attract public funding of particular projects needs to be controlled for to isolate the marginal effect of public investment.

Table 6. Benefits and challenges of econometric approaches

	Benefits	Challenges
National macro analysis	» All spillover effects within the country are taken account of. » Public funding can be considered exogenous.	» Controlling for the relevant drivers of private sector investment. » Accounting for the lag effects of public investment. » Using the appropriate dependent variable. » Accounting for time series issues.
Cross-country macro analysis	» Additional observations, compared to macro studies, can lead to more robust estimates of additionality. » The panel structure of the dataset allows more sophisticated regression techniques to be used, which may in turn also lead to more robust results.	» Controlling for the additional variation. » Selecting appropriate countries to include in the analysis.
Micro level analysis	» Additional observations, compared to macro studies, can lead to more robust estimates of additionality. » Additionality at the level at which we are concerned with can be analysed.	» Controlling for potential selection bias. » Appropriately reflecting the spillover effects.

See Annex A for further discussion of these points

4.4. Results from ONS data analysis

Our primary macro level analysis is based on ONS data and our main findings are that:

- Our analysis of UK GERD data is consistent with a crowding-in effect that it is economically and statistically significant. That is, public sector investment increases the amount of private sector investment in R&D.
- We estimate a long-run coefficient of additionality of between 0.48 and 0.68 – giving a mid-point of 0.58. That is, a 1% increase in public funding gives rises to between a 0.48% and 0.68% increase in private funding, controlling for other factors that are likely to influence the level private funding.
- The data also suggests that the effect of public funding on private funding is not instantaneous, with a lag of approximately one to two years before the effect is seen. This is consistent with our framework and previous empirical studies.
- The effect of public funding appears to be strongest for business enterprise funding and weakest for charity funding. That is, public sector investment has a greater impact on business investment than charity investment in R&D.
- The data also indicates that there is no statistically significant difference between the effect of public funding through what is primarily the BIS budget and other government funding. Estimation of any differential effects is hindered by the very high correlation between types of public expenditure over time.

The rest of this section is divided into the following parts:

- overview of ONS data;
- consideration of control variables;
- aggregate level analysis;
- disaggregated level analysis;
- comparison with BIS budget; and
- discussion of findings from ONS analysis.

4.4.1. Overview of ONS data

Here we provide a short overview of the ONS data (a fuller description is given in Annex B).

The ONS collects GERD data through surveys and census, which includes both operating (current) and capital spending. Data is collected in line with the Frascati Manual (OECD). The data shows both expenditure by funding sector (e.g. whether businesses or Research Councils made the funds available for R&D) and by performing sector (i.e. whether businesses or Research Councils undertook the R&D). These breakdowns for 2012 are given in section 3 in Table 3.

We define the public sector expenditure as the sum of funding from:

- higher education;
- Higher Education Funding Councils;
- Research Councils; and
- other government sources.

In Annex C we compare the BIS budget and these groupings.

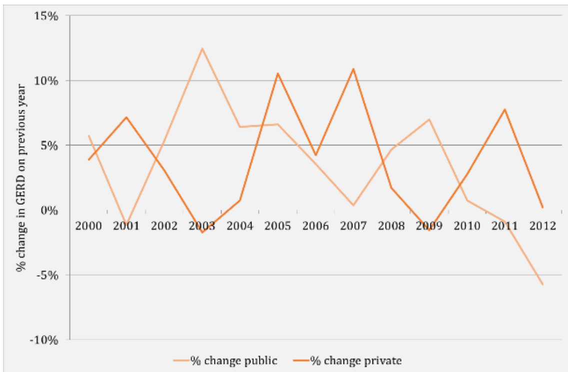
The private sector is defined as funding from:

- businesses;
- charities; and
- overseas.

We use annual data from 1997 to 2012 (inclusive) for our econometric analysis i.e. 16 observations.

Before conducting regression analysis we examine the relationship graphically. The following chart shows the annual percentage change in public and private expenditure.

Figure 27. Annual percentage change in public and private expenditure

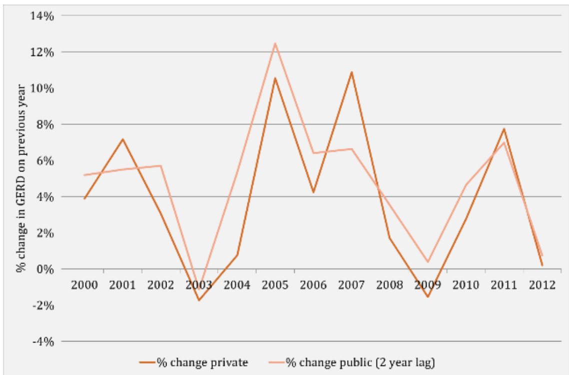


Source: EI analysis of ONS GERD data

One may expect to see a positive correlation between the two series. In fact, the figure indicates that private funding falls (rises) when public funding rises (falls) sometimes i.e. there is a negative relationship between the two variables. Taken at face value, this could indicate that public funding crowds out private funding. However, such a conclusion would be premature, as there are various other possibilities for this pattern in the data, which we explore further.

As addressed in the existing literature, there may be a lag between public expenditure and its effect on private expenditure. This could explain the lack of correlation in the growth rates. The following chart shows that when the growth of public expenditure is lagged by two years, the two series become very highly correlated.

Figure 28. Annual percentage change in (2 years lagged) public and private expenditure



Source: EI analysis of ONS GERD data

This correlation is consistent with there being a lagged relationship between public and private investment.

Another reason why there isn't a positive correlation in Figure 27 could be that there are other factors driving private investment, other than public expenditure. We discuss the control variables that we have considered for this analysis in the next section.

4.4.2. Consideration of control variables

The advantage of regression analysis is that multiple factors that affect private investment can be taken account of. Drawing on the literature and general economic theory, we present a number of control variables that we have investigated for the analysis of the ONS data:

- ***GDP*** is likely to be related to both private and public investment in R&D. Higher levels of economic activity may be associated with easier access to finance, making investing cheaper. Also, research may be more profitable if incomes are higher, as individuals can better afford products that result from research.
- If projects are financed through borrowing money, the cost of research will be directly linked to ***interest rates***. Additionally, if the interest rate is low, it may be more profitable to invest in research than lend the money and receive the rate of interest. We have investigated the effect of an average base rate that retail banks charge because this should be more closely related to the cost of finance that the private sector faces, compared to, for example, the Bank of England base rate.
- As discussed earlier, as staff costs are a significant element of research costs the wage rate can inflate the amount of investment in nominal terms. Similarly the ***price level*** of other inputs will influence the degree of investment. One way to deal with this is to include measures of inflation as explanatory variables. We have investigated including general inflation and wage rates as control variables. Furthermore, we have also run models using real and nominal variables, as discussed later.
- The level of investment in UK R&D will depend on the conditions within the UK but also in competitor countries. For example, if research becomes cheaper to conduct in other countries, all else equal, you would expect research investment in the UK to reduce. We have explored ***exchange rates*** to account for international competitiveness.

Given the limited data points in the ONS dataset, it is not possible to include large numbers of control variables. One of the advantages of the Eurostat dataset is that it includes many more observations and more control variables can be included.

An alternative to including all the possible drivers of private sector investment decisions is to use a proxy for the decision as a whole. ***Fixed capital formation*** measures private firms' investment into capital such as land and buildings. The ONS defines Gross Fixed Capital Formation as per the box below.

Box 1. Gross Fixed Capital Formation

"Gross fixed capital formation (GFCF) is the estimate of net capital expenditure (acquisitions less the proceeds from disposals) on fixed assets by both the public and private sectors. Fixed assets are produced assets used in production processes for more than one year. Examples of capital expenditure include spending on machinery and equipment, transport equipment, software, artistic originals, new dwellings and major improvements to dwellings, other buildings and major improvements to buildings, and structures such as roads."[20]

Gross Fixed Capital Formation is one of a number of components of total GDP. The potential advantage of this measure is that, like investment in R&D, investment in fixed capital will be made on the basis of revenues and costs that businesses expect in the future. As discussed in the results section, this control performs well in the models.

[20] *http://www.ons.gov.uk/ons/rel/naa1-rd/united-kingdom-national-accounts/the-blue-book--2014-edition/rpt---chapter-9.html*

A potential concern associated with the measure is that it is endogenous. This could arise, for example, if the private sector set a fixed investment budget and any increased R&D funding came at the expense of other investments – or if R&D funding was viewed as a substitute or complement to other forms of investment in fixed capital. But there are two reasons to think that these concerns may not be material in practice.

- First, in relation to setting fixed investment budgets, it is not clear that businesses do make investment decisions in this way. Rather, investments are likely to be evaluated on the basis of whether they are individually profitable (i.e. where their expected return exceeds the cost of capital), rather than being determined by the difference between a budget and other investment spending. Charities are also unlikely to substitute between different forms of investment.
- Second, in relation to the substitutability or complementarity of different investments, the key issue here is whether the degree of substitutability or complementarity rises or falls over time. That is, whether we could wrongly conclude that an increase/fall in fixed capital expenditure is caused by underlying drivers of expected future revenues or costs, when in fact it is caused by something else. Although we cannot rule this possibility out, neither do we have reason to suspect it as a major issue.

Fixed capital formation will take account of some international aspects, but may not fully control for the decision between investing in the UK or overseas. Investors in UK fixed capital take into consideration the potential returns from investing in other countries. However, fixed capital and R&D can have different properties in terms of mobility and location importance. R&D can easily be performed in one country and its findings implemented in another. Fixed capital, on the other hand, is sometimes tied to the geographic location in which the investment is made. For example, some forms of medical research could take place anywhere in the world, but patients need to be treated close to home.

Specific tax breaks in relation to R&D will also not be fully captured in a proxy measure such as fixed capital formation.

As demonstrated, fixed capital formation, and any other such proxy variables, will take account of multiple drivers of the R&D investment decision but are unlikely to cover all of them. For this reason we have explored models that include both individual investment decision drivers (such as interest rates and exchange rates) and proxy measures such as fixed capital formation. As will be seen, our chosen models are relatively parsimonious in relation to the number of control variables included.

4.4.3. Aggregate level analysis

In this section we present the results of our primary macro analysis. This is conducted at the 'aggregate' level, where we consider the effect of all public expenditure on all private expenditure. In section 4.4.4 we present our 'disaggregated' macro analysis using ONS data, which considers, for example, the effect of all public expenditure on all private business expenditure.

The general specification we have used to estimate additionality using the ONS data is as follows:

$$\ln(private\ funding)_t = a + b.\ln(public\ funding)_t + c.controls + e_t$$

Assuming that the equation is properly specified, the parameter b measures the elasticity of private funding with respect to public funding i.e. the % change in private expenditure brought about by a 1% change in public expenditure, other things being equal.

Here, in the main body of the report, we present three 'core' aggregate models and discuss the sensitivity analysis that we have conducted.

Core models

Our three core models are:

- ***Model 1*** relates public expenditure in year t to private expenditure in year t, with no control variables.
- ***Model 2*** builds on Model 1 by including a measure of UK gross fixed capital formation and the previous year's level of private expenditure.
- ***Model 3*** is the same as Model 2 except that the previous year's level of public funding is included instead of the current year's level in order to recognise and capture any possible 'delay' in its effect on private funding.

The results of these models are presented in the following table.

Table 7.

	Model 1	Model 2	Model 3
ln(public funding)$_t$	0.91*** (0.07)	0.16 (0.10)	
ln(public funding)$_{t-1}$			0.29** (0.12)
ln(fixed capital)$_t$		0.43*** (0.14)	0.42*** (0.11)
ln(private funding)$_{t-1}$		0.71*** (0.10)	0.57*** (0.12)
R-squared	0.91	0.98	0.98
Implied long-run elasticity	0.91	0.54	0.68

Statistically significant at the 10% level, 5% level** and 1%****

- Model 1 is our most basic model and gives an elasticity of 0.91. However, for the reasons discussed elsewhere in this report, this model fails to take account of the other factors that drive private funding, and so is likely to be biased. Moreover and unsurprisingly, the model performs poorly statistically, with evidence that the model has omitted variables and serially correlated residuals (see Annex B for further details).

Model 2 and 3 address these deficiencies.

- Model 2 includes a measure of gross fixed capital formation to control for other factors that are likely to influence the level of private funding. Given the limited degrees of freedom available to us it is not possible to include a large number of explanatory variables, and the model is unlikely to be able to 'unpick' the effect of many different drivers. For this reason, we have used gross fixed capital formation as a proxy for all of the factors that drive private sector investment in general, as discussed in section 4.4.2. As can be seen, gross fixed capital formation is statistically significant in Model 2 – suggesting that it is a suitable control variable.

  Model 2 also includes the previous year's level of private funding as an explanatory variable. This is to help capture possible 'memory' in private spending. Research contracts that involve private funding can be set over multiple years and as such one may expect a high correlation between private funding in two separate years. The results suggest that there is such an effect present in the data.

  The coefficient on public funding falls significantly in Model 2, but due to the inclusion of a lagged dependent variable an adjustment needs to be made to calculate the equivalent 'long-run elasticity'. This implied 'long-run' elasticity is shown in the final row of the table. It shows that the elasticity falls from 0.91 to 0.54. This is perhaps unsurprising as the control variable (UK gross fixed capital formation) is economically large (0.43) and statistically significant – and so the public funding variable is likely to have erroneously captured the effect of other factors in Model 1.

- Model 3 builds further on Model 2 by including the lag of public funding. As discussed previously, this is to account for the delay with which public funding may have an effect. Including the lag of public investment results in a long run elasticity of 0.68.

Consistent with the findings of previous studies, a comparison of Model 2 and Model 3 suggests that the contemporaneous effect of public funding is smaller than the lagged effect of public funding. Indeed, the coefficient on public funding is statistically insignificant in Model 2. Given results from previous studies and our understanding of the spillover effects of public investment, the inclusion of the lag of public investment is a desirable characteristic. The long-run elasticity, or coefficient of additionality, from Model 3 suggests that a 1% increase in public funding will lead to a 0.68% increase in private funding (in the long-run).

Sensitivity analysis

To check the robustness of Model 3 we have run a number of additional models as sensitivity analysis. We discuss some of these below – a fuller discussion of our sensitivity analysis is given in Annex B.

- We include UK GDP as a control variable in addition to UK gross fixed capital formation. The coefficient on GDP is insignificant, suggesting that fixed capital captures macro effects properly.
- Specifying the models in levels rather than in logs produces a similar estimate of additionality (0.72) to Model 3.
- Similarly, constraining the time period used to the later data (2002-2012) also produces a similar estimate of additionality (0.73).

Further to the points above, we have also conducted sensitivity analysis to account for potential omitted variable bias. Specifically, the cost of labour used in R&D.

The solution to omitted variable bias is to include the relevant missing variables. We have used a measure of mean wages for 'professional occupations' sourced from the ONS's Annual Survey of Hours and Earnings (ASHE).

The results of simply adding this measure to Modal 3 are shown in the table below under Model 7. The implied elasticity estimate fell slightly from 0.68 to 0.64, however, the wage variable was statistically insignificant. This could be for a number of reasons, including that: the other control variable adequately captures the wage effect or – as noted in the literature – the inclusion of the lagged dependent variable 'picks up' some or all of the effect of potentially relevant independent variables. This may particularly be an issue in relatively short time series datasets, as we have here.

To examine the latter possibility we ran the same regression, but excluded the lagged dependent variable. The results of this regression are shown under Model 8 below. It shows that the elasticity falls to 0.48.

Table 8.

	Model 3	Model 7	Model 8
ln(public funding)$_{t-1}$	0.29** (0.12)	0.28* (0.15)	0.48** (0.18)
ln(fixed capital)$_t$	0.42*** (0.11)	0.42*** (0.12)	0.50** (0.17)
ln(private funding)$_{t-1}$	0.57*** (0.12)	0.56*** (0.13)	
ln(wage)$_t$		0.03 (0.22)	0.50* (0.25)
R-squared	0.98	0.98	0.97
Implied long-run elasticity	0.68	0.64	0.48

Statistically significant at the 10% level, 5% level** and 1%****

4.4.4. Disaggregated level analysis

As displayed in Table 3, ONS data splits out the both the source of both public and private UK GERD. Using this split we have undertaken two 'disaggregated' types of analysis:

- ***Analysis by type of private funding*** estimates the effect of total public funding on: business funding; overseas funding; and charity funding.
- ***Analysis by type of public funding*** estimates the effect of public funding from: RCs, HEFCs and Higher Education; and other government funding.

The results of these two pieces of analysis are presented in the sections below.

Analysis by type of private funding

Using Model 3 as a basis, we have constructed three more models to explore the effect of public investment on different types of private funding. These three models presented in the following table are replications of Model 3 run separately for: business funding, charity funding; and overseas funding.

Table 9.

	Business	Overseas	Charity
ln(public funding)$_{t-1}$	0.45*** (0.10)	0.21 (0.29)	-0.03 (0.21)
ln(fixed capital)$_t$	0.35* (0.16)	0.86 (0.49)	0.42** (0.16)
ln(dep var)$_{t-1}$	0.37** (0.13)	0.62** (0.22)	0.87*** (0.16)
R-squared	0.97	0.88	0.98
Implied long-run elasticity	0.72	0.55	-0.24

Statistically significant at the 10% level, 5% level** and 1%****

The results suggest that the association between public funding and private funding is strongest for business funding and weakest for private non-profit funding, specifically:

- The estimated long-run elasticity for business funding is 0.72 and is statistically significant at the 1% level.
- The estimated long-run elasticity for overseas funding is lower at 0.55 and is not statistically significant. Neither is the control variable.
- The estimated long-run elasticity for private non-profit funding is small and negative and is not statistically significant.

Analysis by type of public funding

To assess the effect of different types of public funding we ran two additional regressions as presented in the following table.

Table 10.

	Private	Business
ln(RC, HEFC, HE)$_{t-1}$	0.25 (0.15)	0.42*** (0.12)
ln(Other gov)$_{t-1}$	0.32** (0.13)	0.54*** (0.12)
ln(fixed capital)$_t$	0.42*** (0.13)	0.34*** (0.18)
ln(dep var)$_{t-1}$	0.60*** (0.14)	0.38** (0.15)
R-squared	0.98	0.98
Implied long-run elasticity RC, HEFC, HE	0.36	0.37
Implied long-run elasticity Other gov	0.44	0.51

Statistically significant at the 10% level, 5% level** and 1%****

The first model includes different explanatory variables for public funding from: RCs, HEFCs and Higher Education; and other government. We divide public expenditure between these two groups due to the high correlation between the spending of RCs, HEFCs and Higher Education. As the spending of these three sources are very highly correlated we cannot build a model that differentiates between the effects of them.

The second model differs only in the fact that the dependent variable is just business expenditure.

One advantage of splitting public funding in the way described above is that it aligns closely with the BIS budget (Annex C provides a reconciliation between sources of funding in the ONS data and the BIS budget). The grouping 'RCs, HEFCs and HE' aligns closely with the BIS budget and we therefore interpret the estimated coefficient as reflective of the additionality of BIS spending.

However, in both models presented above the differences between the coefficients on the two sources of public funding are not statistically significant. Therefore, we draw from this that the effect of BIS spending compared to other government spending is similar in terms of additionality. The coefficients from the aggregate models are applicable to estimating the effect of changes in the BIS budget.

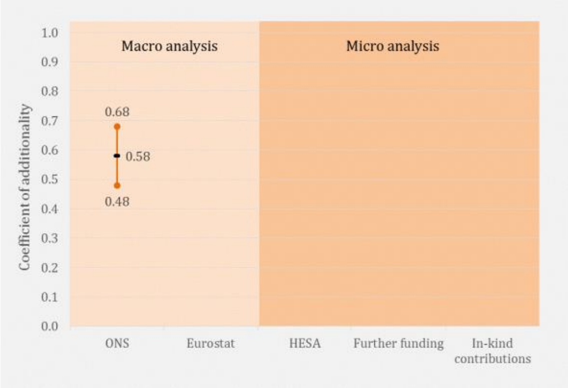
4.4.5. Summary of findings from ONS analysis

The aggregate level models that we constructed using ONS data give a variety of estimates of the coefficient of additionality. As can be seen, they range from 0.91 (Model 1) to 0.48 (Model 8). From the models presented above, we have identified two preferred models:

- Model 3 is preferred to the other core models because it controls for factors that drive investments in general and the lag effects of public and private investment in R&D. Model 3 gives a coefficient of additionality of 0.68.
- Model 8 attempts to control for wages, which may not be fully reflected in the fixed capital formation control. However, the measure used for wages is not specific for researchers. The model also does not include the lag of private investment, which controls for the fact that research budgets may be set over multiple years. Model 8 gives a coefficient of additionality of 0.48.

The upper and lower bounds given by these two models, and the mid-point of 0.58, are illustrated below using the chart presented in section 4.1 to compare the results from our different pieces of analysis.

Figure 29. Range of preferred estimates from ONS analysis



The ONS analysis therefore gives a 'central' estimate of the coefficient of additionality of 0.58. This suggests that an increase in total public sector investment in R&D would lead to an increase in total private sector investment of 0.58%. As we discuss in section 4.10, this figure can be used to estimate the £ change in private funding that might occur due to a change in the BIS budget.

If any changes are made to public sector investment in R&D, our disaggregated analysis suggests that the effect will be primarily seen in the amount of investment by UK businesses, rather than by UK charities or from overseas.

4.5. Results from Eurostat data analysis

In addition to our primary macro analysis based on ONS data, we have also analysed Eurostat data as a cross-check. As discussed in section 4.3 the additional degrees of freedom given by the Eurostat data may allow for more robust results. The analysis also allows us to compare the relative performance of the UK with other countries. Our main findings are that:

- Our analysis of Eurostat data is consistent with that of ONS data. The coefficients of additionality at the aggregate level from our Eurostat analysis are within the range from our ONS analysis. Specifically, the Eurostat analysis gives a range of coefficients of additionality of between 0.49 and 0.58.
- Our Eurostat analysis estimates a coefficient of additionality that is applicable to all countries within the model. When tested, we find no statistically significant difference between additionality within the UK and the other comparator countries on average.
- The effect of public investment on different types of private investment does not appear to differ considerably. This is converse to the ONS analysis.
- The analysis does suggest that private funding is more sensitive to government funding as opposed to higher education funding.

The rest of this section is divided into the following parts:

- overview of Eurostat data;
- aggregate level analysis;
- disaggregated level analysis; and
- summary of findings from Eurostat analysis.

4.5.1. Overview of Eurostat data

A fuller description of the Eurostat data, and our subsequent analysis, is given in Annex D, but here we provide a shorter overview.

The Eurostat dataset contains very similar information and splits to that in our ONS dataset. Data is compiled following the guidelines laid out in the Frascati Manual (OECD) and the Regional Manual (Eurostat). The data shows both expenditure by the sector that provides the funding and the sector that performs the research.

Public and private sectors are defined as they are in our ONS analysis. Specifically, the public sector consists of funding from:

- government (which in the case of the UK includes RCs and HEFCs); and
- Higher Education.

The private sector consists of funding from:

- businesses;
- charities; and
- overseas.

There are, however, some differences in how countries account for R&D expenditure. For example, Denmark, Finland and Netherlands incorporate charity funding within government expenditure. We bear this in mind when considering our disaggregate analysis.

We have chosen to use a subset of countries for which Eurostat reports data. These countries are:

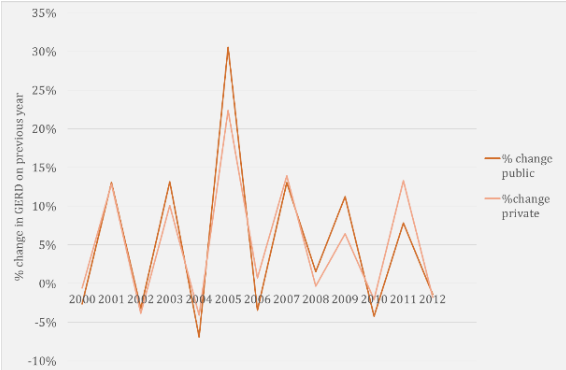
- the 11 countries that joined the Euro in 1999;
- the US;
- China (excluding Hong Kong);
- Japan; and
- the UK.

The full list of countries is included in our Eurostat analysis is in Annex D, and a discussion of the criteria used to select countries is provided in Annex A.

We use annual data from 1999 to 2012 inclusive. All data has been collected in national currencies and converted into Euros using exchange rates from Thomson Reuters Datastream.

Before presenting the econometric results, we examine the relationship between public and private investment in R&D graphically. The following chart shows the annual percentage change in in public and private expenditure, for our 11 Euro-area countries included in our analysis.

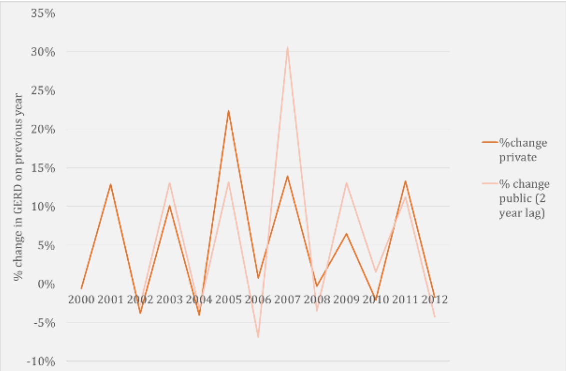
Figure 30. Annual growth of original 11 Euro country public and private R&D expenditure



Source: EI analysis of Eurostat data

Conversely to the pattern seen in the ONS data, there is a very high correlation between the growth of public and private expenditure in our Euro-area countries. To explore the possible lag structure of the data, the following chart shows the growth of private expenditure against a two year lagged growth rate of public expenditure.

Figure 31. Annual growth of original Euro country public (2 year lag) and private expenditure



Source: EI analysis of Eurostat data

As can be seen, there is also a positive correlation when the growth of two year lagged public expenditure is considered. We investigate lagged effects further in the econometric analysis presented in the next section.

4.5.2. Aggregate level analysis

In line with our analysis of ONS data, we first consider additionality at the aggregate level and then the disaggregated level. As discussed in section 4.3, we take advantage of the structure of the dataset and use panel data approaches. Here we present the findings from fixed effects models, and in Annex D there are equivalent random effects models. Both of these panel data approaches give similar results. The general specification we have used is as follows:

$$\ln(private\ funding)_{it} = a_i + b.\ln(public\ funding)_{it} + c.controls + e_{it}$$

The fixed effects model allows each country to have its own specific effect – captured in a_i. In effect, each country has a dummy variable that can incorporate all of the country-specific factors that affect private investment.

The following table presents three aggregate level specifications:

- *Model 1* relates public and private investment with no controls.
- *Model 2* includes a measure of GDP as a control variable.
- *Model 3* includes lags of both public and private funding instead of the current level of public funding.

Table 11.

	Model 1	Model 2	Model 3
ln(public funding)$_{it}$	0.96*** (0.04)	0.49*** (0.11)	
ln(public funding)$_{it-1}$			-0.10* (0.05)
ln(gdp)$_{it}$		0.67*** (0.20)	0.36*** (0.08)
ln(private funding)$_{it-1}$			0.84*** (0.03)
R-squared (overall)	0.93	0.92	0.99

Statistically significant at the 10% level, 5% level** and 1%****

Model 1 estimates a coefficient of additionality of 0.96, but does not account for any other drivers of private investment.

Model 2 includes a measure of GDP to control for general factors that may influence private investment. Gross fixed capital formation, as used in the ONS analysis, was tried but its effect was statistically insignificant. Model 2 reduces the coefficient of additionality to 0.49.

In line with the ONS analysis, Model 3 includes lagged public and private expenditure variables to account for the delayed and 'memory' effects of investment in R&D. However, as can be seen, the coefficients of additionality is only statistically significant at the 10% level. Furthermore, it implies a negative relationship between public and private investment, which is contrary to the rest of our results.

We also tested whether the effect of public expenditure is different for the UK compared to the other countries. We included an interaction terms between a UK dummy and the amount of public investment. However, the coefficient was not significant and the evidence therefore suggests that the UK does not experience different additionality compared to the average of other countries we have included in our sample.

4.5.3. Disaggregated level analysis

We now turn to analysing additionality at the disaggregated level, looking specifically at the effect of public expenditure on types of private funding and the effect of different types of public funding.

Analysis by type of private funding

We re-estimated Model 2 but separately for the different sources of private funding. This is to establish whether the effect of public expenditure has different effects on different types of private expenditure. The results of these models are shown in the following table.

Table 12.

	Business	Charity	Overseas
ln(public funding)$_{it}$	0.41*** (0.13)	0.38* (0.22)	0.58*** (0.19)
ln(gdp)$_{it}$	0.71*** (0.23)	1.22*** (0.37)	1.14*** (0.34)
R-squared (overall)	0.91	0.82	0.75

Statistically significant at the 10% level, 5% level** and 1%****

As can be seen, the effect of public expenditure is relatively similar across the different types of private funding. Overseas funding does appear to be slightly more reactive.

Analysis by type of public funding

The Eurostat data also allows us to analyse whether private sector funding is more sensitive to funding from either Higher Education or government (which in this case includes RCs and HEFCs for the UK).

The following table shows the results of models that include HE and government funding as separate explanatory variables, and GDP as a control variable. Models are run with total private sector investment and business only investment as the dependent variables.

Table 13.

	All private sector	Business only
ln(gov funding)$_{it}$	0.68*** (0.12)	0.62*** (0.13)
ln(HE funding)$_{it}$	0.18*** (0.03)	0.20*** (0.03)
ln(gdp)$_{it}$	0.09 (0.19)	0.07 (0.21)
R-squared (overall)	0.92	0.91

Statistically significant at the 10% level, 5% level** and 1%****

The results suggest private sector investment is more sensitive to government, as opposed to HE funding.

4.5.4. Summary of findings from Eurostat analysis

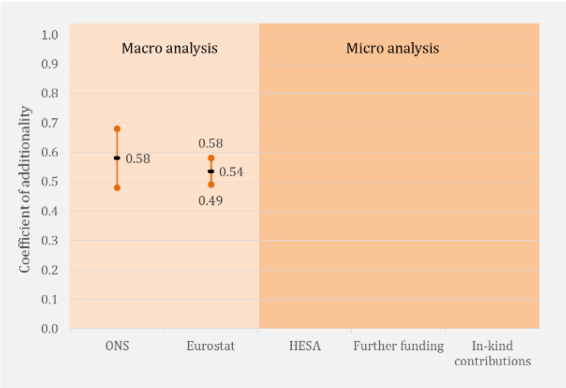
The results of our analysis of Eurostat data are broadly consistent with those of the ONS analysis, and are supportive of a crowding-in effect.

Our preferred aggregate level model from the Eurostat analysis is Model 2. This is because it takes account of other drivers of private sector investment, apart from public expenditure (which Model 1 does not). Furthermore, the estimated coefficient of additionality is statistically significant at the 1% level and the sign (positive) that we expected. Model 3 fails in these two respects. We therefore use the coefficient of additionality, of 0.49, from Model 3.

To provide a range of estimates we have also taken the result from the random effects model that is equivalent to Model 3. The coefficient of additionality from this model is 0.58 – more details can be found in Annex D.

From this analysis we therefore take a range of estimates for the coefficient of additionality of 0.49 to 0.58 – giving a mid-point of 0.54. This is illustrated in the following chart.

Figure 32. Range of preferred estimates from Eurostat analysis



As can be seen, the range of additionality estimates from our Eurostat analysis is consistent with our ONS analysis. That is, the range of 0.49 to 0.58 from the Eurostat analysis lies within the range from the ONS analysis of 0.48 to 0.68. As such, for the purpose of acting as a cross-check, the Eurostat analysis is supportive of the ONS findings.

The Eurostat analysis also suggests that private sector funding from abroad is more sensitive to public sector funding than domestic business or charity funding. This could be a result of, for example, overseas funding being internationally mobile and 'following' the public sector funding across countries.

The analysis also suggests that HE funding has less of an impact on private sector funding than government funding. This could be due to HE funding being spent on more basic research and facilities, rather than specific research that attracts in higher levels of private investment.

4.6. Results from HESA data analysis

This section presents the results of our main micro analysis, which is based on HESA data. It looks specifically at the effect of publicly funded research conducted within HEIs on the amount of private funding of research conducted within HEIs. Our main findings from this analysis are that:

- Our analysis of the HESA data is also consistent with a crowding-in effect. Here we estimate the effect of public sector investment in R&D performed within HEIs on the amount the private sector invests in research conducted within HEIs. We find a range of estimates of coefficients of additionality, from 0.25 to 0.81 – giving a mid-point of 0.53.
- This analysis suggests that overseas funding appears to be marginally more sensitive to public funding than business or charity funding.
- The analysis is inconclusive with regard to the effectiveness of different types of public funding. We look specifically at RC versus other sources of public funding but cannot make a firm conclusion as to whether one is more effective than the other.

The rest of this section is divided into the following parts:

- overview of HESA data;
- consideration of control variables;
- aggregate level analysis;
- disaggregated level analysis; and
- summary of findings from HESA analysis.

4.6.1. Overview of HESA data

A fuller description of the HESA data and our subsequent analysis is given in Annex E, but here we provide a shorter overview.

The Higher Education Statistics Agency (HESA) collects financial information on the activities of all UK higher education institutions (HEI) via the annual Finance Statistics Return (FSR). We use data for the period 2003/04 to 2012/13.

For the purpose of this analysis we have grouped research income into two broad categories:

- ***UK public funding***, which comprises (i) BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh (henceforth referred to as RCs funding), (ii) UK central government bodies, local authorities, health and hospital authorities(henceforth referred to as other government funding), and (iii) QR research related research funding: Funding Body Grants for recurrent (research).
- ***Private funding***, which comprises (i) UK-based charities, (ii) UK-based charities (open competitive process), (iii) UK-based charities (other), (iv) UK industry, commerce and public corporations, (v) EU government bodies, (vi) EU-based charities (open competitive process), (vii) EU industry, commerce and public corporations, (viii) EU other, (ix) Non-EU-based charities (open competitive process), (x) Non-EU industry, commerce and public corporations, (xi) Non-EU other, and (xii) Other sources.

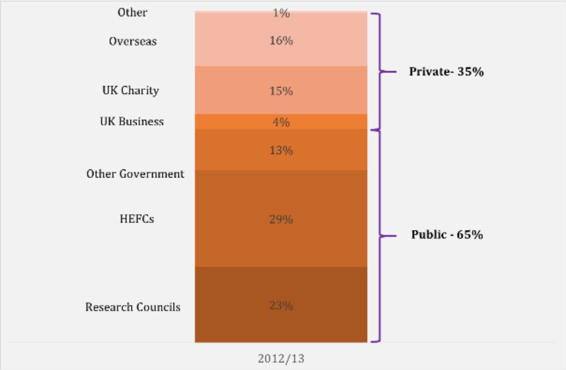
These definitions of the public and private sectors align with those used in the ONS and Eurostat analysis. We highlight though that within the HESA data EU government bodies represent approximately 25% of 'private' sector funding.

For a more detailed analysis we have made further splits of the data, namely:

- ***RC funding***: this is equivalent to (i) BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh income for research grants and contracts
- ***Government funding (non-RC)***: this is equivalent to (i) UK central government bodies, local authorities, health and hospital authorities, and (ii) QR-related research funding.
- ***Business funding***: relates solely to UK business investment, i.e. (i) UK industry, commerce and public corporations
- ***Charities funding***: relates solely to UK charities, namely: (i) UK-based charities, (ii) UK-based charities (open competitive process), (iii) UK-based charities (other).
- ***Overseas funding***: comprises all research income from abroad: (i) EU government bodies, (ii) EU-based charities (open competitive process), (iii) EU industry, commerce and public corporations, (iv) EU other, (v) Non-EU-based charities (open competitive process), (vi) Non-EU industry, commerce and public corporations, (vii) Non-EU other.

These splits broadly align with the ONS splits and definitions that we have used in our other analysis. The following chart illustrates the split at the total HEI level for 2012/13.

Figure 33. Sources of R&D income (2012/13)



Source: EI analysis of HESA data

There are however significant differences between institutions. This naturally leads us on to the question of whether the amount of public funding that is received affects the amount of private funding that is received. As per the other pieces of analysis presented above, we investigate this question through regression analysis.

4.6.2. Consideration of control variables

Drawing on the literature and general economic theory, we considered the following control variables to use in the econometric analysis of HESA data:

- **»** ***Size***: Larger HEIs are likely to attract more funding. We tried various control variables for size, such as: total staff FTE; total academic staff FTE; total research staff; total staff; total income; and total expenditure.
- **»** ***Subject area***: Certain areas of research naturally attract higher levels of funding. To control for this, we have included size variables of the following departments at each HEI: Medical and Human Sciences; Life Sciences; Engineering and Physical Sciences; and Humanities.
- **»** ***Quality***: One may reasonably expect quality to be an important driver of funding. We have therefore considered the following control variables: the ratio of total staff FTE to total students FTE; TRAC Peer Groups; and RAE scores.
- **»** ***Region***: We have considered the region in which each institution is.
- **»** ***Macroeconomic conditions***: As further controls we have also explored macroeconomic variables such as GDP and Gross Fixed Capital Formation.

4.6.3. Aggregate level analysis

Turning to the econometric results, we first investigate additionality at the aggregate level. That is, the effect of total public research income on total private research income. The general specification we have used is as follows:

$$\ln(private\ funding)_{it} = a_i + b.\ln(public\ funding)_{it} + c.controls + e_{it}$$

We use two types of regression technique here:

- **»** ***Pooled OLS*** takes all the observations across institutions and time periods and runs a standard OLS model.
- **»** ***Fixed effect models*** take advantage of the panel structure of the dataset and control for HEI-specific effects that are not captured by the control variables.

We also make the distinction between Russell Group and non-Russell Group universities. We note that Russell Group universities receive about 70% of the total HEI research income, and given their long standing focus on research there is reason to believe that they might experience different effects to other institutions. As such, we create models based on Russell Group (RG) and non-Russell Group (Non-RG) institutions.

Table 14 shows the results of three pooled OLS regressions (Model 3, 3.1 and 3.2), including our selected control variables: for all institutions together; RG HEIs only; and non-RG HEIs only.

Model 3 gives a coefficient of additionality of 0.81. Notably our measure of quality is not significant – this may be because the peer group dummies are accounting for the differences it would otherwise pick up.

Models 3.1 and 3.2 give different coefficients of additionality and we take a weighted average of them to be representative of the total sample. This results in a coefficient of additionality of 0.68.

Models 4, 4.1 and 4.2 are equivalent specifications but use a FE estimation technique. Model 4 gives a coefficient of additionality of 0.25, and the weighted average of those from Model 4.1 and 4.2 is 0.48.

Our aggregate micro analysis therefore gives a wide range of coefficients of additionality. We discuss the weight we place on each of them in section 4.6.5.

4.6.4. Disaggregated level analysis

In keeping with the other pieces of analysis we estimate the effect of public funding on different types of private funding, and the effect of different types of public funding.

Analysis by type of private funding

We have analysed the effect of public expenditure on private expenditure arising from: UK businesses; UK charities; and overseas. In order to do so we have run both pooled OLS and FE models, and run separate models for all institutions, RG and non-RG institutions. For practical reasons we do not present these models in the main body of the report, but they are available in Annex E.

We have taken the highest and lowest coefficients of additionality from: the models that include all HEIs; and the weighted average of the models that look at RG and non-RG institutions separately. The subsequent ranges of results are given below.

- For UK business funding, we find a coefficient of additionality of between ***0.36*** and ***0.78***.
- For UK charities, we find a coefficient of additionality of between ***0.31*** and ***0.74***.
- For overseas funding, we fund a coefficient of additionality of between ***0.42*** and ***1.10***.

As can be seen, the ranges above would suggest that overseas funding is marginally more sensitive to public funding of HEI research than that from UK businesses or charities.

Analysis by type of public funding

We make the distinction between public funding from: (i) Research Councils and (ii) UK central government bodies, local authorities, health and hospital authorities, and QR related research funding. In order to distinguish between the effects of these two categories of funding we include the percentage of funding that is from RCs as an explanatory variable in our preferred aggregate level models. The specific results of these can be found in Annex E.

Pooled OLS results suggest that there may be a positive relationship between the percent of public funding that comes from RCs and the amount of private funding that is received. However, FE models do not find any statistically significant effects of the percentage of public funding that comes from RCs. As such, the results are inconclusive as regards to whether the source of public funding affects the amount of private sector investment.

4.6.5. Summary of HESA analysis results

Our analysis of HESA data is consistent with a crowding-in effect. The aggregate level models that we constructed using HESA data give a variety of estimates of the coefficient of additionality. We place equal weight on the OLS and FE results for the following reasons:

- The robustness of the OLS specifications relies on the control variables accounting for all the factors that drive private sector investment. Given that all but one of the control variables are statistically significant, and we have controlled for all the measurable factors our framework suggests, we do not see any major deficiencies with these models.
- The benefit of the FE models is that they can take account of HEI-specific factors that drive private investment, but which are not captured through

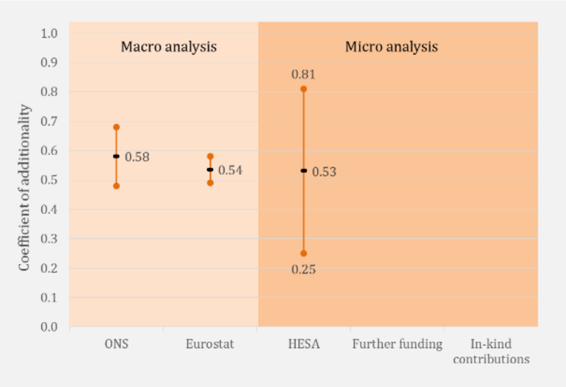
Table 14.

	Model 3	Model 3.1 (RG)	Model 3.2 (Non-RG)	Model 4	Model 4.1 (RG)	Model 4.2 (Non-RG)
ln(public funding)$_t$	0.81*** (0.03)	0.64*** (0.10)	0.78*** (0.04)	0.25*** (0.05)	0.58*** (0.09)	0.24*** (0.06)
ln(Medical and Human Sciences)$_t$	0.12*** (0.02)	0.55*** (0.05)	0.09*** (0.03)	0.09 (0.08)	0.22** (0.09)	0.08 (0.09)
ln(Life Sciences)$_t$	0.06*** (0.02)	0.21*** (0.04)	0.09*** (0.03)	-0.03 (0.04)	-0.02 (0.07)	-0.03 (0.05)
ln(Engineering and Physical Sciences)$_t$	0.11*** (0.02)	0.06 (0.05)	0.13*** (0.03)	-0.08 (0.06)	0.65*** (0.18)	-0.08 (0.07)
ln(Humanities)$_t$	-0.52*** (0.06)	0.07 (0.05)	-0.63*** (0.10)	0.06 (0.14)	-0.13 (0.12)	0.09 (0.17)
ln(quality)$_t$	0.03 (0.07)	0.75*** (0.08)	-0.10 (0.09)	-0.39*** (0.14)	0.22 (0.17)	-0.42** (0.16)
ln(total staff FTE)$_t$	0.25** (0.12)	-0.85*** (0.22)	0.42*** (0.15)	0.50* (0.22)	-0.39 (0.29)	0.47* (0.25)
ln(fixed capital)$_t$	0.83*** (0.20)	0.58*** (0.18)	0.95*** (0.24)	0.98*** (0.17)	0.63*** (0.12)	1.01*** (0.20)
Peer group dummies not shown	-	-	-	-	-	-
R-squared	0.91	0.92	0.85	0.75	0.71	0.57

Statistically significant at the 10% level*, 5% level** and 1% level*** the observed variables. However, the FE models rely on the variation within HIEs to estimate the effect of public expenditure. Given that funding levels are relatively stable over time may result in the HEI-specific term taking account, to a certain degree, of the effect of public expenditure.

Therefore, we take the higher and lower estimates of the coefficient of additionality of 0.25 and 0.81. This gives a mid-point of 0.53, as illustrated below.

Figure 34. Range of estimates from HESA analysis



Based on the mid-point, the HESA analysis therefore suggests that a 1% increase in public funding of research performed in HEIs gives rise to an increase in private funding of research conducted in HEIs of 0.53%. We discuss what this means in monetary terms in section 4.10.

Whilst the ONS analysis did not find a significant effect of public expenditure on charity funded R&D, the HESA analysis does. This could be a result of public funding of HEI research pulling in charity funding from other sources. Specifically, research conducted within charities or other HEIs may be diverted towards HEIs that receive more public funding. This effect would result in neutral additionality at the macro level – explaining why it is not observed in the ONS analysis.

The HESA analysis also suggests that overseas funding is the most sensitive to public expenditure. This could suggest that further public funding aimed at facilitating overseas investment would generate more private investment than funding aimed at UK businesses or charities.

Specifically in relation to the type of public funding, our analysis could not identify a difference between RC funding and that from other public sector organisations.

4.7. Academic subject extension to HESA analysis

In addition to the analysis of HESA data presented in the section above, we have undertaken an extension that focuses on academic subjects. Specifically, this extension considers whether additionality differs by subject area.

To the extent that there may be existing perceptions regarding differences in additionality between subject areas, we test empirically as to whether there is evidence to suggest these differences exist in reality, and, if so, to also identify subjects that attract the most additional private sector funding given investment by the public sector. Existing perceptions may be based on the absolute size of private sector investment into a particular subject, or by the 'closeness' of a subject to the commercial world.

The main findings from this analysis are:

» In line with the other analyses, the subject level HESA data is consistent with a crowding-in effect. We regress the level of private funding on the level of public funding from research contracts and grants (i.e. excluding QR funding) and find a positive coefficient of additionality for all subject areas. The coefficients of additionality lie within the range of zero to one – which aligns with our expectations based on previous studies (although none have been conducted at the subject level).

» The analysis suggests that 'engineering & technology', and 'medicine, dentistry & health' have the highest levels of additionality. That is, these two areas are likely to see the greatest percentage increase in private funding if public funding is increased by 1%. However, results are sensitive to the exact specification used and the confidence intervals around the additionality coefficients are relatively wide. We therefore cannot say with certainty the rank order of subjects in terms of additionality.

» In addition to models based on all HEIs, we also ran models on just Russell Group institutions, as they represent about 74% of total research income from contracts and grants. These models suggest that other subject areas such as 'biological, mathematical & physical sciences', 'architecture and planning' and 'agriculture, forestry & veterinary science' also have high levels of additionality compared with others. Differences between results from models based on all institutions and models based on just the Russell Group suggest that additionality varies between type of institution.

The rest of this section is divided into the following parts:

- differences in the data used;
- correlation analysis;
- econometric analysis; and
- summary of HESA extension analysis results.

Further details of this analysis can be found in Annex F.

4.7.1. Differences in the data used

The underlying data used for this analysis is the same as that used in the HESA analysis presented in the previous section. However, here we do not include QR-related funding as this is not available at a subject level within the dataset. This analysis therefore estimates the relationship between public funding of contract and grant research on private funding of research.

At the most granular level the data is split by 45 different subjects, but for most of our analysis we use the following ten subject groupings:

- medicine, dentistry & health;
- agriculture, forestry & veterinary science;
- biological, mathematical & physical sciences;
- engineering & technology;
- architecture & planning;
- administrative & business studies;
- social studies;
- humanities & language based studies & archaeology;
- design, creative & performing arts; and
- education.

As discussed in the next section, there is consistency between the correlations of the 45 subject areas and the correlations of the higher level groupings. For this reason, we believe that the groupings do not lose any of the granular detail and add to the robustness of the data.

We have used the same control variables as in the above HESA analysis. As the focus of this analysis is on differences in additionality coefficients between academic subjects, we will examine their relative positions in detail, rather than the absolute value of the coefficients.

We have undertaken two types of analysis, which we explore below: (i) correlation analysis, and (ii) econometric analysis.

4.7.2. Correlation analysis

Before presenting the econometric analysis we show the correlations between public and private expenditure for the different subjects. We have conducted this analysis at both the disaggregated level (45 subjects) and the aggregated level (10 subject areas). This analysis provides valuable insights and an indication of what the econometrics might show. However, it is not able to control for factors which may be influencing this relationship, such as HEI size or quality.

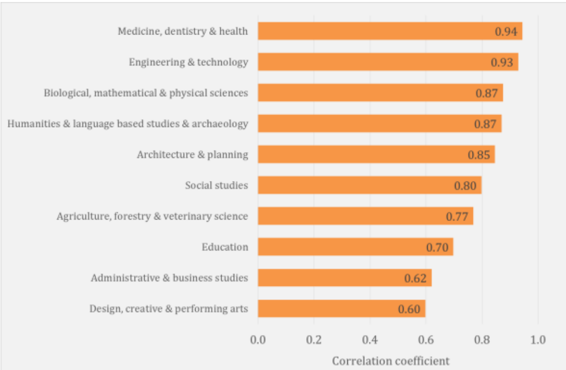
Disaggregated level analysis

At a disaggregated level, the correlation between public and private funding is highest for: (i) clinical medicine – 0.95; (ii) mechanical, aero and production engineering – 0.94; (iii) physics – 0.94; (iv) anthropology & development studies – 0.92; and (v) general engineering – 0.91. The subjects with the lowest correlations were: (i) catering & hospitality management; (ii) classics; and (iii) music, dance, drama & performing arts. Generally, scientific subjects have higher correlations than non-scientific subjects.

Aggregated level analysis

At an aggregated level (ten subject areas), the correlation between public and private income is highest for: (i) medicine, dentistry & health; (ii) engineering & technology; and (iii) biological, mathematical & physical sciences. The subjects with the lowest correlation are: (i) design, creative & performing arts; (ii) administrative & business studies; and (iii) education. The chart below shows the correlation for each subject group.

Figure 35. Correlation coefficients by subject groups



Source: EI analysis of HESA data

The correlations are consistent with the science subjects having higher levels of additionality. However, simple correlation analysis does not control for other factors that might be driving private sector investment. We address this using econometric analysis presented in the next section.

4.7.3. Econometric analysis

The econometric analysis closely follows the preceding HESA analysis. We investigate additionality of each academic subject group. That is, the effect of total public research income (excluding QR funding) for each specific subject group on total private research income for that group. The general specification we have used is as follows:

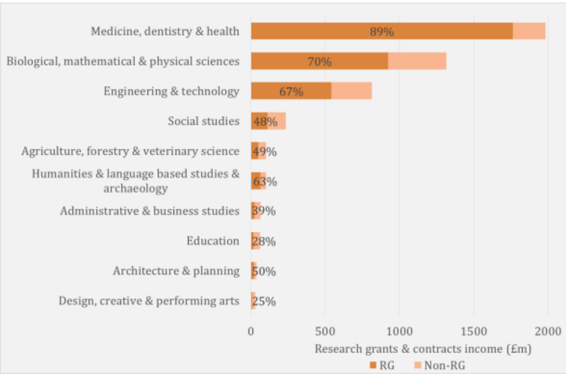
$$\ln(private\ funding\ subject\ group)_{it} = a_i + b.\ln(public\ funding\ subject\ group)_{it} + c.controls + e_{it}$$

We use two types of regression technique here:

- ***Pooled OLS*** takes all the observations across institutions and time periods and runs a standard OLS model.
- ***Fixed effect models*** take advantage of the panel structure of the dataset and control for HEI-specific effects that are not captured by the control variables.

We also make the distinction between Russell Group and non-Russell Group universities. We note that Russell Group universities receive about 74% of the total HEI income for research contracts and grants, and given their long standing focus on research there is reason to believe that they might experience different effects to other institutions. As such, we create models based on all institutions and on Russell Group (RG) institutions only. The chart below shows the split between RG and non-RG for each subject area in terms of research income (excluding QR funding).

Figure 36. R&D income by subject group and RG, non-RG (2012/13)



Source: EI analysis of HESA data

We have four types of model (OLS and FE specifications for all and RG only institutions). These four types of model give a wide-ranging set of additionality estimates for each subject group. As an indicative sense check, the average of all of the additionality estimates is 0.43, which compares to the mid-point of 0.53 calculated in the main HESA analysis. These estimates are of a similar magnitude, but it should be remembered that they are estimating different effects i.e. this analysis does not include the effect of QR funding. Nonetheless, this provides a level of confidence in the subject level results.

The rank order from each of the four model types, for each subject area, is presented in the following table.

Table 15. Ranking of academic subjects' additionality coefficients according to different models

	POLS	POLS (RG)	FE	FE (RG)
Medicine, dentistry health	6	1	10	2
Agriculture, forestry & veterinary science	1	8	2	5
Biological, mathematical & physical sciences	4	5	6	4
Engineering & technology	2	2	1	1
Architecture & planning	5	3	3	3
Administrative & business studies	7	6	4	8
Social studies	3	4	8	6
Humanities & language based studies & archaeology	8	7	7	9
Design, creative & performing arts	10	10	5	10
Education	9	9	9	7

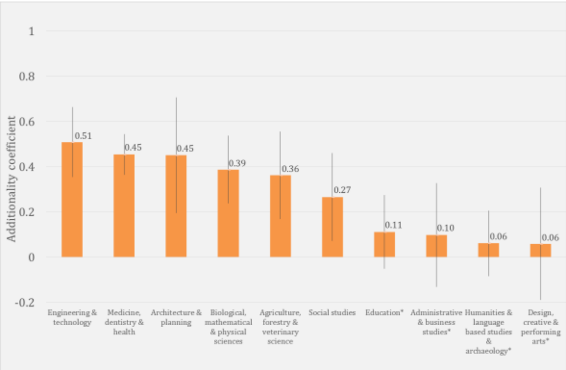
As can be seen, there is considerable difference between the rank order from the different models. 'medicine, dentistry & health', for example, has the highest additionality estimate based on the pooled OLS regression for Russell Group institutions, but the lowest based on the fixed effect model for all institutions. The differences between RG and non-RG models suggest that additionality varies between type of institution. This is understandable given the research focus of the Russell Group.

The low ranking of 'medicine, dentistry & health' in the FE model for all institutions is likely an artefact of the concentration of medical research in UK HEIs.

That is, a small number of HEIs conduct the vast majority of medical research and the fixed effect term in the model explains most of the variance across institutions.

The coefficients of additionality and their confidence intervals from the fixed effects Russell Group only model are presented in the following chart.

Figure 37. FE (RG) regression results (coefficients of additionality) with confidence intervals



Source: EI analysis of HESA data

As can be seen, 'medicine, dentistry & health' and 'engineering & technology' have the highest coefficients of additionality – 0.51 and 0.45 respectively. However, the confidence levels around these coefficients are relatively large and we cannot say that they are statistically significantly different from the third and fourth highest additionality estimates ('architecture & planning' and 'biological, mathematical & physical sciences').

As with the other models, subjects such as 'design, creative & performing arts', 'humanities & language based studies & archaeology' and 'education' have relatively low estimates of additionality. Furthermore, the coefficients from this model are not statistically different from zero (although all coefficients in the other models are significant).

4.7.4. Summary of HESA extension analysis results

Our extension of the HESA analysis provides further evidence for a crowding-in effect. The main focus of this analysis is whether additionality differs by academic subject and whether some academic subjects are 'better' than others at crowding-in private investment.

Due to the substantial differences between types of institution, regression results based only on the Russell Group are likely to give a better indication of the additionality that they experience, compared to models that include all institutions. As with the main HESA analysis, we investigate both POLS and FE models. In both cases (POLS RG and FE RG), 'medicine, dentistry & health' and 'engineering & technology' are the two highest ranked subject groups in terms of their coefficient of additionality.

Furthermore, in general, STEM subjects tend to have higher additionality coefficients than others. However, this was not consistent throughout all the models. Subjects such as 'design, creative & performing arts', 'humanities & language based studies & archaeology' and 'education' tend to have lower levels of additionality.

This pattern across different subjects aligns broadly with the 'closeness' of the subject to the commercial world. Medicine and engineering research, for example, can be commercially very valuable, whereas research into humanities and arts is harder to commercialise.

4.8. Further funding

One way in which spillover effects from research can be realised is through 'further funding'. This is where additional funds are received to explore new, but related, research as a result of an original award. The MRC defines further funding as competitive peer reviewed funding, which may include scholarships, studentships, fellowships and travel awards.

It could be the case, for example, that the public sector (e.g. through a RC) funds the initial research and then the private sector invests in subsequent related research. Further funding can be seen as a relatively 'close' form of spillover effect, as opposed to, for example, applied research carried out in industry as a result of publicly funded basic research.

Given the function of further funding, and the fact that MRC has made data available on it specifically, we have analysed it separately. The main findings from our analysis of the MRC data are as follows – these may differ slightly from analysis and information reported by the MRC elsewhere due to differences in the parameters of the dataset or how the analysis has been carried out.

- Further funding can take years to arise but the majority arrives within the first three years following the start of the original award. Consistent with our econometric analysis of ONS data, this would suggest that the full effect of public sector investment is not instantaneous.
- We estimate that 65% of MRC awards receive further funding and 45% receive further funding from private sector organisations.
- In relation to original awards that have received further funding, 25-30% of the total spend (including the original award spend and public and private further funding) is from the private sector.

This is equivalent to a private sector percentage statistic.

» Our econometric analysis is consistent with a crowding-in effect. It suggests that increased public sector investment increases the amount of private sector further funding. We find a coefficient of additionality of between 0.38 and 0.76 – giving a mid-point of 0.57.

In the sections below we present our findings that are based on descriptive statistics and econometric analysis.

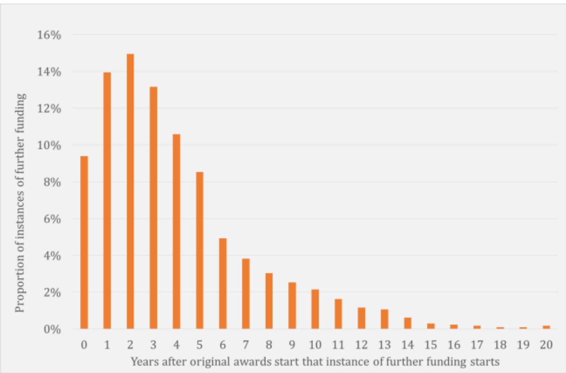
4.8.1. Occurrences of further funding

The MRC provided us with data relating to their awards, which includes information on further funding. From this data we make a number of observations that are of relevance to this study, which we discuss below. We note that further funding data is self-reported by PIs, and therefore should be considered with this in mind. Further details of our analysis of MRC data can be found in Annex G.

Speed of further funding

In the first instance, we recognise that further funding can take many years to occur. The chart below shows the years after the original award starts that each instance of further funding was received.

Figure 38. Speed at which further funding is received



Source: EI analysis of MRC data

As can be seen, most instances of further funding are received within the first few years of the original award starting – about 50% were received within the first three years. In line with the literature and our analysis of the ONS data, this suggests that spillover effects from publicly funded research may take years to be realised. Furthermore, this evidence suggests that there will be both a contemporaneous effect (further funding received within the same year as the original award) and a lagged effect.

Receipt of multiple instances of further funding

MRC awards that have received further funding have often received more than one instance of further funding. About two thirds of original awards that had received further funding in our datasets had received more than one instance. This suggest that research is far from 'linear' in that one project can give rise to many subsequent areas for investigation.

We have also been able to look at the number of awards that a PI has received further funding for. The large proportion of PIs in our dataset had only received further funding on one original award, although 15% had received further funding in relation to two awards and there was a long tail of occurrences of more.

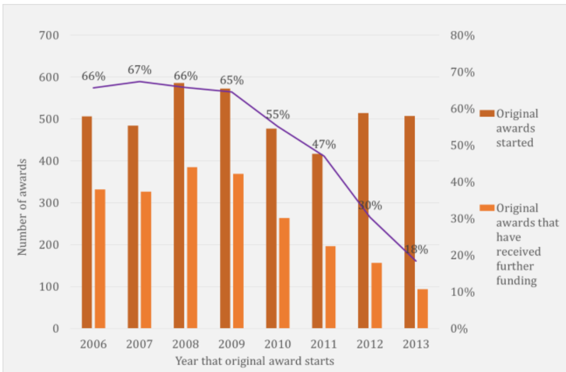
A learning effect may be present in this data and explain why some PIs have received further funding on many awards. A reasonable hypothesis could be that a PI 'learns' how best to attract further interest in their work and after receiving further funding on one project are able to draw it on others.

The observation that some PIs have received further funding on multiple awards may also be a function of the number of projects they have been PI on – which might relate to the number of relationships they have. Alternatively, the type of research may have a strong bearing on the suitability of further funding.

Proportion of awards that have received further funding

The data that we have received allows us to compare all MRC managed awards with those that have received further funding. Specifically, we can look at the proportion of MRC managed awards that have received further funding, as shown in the chart below.

Figure 39. Proportion of awards that received further funding



Source: EI analysis of MRC data

As can be seen, roughly 65% of awards that started in the years between 2006 and 2009 have received further funding. This percentage decreases with more recent cohorts.

This difference between award start year is due to the fact that awards that started longer ago have had more time to receive further funding. As we know from Figure 38, it can take years for instances of further funding to be realised. We therefore place more weight on the observations of projects that stated earlier in time – we expect the newer projects to receive further funding in the future and the percentage within those cohorts to increase to a similar level as the earlier time periods. The timing of an award is an important aspect in our analysis of further funding, and we discuss it in more detail later.

4.8.2. Effect of public funding on private further funding

The data from MRC includes information on the source of the further funding i.e. whether it is from a public or private sector source. This enables us to assess the relationship between public and private expenditure.

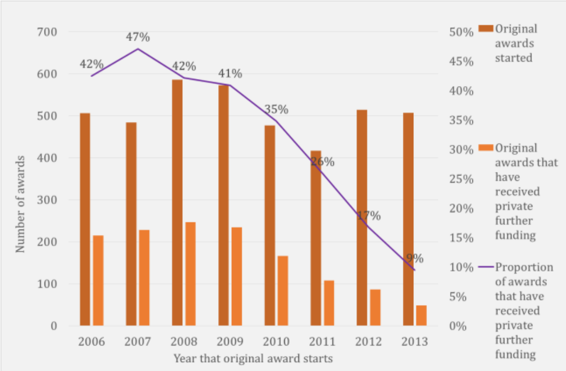
In order to do so, we make a simplifying assumption. The data we have on original award spend relates to awards that are managed by MRC. These awards can include both MRC funding and that from co-funders. We understand contributions from co-funders to be a relatively small proportion of the spend that MRC manages, and contributions from private sector co-funders to be even smaller. As such, we make the simplifying assumption that spend on MRC managed awards is purely from the public sector.

In turn, we look at: the proportion of awards that have received further funding from the private sector; the value of private sector further funding; and the effect of public expenditure on private sector further funding.

Proportion of awards that have received further funding from the private sector

The chart below is the equivalent to Figure 39, but based only on private sector further funding. It shows that about 45% of projects at the beginning of the time period have received further funding from a private sector organisation.

Figure 40. Proportion of awards that have received private further funding



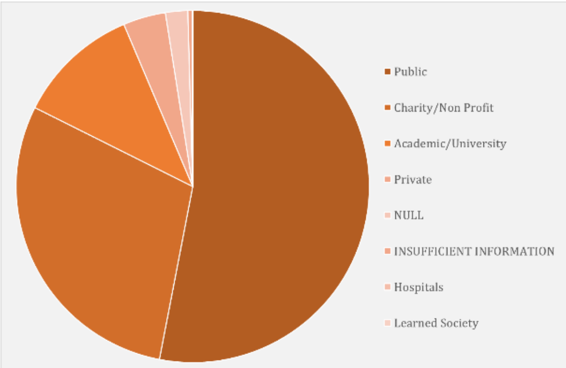
Source: EI analysis of MRC data

Therefore, a significant proportion of awards receive further funding, and about two thirds of those that do receive further funding from the private sector.

Value of private sector further funding

In relation to the value of the further funding that the original awards attract, the majority is from public sector organisations, as shown in the following chart.

Figure 41. Source of further funding (value)

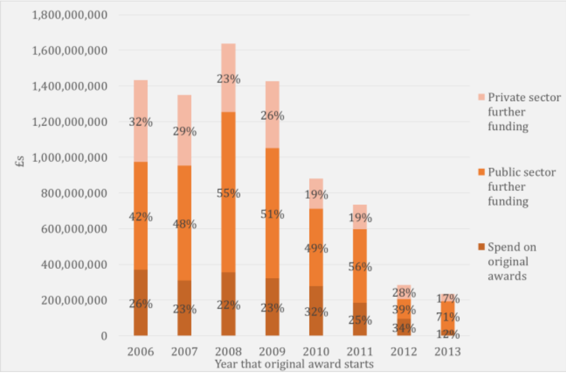


Source: EI analysis of MRC data

Charity further funding is, however, a significant proportion (29%) and "private" – assumed to be mainly industry – a much smaller fraction (4%).

Compared to the original award, further funding adds significant value to the research, and private sector further funding adds roughly the same as the value of the original award. This is shown in the chart below.

Figure 42. Value of original awards and further funding



Source: EI analysis of MRC data

In the context of all of the spend that is connected to an original award (i.e. including further funding) the private sector contributes roughly 25-30% (based on the years 2006-2009 in the chart above). For projects that receive further funding, this is equivalent to a private sector percentage of 25-30%.

Effect of public expenditure on private sector further funding

The data also allows us to estimate the relationship between public expenditure on original awards and the level of private follow-on funding that is received. In keeping with the econometric methodology used to assess the other datasets, we estimated models of the following form:

$$ln(follow\text{-}on_i) = \alpha + \beta ln(public_i) + \gamma(controls_i) + e_i$$

We have constrained the analysis that we have conducted to take into account only occurrences where further funding is received. We are therefore estimating the effect of public expenditure on private further funding, where private further funding occurs.

Given the data available, we have included controls for two factors. Firstly, and as discussed previously, the age of an award is assumed to affect the amount of further funding that it has received. Projects that started longer ago have had more opportunity to receive further funding. We know that instances of further funding can take many years to occur and that the proportion of awards that have received further funding decreases with how recent the start date is.

Furthermore, by inspecting the charts above one can see that the effect of the start date of the award diminishes with older projects. That is, cohorts 2006-2009 appear roughly similar, whereas, for example, the proportion of awards that have received further funding diminishes significantly for cohorts 2010-2013. To account for this apparent non-linear effect we include the start year and the square of the start year as control variables.

The second factor that we attempt to control for is the amount of public sector further funding that is received. This has two aspects to it:

- Firstly, it may be a proxy for the quality of the research and its suitability for further research. There may be certain factors that make an award suitable for both public and private further funding, such as the specific research topic. These factors may also be correlated with the size of the original award. Using such a control is similar to the use of fixed capital formation or GDP in the macro analysis.
- Secondly, the amount of public sector further funding may directly affect the amount of private sector further funding. As with original research, public sector further funding may make private investment more profitable/desirable.

The following table shows the coefficient of additionality from three regressions. The first, doesn't include any control variables, the second includes controls for the original award start date, and the third includes controls for both the original award start date and the amount of public further funding that was received.

Table 16. Coefficients of additionality of public expenditure on private further funding

Factors controlled for	Coefficient of additionality
No controls	0.72
Start year of original award	0.76
Start year of original award and public sector further funding	0.38

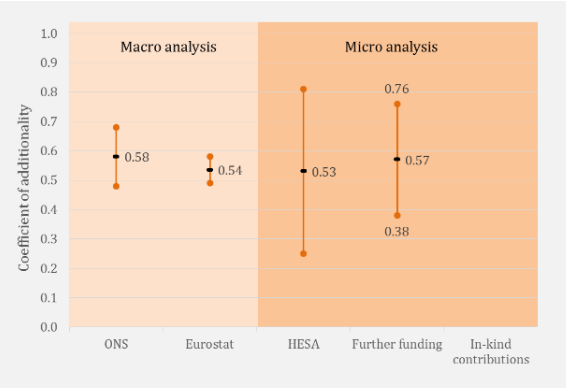
As can be seen, the coefficient of additionality remains similar between the first two models – around 0.75. The controls for the start date of the original award are statistically significant, indicating that it does affect the amount of further funding that is received. The coefficient of additionality in the third model reduces to 0.38. The controls for award start date become insignificant but the public further funding variable is significant. This suggests that either public further funding is driving private further funding, or there are similar factors driving both public and private sector further funding.

4.8.3. Summary of further funding analysis

Our analysis of the effect of public expenditure on private further funding is consistent with crowding-in. The models suggest that public expenditure has a positive effect on the amount the private sector subsequently invests in related research.

The chart below illustrates the range of estimates of the coefficient of additionality from this piece of analysis, along with the mid-point.

Figure 43. Range of estimates from further funding analysis



The limitations of this analysis should be taken into account when considering these results. The measure of additionality that is produced from this analysis is only in relation to further funding. It does not capture research that has resulted from the original award that is conducted by other academics or entirely within the private sector. The estimate of additionality may well therefore be an underestimate of the total effect of original award spend.

Furthermore, the analysis does not take account of substitution effects between awards. For example, private funds may be diverted away from one type of research to another that receives more public funding. In this case no additional private sector funds are allocated, they are simply redistributed.

The results also do not provide evidence as to whether there are economies of scale with regards to public expenditure and the amount of private further funding. That is, the results do not say whether one large award results in more private further funding than two awards half the size.

4.9. In-kind contributions

The data used in previous sections to calculate private sector percentages and additionality have been based on measures of cash expenditure by public and private sectors. In addition to providing money, partners often contribute to research in non-monetary ways. For example, an industry partner may provide a certain amount of time of one of their researchers. Typically, such in-kind contributions can consist of:

- researcher time;
- access to facilities or equipment; and/or
- data or information.

Such in-kind contributions can provide valuable inputs into research and therefore taking account of them will give a clearer picture of the contributions the private sector makes to R&D.

In the following sections we present analysis primarily based on HEBCI data. We find that:

» HEBCI data suggests that in-kind contributions represent roughly twice as much as cash contributions from collaborators. As such, in-kind contributions represent a non-negligible source of research income for HEIs. This represents an additional 2% of value on top of total HEI monetary income for research.

» Our econometric analysis of HEBCI data is consistent with a crowding-in effect found in other datasets.

» The data also suggests that HEIs with higher levels of public funding receive a greater proportion of research income as in-kind contributions. However, we have only found a weak relationship and firm conclusions should not be drawn from this analysis.

» MRC data also suggests that in-kind contributions are of significant value.

» However, without knowing further information about in-kind contributions from both public and private sectors is it not possible to draw firm conclusions about the effect of public funding on private in-kind contributions.

The rest of this section is divided between the following parts:

- Estimate of in-kind contributions using HEBCI data;
- Relationship between in-kind and contributions and public funding;
- The effect of in-kind contributions on estimates of additionality;
- Alternative ways of estimating in-kind contributions; and
- Summary of in-kind contributions analysis.

4.9.1. Estimate of in-kind contributions using HEBCI data

The annual Higher Education Business and Community Interaction (HEBCI) survey collects information from HEIs relating to the value of in-kind contributions it receives from interactions with 'the wider world'. Such interactions occur between HEIs and non-academic institutions. All 161 publicly funded UK HEIs report the amount of funding that they receive in relation to these interactions.

Income from business and community interactions is reported in seven main streams:

- collaborative research;
- consultancy;
- contract research;
- CPD and continuing education;
- facilities and equipment related services;
- intellectual property; and
- regeneration and development programmes.

Income from collaborative research, which is the focus of this section, is reported broken down into: funding received from public funding bodies, cash received from collaborators, and in-kind contributions from collaborators.

Collaborators are defined as non-academic organisations, including charities, public and not-for-profit organisations as well as commercial business. This category does not strictly align with our distinction between public and private funding as it appears to include some 'public organisations'. This prohibits us from making firm conclusions regarding private sector in-kind contributions.

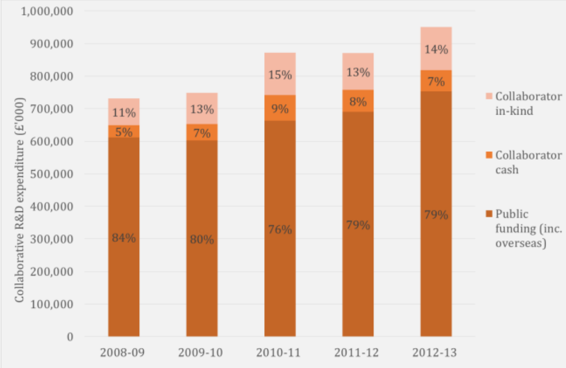
When HEIs complete the survey, the guidelines state that in-kind contributions should be 'contractually explicit' i.e. the external partner should be aware of the financial values assumed for their contribution. Only in-kind contributions that have been formally recorded, for example on Finance or Research Project Management Systems, should be included within the data.

We note that estimating the value of in-kind contributions is intrinsically difficult and subjective. For example, an industry researcher's time could be valued on a pro-rata basis of their salary, or alternatively as the cost of going to market and hiring a suitably qualified individual for that amount of time. Furthermore, where the in-kind contributions are relatively unique, such as a particular dataset, there may not be an appropriate market price from which to estimate value.

Given the difficulty of estimating the value of in-kind contributions, we are aware that the self-reported values may not be calculated on a consistent basis, and ultimately the method of estimating any particular value is unknown. As such, we are cautious of the conclusions that we can draw from the data. Subsequently we also discuss alternative methods of estimating in-kind contributions. In section 6 we make recommendations regarding the collection of in-kind data.

The chart below shows the split between different sources of collaborative funding, as reported in HEBCI.

Figure 44. Sources of collaborative research income

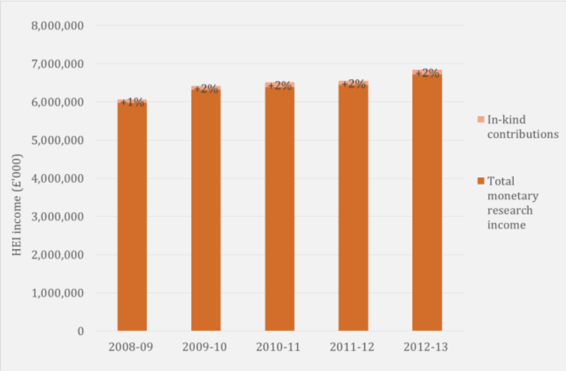


Source: EI analysis of HEBCI data

As can be seen, in-kind contributions from external collaborators amounted to 14% of the total value of collaborative research income, and cash contributions from external collaborators amounted to 7%. That is, in-kind contributions were twice the value of the cash funding received from external collaborators. The definition of 'collaborators' (as per above) should be kept in mind when considering this comparison as it does not align exactly with the funding sources we have been discussing in the rest of this study. However, it still gives an indication of the relative size of in-kind contributions.

To put in-kind contributions in context with the totality of research funding that HEIs receive (i.e. including QR and RC funded projects that are conducted entirely within academia), we compare the value of in-kind contributions with total HEI research income. The following chart illustrates that in-kind contributions, as measured by HEBCI, add an additional 2% on to the total cash income that HEIs receive for research.

Figure 45. Value of in-kind contributions compared to total HEI monetary research income



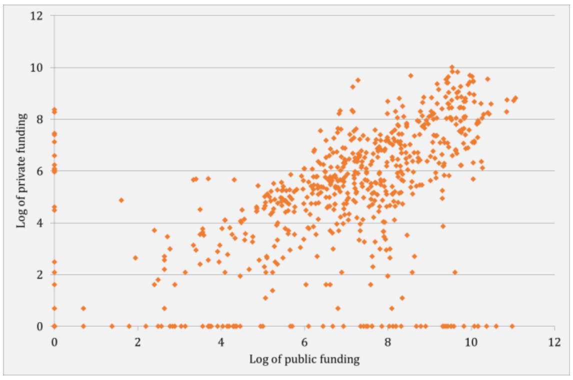
Source: EI analysis of HEBCI and HESA data

4.9.2. Relationship between in-kind contributions and public funding

The data from HEBCI also allows us to investigate whether there is a relationship between public and private investment, and importantly whether there is a relationship between public investment and the amount of in-kind contributions. We do this by analysing the data at the HEI level.

We first investigate the relationship between 'public' and 'private' expenditure on collaborative research. In the case of this dataset, 'public' includes foreign government expenditure (including EU). As can be seen in the following chart, there is a positive relationship between 'public' and 'private' funding.

Figure 46. Public and private funding of collaborative research (logs)



Source: EI analysis of HEBCI data

Indeed, a simple OLS model finds a positive relationship and a coefficient of additionality of 0.68. However, this does not include any of the controls that we have used in other pieces of analysis and therefore may merely be identifying the underlying correlation between public and private spending, rather than a causal relationship. Furthermore, panel data approaches, which take account of HEI specific effects, reduce the effect to be statistically insignificant. Further details of these models are given in Annex H.

As such, the HEBCI data does not contradict our other analysis on additionality in that it is consistent with a crowding-in effect. However, this analysis is not robust enough to draw any firm conclusions.

We have also investigated whether there is a relationship between the amount of 'public' funding that is received and the proportion of private funding that is in-kind. Put another way, we have sought to establish whether HEIs which get more 'public' funding receive a higher proportion of their private funding as in-kind contributions.

The econometric models that we have constructed suggest that there is a positive relationship, however the relationship is quite weak, and we do not draw any definitive conclusions from this. Again, further details of the models we have constructed are in Annex H.

4.9.3. The effect of in-kind contributions on estimates of additionality

The presence of in-kind contributions will affect our estimates of additionality if:

» (a) the value of in-kind contributions are not already captured in the estimates of public and private expenditure; and

» (b) private in-kind contributions are more or less sensitive to public expenditure than private cash contributions.

From the data available to us it is not clear whether either of these conditions are met. Firstly, private sector organisations may or may not be reporting in-kind contributions as part of their expenditure on R&D. Private sector organisations that provide in-kind support in the form of a researchers' time could report the costs of hiring the researcher as their own expenditure on R&D. Alternatively, they could recognise that the research was conduct outside of the organisation and not report the spend in the BERD survey.

It is also not clear where in-kind contributions that public sector organisations make are reported. For example, in the case of a persons' time, the cost could be recorded against the department for which they work, or against collaborative research with an HEI.

In relation to the second condition, the reaction of private in-kind contributions could be different to the reaction of cash contributions. But without accurate data on in-kind contributions from the public and private sector, it is not possible to determine whether this is the case or not.

4.9.4. Alternative ways of estimating in-kind contributions

Due to the inherent difficulty and subjectivity of estimating the value of in-kind contributions, we have also explored three alternative sources to HEBCI: MRC data; survey data; and ONS data. We discuss each of these in turn below.

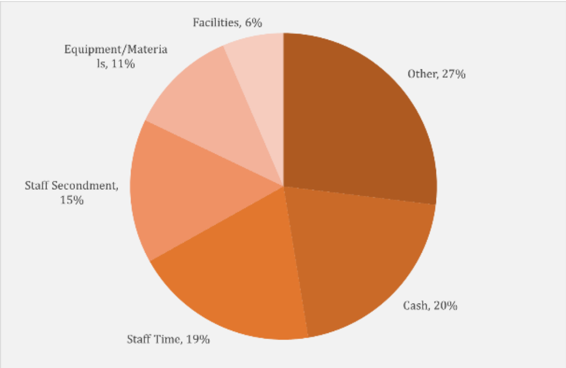
MRC data

The data that has been supplied to us by the MRC includes information on the value of cash and in-kind contributions from project partners. A project partner is an organisation that provides a specific contribution to an award but is not seeking funding from the RC for its involvement. This data therefore only represents a small proportion of the sources of in-kind contributions because it is: (i) only for MRC awards; and (ii) only in relation to project partners i.e. it doesn't not include data on collaborative funders.

Furthermore, we understand that this information is based on self-reporting and is not always complete. It will also face the same in-kind valuation issues as discussed in relation to the HEBCI data. Even so, it gives another indication of the relative size and importance of non-monetary contributions to research.

The following chart shows how the total value of contributions from project partners breaks down between cash and different types of in-kind contributions.

Figure 47. Type of project partner contributions to MRC awards



Source: EI analysis of MRC data

As can be seen, cash and staff form large proportions of total contributions. Equipment, materials and facilities form relatively smaller proportions. However, the 'other' group is relatively large and visual inspection of the data suggests that a lot of the observations could be allocated to the other categories.

However, these data are consistent with the HEBCI data in that they suggest that in-kind contributions add significant value on top of cash contributions. They also indicate that staff time is a particularly large component of in-kind contributions made by project partners.

Survey data

Given that a large proportion of in-kind contributions are in the form of staff time, we investigated whether there were any survey measures of the amount of time that researchers spent collaborating with external organisations. If so, we could make the assumption that the same amount of time was spent by the member of staff from the external organisation and multiply this by a wage rate. This would give a rough estimate of the value of staff time that external organisations contributed to collaborations.

However, we were unable to find such a measure in researcher surveys (such as PIRLS or CROS[21]) and have not pursued this approach any further.

ONS data

The third alternative source we investigated was ONS. The rationale was as follows. Organisations that make in-kind contributions are paying the wages of researchers and the rent on facilities that they lend to research projects. As such, their value should be captured within total expenditure on R&D. Expenditure on R&D by sectors providing the funds is then broken down by the sector performing the funds (as given in Table 3). Assuming that this allocation is correct, the difference between, for example, business expenditure on research conducted in higher education and HEI cash income from businesses would give an estimate of in-kind contributions from businesses.

However, ONS data on research funded by businesses and performed in higher education is sourced from HEIs and appears to relate to only cash income, as explained below.

The Business Enterprise Research and Development (BERD) survey primarily captures data relating to R&D performed in businesses. It asks companies to report how much R&D they conducted and the source of the funding i.e. whether it was funded by themselves or an external organisation. Research funded by businesses and performed in HEIs should therefore not be included in this part of the survey.

21 *The Principal Investigators and Research Leaders Survey (PIRLS) and Careers in Research Online Survey (CROS) are run by Vitae*

However, as discussed above, this may not be clear cut in practice.

In addition, the survey asks about the purchase of R&D conducted outside the business, but is only reported in terms of the businesses that it was purchased from (rather than HEIs). Furthermore, the survey appears to be focused on monetary purchases, rather than an exchange based on in-kind contributions.

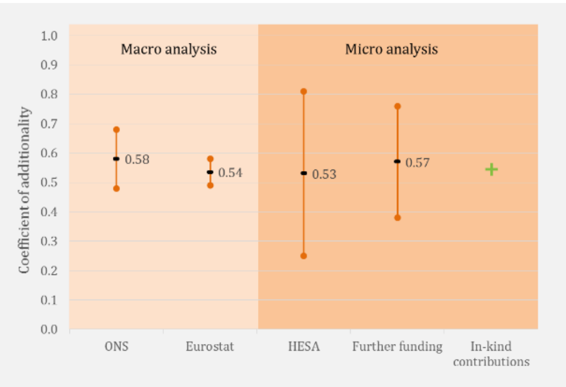
Data on the expenditure of businesses on research conducted within higher education is collected as part of the GovERD annual census. HEFCs and RCs are asked about the research income that HEIs receive from different sources. This information will originally come from HEIs and presumably the same source as the data in the HEBCI results.

Therefore, ONS does not provide us with an additional source of information with regards to in-kind contributions. Data on business expenditure on R&D is only collected in relation to in-house research, and data on privately funded research in HEIs is collected from HEIs – the same source as the HEBCI survey.

4.9.5. Summary of in-kind contributions analysis

In relation to additionality, our analysis of in-kind contributions does not draw any firm conclusions. However, the evidence is consistent with increased public sector investment encouraging further private sector investment – i.e. it points towards a positive coefficient of additionality. The following chart reflects this.

Figure 48. Illustration of findings from in-kind contributions analysis



Of more value though, this analysis suggests that in-kind contributions can add significant value to collaborative research. The HEBCI data suggests that in-kind contributions represent roughly twice as much as cash contributions from businesses and charities. In general, figures relating to the cash contributions to collaborative research may underestimate the value of the engagement.

4.10. Applying the estimated coefficients of additionality

In the preceding sections we have presented five different analyses that utilise different datasets and estimate additionality with respect to different levels of aggregation. So far we have presented additionality in terms of the percentage change in private expenditure resulting from a 1% change in public expenditure, and in this section we discuss how these estimates can be applied to current levels of spending to give the effects in £s.

We focus on two levels of aggregation:

- ***UK national level*** – we provide an estimate of the effect of a £1 increase in public expenditure on total private sector investment in UK R&D. This figure could be used to estimate the effect of a change in the BIS budget.
- ***HEI level*** – we provide an estimate of the effect of a £1 change in public expenditure on R&D conducted within HEIs on the amount of private sector investment into R&D conducted within HEIs.

The remainder of this section is divided into the following parts:

- £ effect at the UK national level;
- £ effect at the HEI level;
- implied spillovers outside of HEIs.

4.10.1. £ effect at the UK national level

As presented above we have conducted macro analysis using two different datasets: ONS and Eurostat. Both of these analyses give an estimate of the percentage change in private expenditure arising from a 1% change in public expenditure. The range estimates and their mid-points are summarised in the table below.

Table 17. Summary of macro analyses results

Analysis	Estimated coefficient of additionality – mid-point (range)
ONS	0.58 (0.48 – 0.68)
Eurostat	0.54 (0.49 – 0.58)

For the purpose of calculating the £ effect of a change in total public sector expenditure we use the estimates arising from the ONS analysis. This is for the following reasons:

- The estimated coefficient of additionality from the Eurostat analysis is for all countries within the dataset, whereas the estimate from the ONS analysis is just for the UK. Although, based on the Eurostat analysis, the effect of UK public expenditure is not statistically different to the rest of the countries on average.
- The results of the Eurostat analysis are consistent with the ONS results i.e. the Eurostat range coincides with the ONS range.
- The ONS range is slightly larger than the Eurostat range and thus reflects the inherent uncertainty in analysis of this type.

The following table shows the calculation of the £ effect at the UK national level based on the ONS mid-point of 0.58.

Table 18. Calculation of £ effect at UK national level

Public expenditure (2012)	£8,054m
Private expenditure (2012)	£18,952m
1% increase in public expenditure	£80.54m
0.58% increase in private expenditure	£109.92m
Equivalent effect of £1 increase in public expenditure on private expenditure	***£1.36***

As can be seen, our macro analysis therefore suggests that a £1 increase in public sector expenditure on R&D will increase private sector expenditure by ***£1.36***. To reflect the inherent uncertainty in this estimate we also calculate a range based on the range of coefficients of additionality from the ONS results (0.48 – 0.68). This gives a range of £ effects of £1.13 to £1.60.

We did not find a statistically significant difference between the effect of what is primarily the BIS budget and other government spending, within our ONS analysis. Therefore, the £1.36 figure can be used as an estimate of the effect of changes in the BIS budget.

The following box estimates that holding the science budget constant in cash terms has resulted in an additional £1.2bn of private sector investment, compared to if they budget was cut in line with other government departments.

Box 2. Effect of holding the science budget constant

The Spending Review 2010[22] set out the coalition government's planned spending for 2011/12 to 2014/15. Whilst the science budget for resource spending was held constant in cash terms at £4.6bn, departmental budgets other than health and overseas aid were planned to be cut by an average of 19% over four years in real terms.

By keeping the science budget for resource spending constant, rather than cutting it by (£4.6bn * 19%) £0.9bn, our estimates suggest that an additional £1.2bn per annum (£0.9bn * £1.36) of private investment has arisen, in the long run.

4.10.2. Time profile of leverage

As discussed above, the £1.36 figure is an estimate of the long-run increase in private expenditure arising from a £1 increase in public expenditure. That is, it is the total increase that would arise of a number of years (strictly speaking, in perpetuity). For appraisal and evaluation purposes, it matters *when* the £1.36 arises i.e. there is a difference between the present value of £1.36 return today versus a £1.36 return in ten years' time.

Of the two econometric models that underpin the £1.36 figure (Model 3 and Model 8), the first of them is flexible enough to estimate how the £1.36 is spread over time.[23] These implied and cumulative figures are shown in the following table. The table shows that the majority of private expenditure occurs within the first 5 years from investment (£1.28 out of £1.36).

[22] *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/203826/Spending_review_2010.pdf*

[23] *The main assumption / limitation underlying this aspect of the econometrics is that the scale of leverage in a given year is X% of the figure in previous year where X is the same in every time period. We use the econometrics to estimate what the initial leverage figure is and what X is in each year.*

Table 19. Time profile of leverage (undiscounted)

Years since expenditure	Annual £	Cumulative £
0	£0.00	£0.00
1	£0.59	£0.59
2	£0.33	£0.92
3	£0.19	£1.11
4	£0.11	£1.22
5	£0.06	£1.28
6	£0.04	£1.31
7	£0.02	£1.33
8	£0.01	£1.34
9	£0.01	£1.35
10	£0.00	£1.36
10 year total	**£1.36**	

The table below shows the same estimates discounted at an annual rate of 3.5% (in line with the figure recommended in the Treasury Green Book).

Table 20. Time profile of leverage (discounted at 3.5%)

Years since expenditure	Annual £	Cumulative £
0		£0.00
1	£0.57	£0.57
2	£0.31	£0.88
3	£0.17	£1.05
4	£0.09	£1.14
5	£0.05	£1.19
6	£0.03	£1.22
7	£0.02	£1.24
8	£0.01	£1.25
9	£0.00	£1.25
10	£0.00	£1.25
10 year total	**£1.25**	

Because the additional leverage is relatively 'front-loaded', the effect of discounting at 3.5% is relatively small – the discounted total is £1.25 compared to the undiscounted total of £1.36.

4.10.3. £ effect at the HEI level

Along with calculating the £ effect of public funding on all private funding, we now turn to the effect of public funding of research conducted within HEIs on private funding of research conducted within HEIs. We conducted three pieces of analysis that estimated additionality at different micro levels. Whist the HESA analysis looked at total public and private spending within HEIs, our analysis of further funding and in-kind contributions looked at more specific types of funding. Therefore, we use the estimates from the HESA analysis in this section. Specifically, the mid-point of 0.53 within the range of 0.25 to 0.81 for the coefficient of additionality.

As per Table 18 the table below illustrates the calculation of the £ effect using the mid-point.

Table 21. Calculation of £ effect at HEI level

Public expenditure on HEI research (2012/13)	£4,331m
Private expenditure on HEI research (2012/13)	£2,382m
1% increase in public expenditure on HEI research	£43.31m
0.53% increase in private expenditure on HEI research	£12.63m
Equivalent effect of £1 increase in public expenditure on HEI research on private expenditure on HEI research	***£0.29***

As can be seen, our analysis suggests that a £1 increase in public funding of research conducted within HEIs will lead to an increase in the amount of private funding of research conducted within HEIs of ***£0.29***. To reflect the uncertainty of such an estimate, we also calculate a range of between £0.15 and £0.45.

4.10.4. Implied spillovers outside of HEIs

The two sections above calculate the £ effect of a change in spending at the total public sector level and the HEI level respectively. As can be seen by the results, there is a significant difference between the two £ effects. The reasons for this, we suggest, is that there are significant spillover effects that arise outside of HEIs as a result of public spending.

The UK national level analysis suggests that a £1 increase in total public funding results in an increase in total private sector funding of £1.36. We found no statistically significant difference between the effect of public funding from different sources (see section 4.4.4). Therefore, if we assume the following:

- A £1 increase in public funding of research conducted in HEIs results in £1.36 additional funding from the private sector in totality – i.e. within HEIs and outside of HEIs.
- A £1 increase in public funding of research conducted within HEIs results in £0.29 additional funding from the private sector into research performed in HEIs.

The implied spillover effects that arise through research conducted outside of HEIs are of the magnitude of £1.07 (£1.36 - £0.29) for each £1 of public funding. Put another way, £1 of publicly funded research that is conducted within HEI results in the private sector funding an additional £0.29 of research that is conducted within HEIs, and an additional £1.07 that is conducted outside of HEIs.

Our analysis therefore suggests that when the effects of public funding of HEI-conducted research are assessed, the implications need to be considered for research taking place outside of HEIs. In terms of £ invested in research, the effects may well be larger outside of HEI-conducted research.

5. What can be done to increase the amount of private sector investment?

This section presents our findings from the qualitative interviews in relation to how private sector investment can be increased.

In line with previous research, our interviews emphasised the importance of the personal relationships supporting the private and public sector collaborations.

(i) The evidence suggested that public and private sector collaborations generally worked well and so there isn't a 'silver bullet' to increase the extent of leverage.

(ii) There may be opportunities to increase the speed / reduce the cost with which collaborations take place and therefore the value of funding.

5.1. Introductory remarks

The evidence set out in the previous sections of this report suggests that there is a positive relationship between the level of public investment in R&D and the level of private investment in R&D. To better understand how such a relationship arises, we conducted telephone and face-to-face interviews with 21 individuals involved in R&D from various research institutions, funding bodies and industry. In particular, we explored the factors that help (or hinder) leverage in practice.

The overarching message from the interviews, consistent with previous research in this area, is that the key factor determining the extent of leverage is the existence, longevity and quality of the personal relationships supporting the public and private sector collaborations. Many of the interviews focused on the conditions and circumstances leading to a successful collaboration including: (a) initiating and maintaining commercial relationships; and (b) agreeing commercial terms and conditions.

All of the individuals we spoke to had been involved in highly productive collaborative research underpinned by a strong common understanding of the objectives of the research and the roles and responsibilities of those involved, and conveyed a sense of mutual trust and respect for their research partners. It was unusual for interviewees to cite occasions where a collaboration had not worked well (only two interviewees) and on those occasions, they put it down to personal relationships, rather than the institutional or funding arrangements surrounding the collaboration.[24]

One could conclude from this that there is little a policy maker can do to increase the extent of leverage for a given level of public investment as it rests largely on factors outside of its control (i.e. the formation of personal relationships). Indeed, none of the interviewees suggested that a 'silver bullet' had been overlooked. However, as discussed further in the conclusions section below, although there may not be a 'silver bullet', our interviews point to various areas where further research might reveal opportunities for policy-led increases in leverage.

The rest of this section summarises what we learned from the interviews. We start by providing an overview of our methodology and comment on its strengths and weaknesses.

5.2. Overview of methodology

The table below shows the research institution and research areas / schemes included in this study. The selection of participants was based partly on suggestions from the steering group and partly on our analysis of HESA data (which we used to identify the top 50 HEIs in terms of private funding per FTE). We aimed, within the limitations of the sample size, to select a reasonable mix of institutions and subject areas.

Table 22. Institutions included in research

	Research institution and research area / scheme	Affiliation of individuals
	5G Innovation Centre at University of Surrey	2 Institution 1 Industry
	Aerospace, Transport Systems at Cranfield University	1 Institution
	Cancer Research UK	1 Funder
	Chemistry, Biochemistry at Queen Mary University	1 Institution
	Earth Science & Engineering at Imperial College London	2 Institution
	Engineering & Physical Sciences at Heriot-Watt University	2 Institution 1 Industry
	Molecular and Clinical Cancer Medicine at University of Liverpool	1 Institution
	National Composites Centre at University of Bristol	3 Institution
	Psychology at University of Oxford	1 Institution
	Sociology at Lancaster University	1 Institution 1 Industry
	WMG at University of Warwick	2 Institution 1 Industry
		1 Funder 4 Industry 16 Institution
Total	11	21

Of the 21 individuals we spoke to: 16 were representatives of the research institution; 4 were representatives of industry partners; and 1 was a funder (i.e. Cancer Research UK). All of the individuals were highly experienced and senior members of their organisations – always occupying 'Director', 'Head' and/or 'Professor' equivalent positions. Their specific backgrounds varied in terms of their experience working in academic and/or industry research setting, but all had significant

[24] *We recognise, of course, that this could be an artefact of the characteristics of the sample we spoke to.*

experience of research collaborations involving industry and academia.

We developed a discussion guide which we sent to participants in advance of interviewing them to help them prepare. The discussion guide is set out in Annex I– Details of interviews. During the interviews, the discussion guide was used as such – we rarely asked every question contained in it and we flexed the amount of time spent on different topics as appropriate. Each interview lasted for around 1 hour.

In interpreting the results of the interviews it is, of course, important to recognise that views given by this sample may not represent the views of the wider research community. Relatedly, it is important to note we have not sought to 'validate' or 'test' the views or perceptions offered by interviewees by conducting further research (for clarity, we have no reason to believe that they are inaccurate).

5.3. Summary of results

In this section we summarise the results of our interviews. The subsequent section sets out what we take from them and the questions raised by them. In line with the discussion set out above, the results are organised around three main themes:

- initiating and maintaining commercial relationships;
- agreeing commercial terms and conditions; and
- leveraging different sources of funding.

Within each theme we have identified between 2-4 topics that were raised by one or more interviewees as being important to leverage. The topics are as follows:

» *For initiating and maintaining commercial relationships* – establishing strategic-level relationships; moving between industry and academia; encouraging multi-partner participation; and funding individual researchers.

» *For agreeing commercial terms and conditions* – agreeing IP rights and contract design.

» *For leveraging different sources of funding* – funding by SMEs; funding by charities; funding from international sources; and leveraging funding via social sciences.

To highlight the points that were raised by interviewees within each topic we provide a case-study based example. The example is usually based on the views of one of the 11 institutions listed above. To provide an indication of the wider support or otherwise for the points raised by that institution, we also set out the related points made by others where relevant. We also provide the context for the case study, by giving the relevant institutional and individual backgrounds.[25]

5.3.1. Initiating and maintaining a commercial relationship

5.3.1.1. Establishing strategic-relationships

Case study example: Engineering and Physical Sciences at Heriot-Watt University

This example illustrates how strategic relationships can increase the efficiency of collaborations between industry and academia.

Context

We discussed the Strategic Alliance between Heriot-Watt and Renishaw, a global company specialising in measurement, motion control, spectroscopy and precision machining. We interviewed a senior representative of Renishaw and a senior member of the faculty at Heriot-Watt – both had worked at their respective organisations for around 20 years.

Key points

» The collaboration between Heriot-Watt and Renishaw was facilitated by personal relationships forged through a PhD supervision.

» The early collaborations were originally around smaller research projects, mostly feasibility studies. These projects lend themselves to collaboration because:

- from Renshaw's perspective, Heriot-Watt gave them access to skills and equipment that would be difficult or prohibitively costly to acquire for a single research project;
- from Heriot-Watt's perspective, the projects can be accommodated within their existing research capacity and help align their research to what is useful for industry (potentially leading to future employment possibilities); and
- for both parties, it allowed them to develop the working relationship needed to embark upon larger research projects.

» However, the partners found that it was time consuming and costly to get each research project started – this process could take between 1-3 months – often due to the legal aspects of agreeing terms and conditions for each project.

[25] *For clarity, the choice of institution as the example is not necessarily related to the importance of the topic to that institution nor does it imply that other topics were not raised by the institution.*

- Therefore, the Strategic Alliance was originally created to provide an 'umbrella' agreement under which the smaller research projects could be undertaken, thus reducing the time and cost associated with starting them. Today, larger / longer-term research projects are undertaken under the Strategic Alliance.
- Other benefits of the Strategic Alliance include: mutually acceptable IP terms and a 20% discount on the full economic cost of R&D for Renishaw. It also facilitated the investment in the Advanced Metrology Centre at Heriot-Watt, supported by a £0.5m donation by Renishaw. For Heriot-Watt, the Strategic Alliance also represents a certain stream of funding.

Points raised by others

- The National Composites Centre and 5GIC (as discussed later) also have different membership options.
- WMG attend conferences and set up initial 'discovery meetings' in which the businesses' needs are discussed.

5.3.1.2. Moving between industry and academia

Case study example: National Composites Centre at the University of Bristol

This example illustrates how individuals moving between industry and academia can increase the productivity of collaborations.

Context

We discussed the establishment of the National Composites Centre (NCC) at the University of Bristol. We interviewed two senior members of the centre, both with over 20 years of research experience. The NCC is one of the seven centres that form the High Value Manufacturing (HVM) Catapult. The Catapult funding structure is based on the principle of 1/3 public funding, 1/3 industry funding and 1/3 collaborative research income. The NCC is a subsidiary owned by the University of Bristol, and as such is able to act 'as a business'.

Key points

- Engineering collaborations facilitate more basic research developed in academia being brought closer to commercialisation by industry partners. This movement along the TRL scale can be made easier when individuals move between academia and industry.
- Academia and industry naturally have different objectives and different ways of working. When there is movement of labour between these two sectors understanding of how the other operates and how to work with them increases.
- Catapults can sit in between academia and industry – being distinct from universities and businesses, but engaging heavily with both.
- The REF may hinder movement from industry to academia because it is based partly on publication history.
- Co-locating people and letting them work together has also been cited as a main point in facilitating industry-academia relationships.
- There may be an opportunity to create a mechanism to sponsor a good university-led idea i.e. to pull it through to the Catapult stage to make it ready for industry.

Points raised by others

- One interviewee (Queen Mary) considered that the lack of industrial experience is a major career impediment for newly qualified PhDs.
- Another interviewee (Heriot-Watt) stated that the switch from industry to academia happens only at the less experienced levels – citing REF as a potential impediment at more experienced levels.
- One person (Warwick University) cited that the REF could impede industry to academia movement due to the requirement of having a publication track record, which those in industry may not have.
- In contrast, one researcher (Imperial College London) considered that REF did not stand in the way of recruiting from industry and collaborating with industry: i.e. universities could recruit different researchers for different reasons.

5.3.1.3. Encouraging multi-partner participation

Case study example: 5G Innovation Centre at University of Surrey

This example illustrates the mechanisms that can be used to encourage and manage the input of multiple industry partners.

Context

We discussed the establishment of the 5G Innovation Centre (5GIC) at the University of Surrey, which is due to formally open in September 2015. We interviewed two senior members of the 5GIC and also of Vodafone – one of 11 founding member companies. 5GIC's member companies are not only British, leading to overseas investment in UK-R&D activity.

Key points

- 5GIC is funded by HEFCE and industry. A requirement for £12m of HEFCE funding was that it should be matched by at least £24m from industry. It now receives approximately £70m of funding from industry (cash and in-kind).

- Vodafone was the first of the 11 founding member companies. Getting Vodafone on board at an early stage was an important factor in encouraging other companies to get involved and offer funding; this was facilitated by a long-term relationship between the University and Vodafone. Other factors included:
  - The availability of HEFCE funding, which signals 'stability' and 'credibility' to industry - referred to some as the 'magic ingredient'.
  - The research reputation of the University of Surrey in this area.
  - Academics that understand industry.
  - The balance of research being undertaken – approximately 75% of the R&D is 'industrial' whereas 25% of the R&D is 'purely academic'.
  - The means of managing the IP created by the centre (discussed further below).
- Large companies have to commit 5 years of investment into the centre to become members and SMEs have to commit 3 years. All founding and 'platinum members' are part of the 'strategy advisory board' and shareholders of '5GIP'.
- As part of the strategy advisory board, members can debate and influence the research topics undertaken by 5GIC.
- 5GIP is a special purpose vehicle which owns the IP created by research at 5GIC. Shareholders share the costs of creating the IP and also share the rights to the IP. Separating the business-part from the research-part is unusual in Europe, but more common in the US.
- From Vodafone's perspective, it is important that the centre can choose its own research path and create genuinely 'disruptive technology' and avoid a situation whereby it simply becomes a 'cheaper' R&D centre. It sees its role on the strategy advisory board as a guidance rather than directing role. It collaborates with (product market) rivals to avoid too much fragmentation and duplication of work (rather than being motivated by risk-sharing per se).
- There has been some discussion as to the appropriate size of the strategy advisory board, where the discussions revolve around the appropriate balance between representing everyone's views on the one hand, and preserving the ability of the board to give guidance.
- Some companies approached 5GIC but decided not to collaborate as they wanted exclusivity of the IP.

Points raised by others

- The National Composites Centre adopts a similar arrangement to encourage industry participation. "T1" membership offers an industry member an opportunity to influence the strategic direction of the NCC's research in return for £1m of funding over three years.

5.3.1.4. Funding individual researchers or research teams

Case study example: Earth Science & Engineering at Imperial College London

This example illustrates how the relationship between an individual researcher and company is established and can evolve.

Context

We discussed the evolution of a relationship between a field leading researcher at Imperial College and a multi-national commodity company.

Key points

- The researcher was originally part of a research consortium whilst at another university. Two industry members of the consortium were particularly interested in his area of research and decided to fund it.
- In 2008, one of the companies provided £6m of funding over 5 years and then provided another £6m of funding over 5 years from 2010. The 5 year funding is unusual - usually it is 1-2 years.
- When the researcher moved from their previous university to Imperial the industry partner continued to fund their research – illustrating the importance of personal, rather than institution, relationships. In this case, the whole research team moved from one HEI to another.
- Over time the IP rights have changed:
  - Initially he had full discretion of what he published.
  - Then it became shared IP i.e. Imperial owned the IP, and the company leased it.
  - Now, the company owns the IP. He can publish the science, but not the application of it.
- The researcher has complete control over how the funding is used, but with it complete responsibility for research success or failure.
- Other researchers are less willing to allow others to own / use their IP. More generally, he noted that there are differences between universities in terms of how they work and how they fund: he felt that at Imperial there is a greater appetite to attract private funding and this attracted different

people and a different type of research as a consequence compared to his previous university.

- His research and time is dedicated to an individual company. This naturally carries some risks with it i.e. what if the company decides to pursue different research? To help manage this he has diversified funding sources and now secures EU funding - but notes that it carries with it a high administrative burden.
- The company outsources the 'industrialisation' of the research.

Points raised by others

- Another interviewee (University of Bristol) noted that researchers varied in terms of their ability and/or willingness to collaborate with industry.

5.3.2. Agreeing commercial terms and conditions

5.3.2.1. Agreeing IP rights

Case study example: WMG at the University of Warwick

This example illustrates how price is used to accommodate different demands over IP.

Context

We discussed Warwick Manufacturing Group's (WMG) work and its long-term partnership (since 1980) with Jaguar Land Rover (JLR). We interviewed two senior members of WMG and a senior representative of JLR. WMG is another one of the seven centres that constitute the HVM Catapult, and hence it follows the same funding principles.

Key points

- WMG found that the first questions companies ask when entering into collaborative agreements were around IP rights, where they either want: (i) exclusivity; or (ii) to share the rights.
- Under (i) the company has to pay the full economic costs of undertaking R&D, whereas they make a contribution under (ii). WMG is generally seen as being easy to deal with in this regard and adopting a commercial approach.
- The consequence of the above is that research that is solely funded by industry tends to be short-term in nature and underpinned by a strategically important question to answer. The motivation for collaborating is that the industry partner does not have enough capacity or the right facilities to complete the research itself. It was noted that SMEs tend to require this type of research.
- The industry partner – Jaguar Land Rover – had found that agreeing liability terms for breaches of confidentiality (as universities cannot agree to unlimited liabilities) as more problematic than agreeing to IP.

Points raised by others

- One interviewee (Heriot-Watt, industry partner) argued that reaching an agreement over IP can be a challenge. He considered that the negotiation on the University side was motivated by using the IP in REF submissions.
- Another (Imperial College London) stated negotiations can stall over IP, but are usually resolved.
- Another (University of Bristol) stated that the control of IP can cause funding-related tensions. For example, in the situation where a PhD student gets Research Council funding and the possibility of some top-up funding from industry in return for IP – the question is whether this compromises the Research Council funding requirement that the resultant research is supposed to be publicly available and for fundamental research?
- Another (University of Oxford) said that they set the price of contract research depending on the willingness to pay of the industry partner.

5.3.2.2. Contract design

Case study example: Aerospace, Transport Systems at Cranfield University

This example highlights that successfully reaching an agreement over liability and unlimited indemnity is seen by some as a critical element of agreeing commercial terms and conditions.

Context

Our interviewee was a senior university researcher, with over 20 years of prior experience in industry. He is part of the EPSRC Centre for Innovative Manufacturing in Laser-Based Production Processes and has extensive experience in research of laser material processing in manufacturing applications (both in industry and academia).

Key points

- In order to join the research programme, the industry partners have to agree to the university's terms and conditions, which amongst other things means that the university retains ownership over the IP created by the research.
- Companies that are 'full partners' get a perpetual royalty free licence to use the intellectual property and full access to all the research outputs. The

funding commitment is £40k per annum. (There are currently 10 full partners, including all aerospace companies and some government departments.)

- Under this approach (i.e. where the university has a policy of retaining ownership over the IP), negotiations over contract terms – specifically associated with liability and unlimited indemnity – are a bigger issue e.g. redress associated with inadvertent publication of the application of the fundamental research.
- The reason for the difficulty given is that university contract departments are not always used to dealing with such issues or with industry.

Points raised by others

- See comments made above by University of Warwick and Imperial College London.

5.3.3. Leveraging different sources of funding

5.3.3.1. Funding by SMEs

Case study example: Chemistry, Biochemistry and Queen Mary University

This example illustrates the perceived difference between working with SMEs and larger corporations.

Context

Our interviewee had over 20 years of experience, including extensive and recent experience as a Project Coordinator of European Commission (EC) Marie-Sklodowska-Curie Action (MSCA) research projects. We discussed the funding of research into chemistry research projects, in particular the development of chemical sensors, using the molecular imprinting technology, for application in the coffee industry. This project has two industry partners: one large international company and a SME.

Key points

- The MSCA research projects are designed to provide research training and are not for a specific topic.
- It is harder to engage with industry for these projects. Collaborating with HEIs is very demanding for the industry partners, not necessarily in financial terms but in non-monetary ways, such as the researchers' required time. The main reason companies engage with them is to foster the transfer of knowledge and increase graduate readiness for working in industry.
- Here, the type of support offered by industry is usually two-way secondments (to the HEI from industry and vice versa), rather than cash funding.
- The interviewee said that it was generally easier to partner with SMEs for this type of arrangement than with larger companies. The reasons given for this were:
  - Necessity - i.e. SMEs were more dependent upon EC funding than larger companies and so more willing to engage with the administration associated with securing EC funding.
  - Flexibility - i.e. the interviewee considered that SMEs were better placed to benefit from this type of engagement than larger companies.

Points raised by others

- One interviewee (Heriot-Watt, industry partner) suggested that larger companies were better placed to secure public funding as they have greater resources to do this (i.e. industry liaison teams).
- Another (Cranfield University) said that SMEs were less likely to give cash funding, but could offer 'in-kind' resources, such as access to equipment.
- Two interviewees (University of Surrey, University of Bristol) discussed their active encouragement of SME involvement e.g. nearly 40 SMEs are involved at the NCC and 5GIC provides a space for SMEs to showcase and test their products.

5.3.3.2. Funding by regional charities

Case study example: Molecular and Clinical Cancer Medicine at the University of Liverpool

This example illustrates how regionally-led charities can contribute to research.

Context

We discussed the funding of cancer research in the North West. Our interviewee was a senior member of the ocular oncology research team and also sat on the board of a regional office of cancer research.

Key points

- The North West Cancer Research centre was originally funded by Cancer Research UK and is now funded by North West Cancer Research (NWCR - a separate organisation).
- The funding supports two researchers at the NWCR centre.
- The NWCR is committed to funding research in the North West and funds two other institutions in a similar way (Lancaster and Bangor). Some donations are specifically for particular institutions and are therefore ring-fenced.
- The funding process is more streamlined for charities compared to Research Councils.

Proposals to charities are usually sent to 4 or 5 reviewers and the decision is based on those. Research Councils may additionally invite you to an interview.

» The interviewee noted that some individuals sit on the boards of the NWCR centre and the charity, which helps to align objectives.

Points raised by others

» None.

5.3.3.3. Funding from international sources

Case study example: Cancer Research UK

This example illustrates how funding from international sources contributes to research in the UK and some of the recent changes in the way research is funded by CRUK.

Context

Cancer Research UK (CRUK) has a research budget of about £350m of which around 1/3 is 'core funding' i.e. funds CRUK institutions in universities, and around 2/3 goes to academics who apply for grant funding. The budget is allocated in its 5 year plan.

Key points

» Historically, CRUK only funded 'UK research'.

» More recently they have started funding international collaborations, but where the funding remains in the UK. For example, they may fund a UK academic who is taking part in internationally collaborative research.

» They might partner with other Western countries for expertise and with other countries for capacity / access to rarer cancers to research. Partnering with other institutions allows for much larger grants than they would be able to support alone.

» They identify the 3 to 5 biggest challenges ('Grand Challenges') within the cancer research space and make £20m available to fund research. Consortia who bid need to be based in the UK, but could include overseas or industry partners.

Points raised by others

» Another interviewee (Queen Mary University) said that the UK legal system is easier to deal with than elsewhere (e.g. Germany). Set against this was that in some of those countries (e.g. Germany) a culture of industry-academia collaboration was better established.

» Two others (University of Surrey, University of Warwick) considered that companies had moved their R&D departments outside of the UK and, until they returned, this would limit the amount of R&D undertaken in the UK.

5.3.3.4. Leveraging funding via social sciences

Case study example: Sociology and Lancaster University

This example illustrates how research in the social sciences attracts interest and funding from industry.

Context

We discussed how social science was being used by industry with a senior representatives of DEMAND (Dynamics of Energy, Mobility and Demand) centre at Lancaster University and ECLEER (EDF's European Centre and Laboratories for Energy Efficiency Research). DEMAND and ECLEER have collaborated on a number of research projects. The DEMAND centre started in May 2013 with a total funding of £5m over five years. EDF has committed £1.6m of funding alongside others, including EPSRC/ESRC, Transport for London and the International Energy Agency.

At the group level, EDF has a 'collaborative policy' with respect to research and tries to fund research in the countries it is present in. Its R&D budget is split between 70% short-term / operational R&D and 30% middle-to-long term R&D.

Key points

» Social sciences are different to other disciplines in terms of the opportunities for academic and industry collaborations. Social sciences are usually approached by government rather than industry for advice and research into policy issues. The interviewee attributed this to a lack of 'natural situations' for industry and social scientists to meet.

» The DEMAND centre collaboration arose through personal contacts. These personal contacts had been formed via:

– originally meeting at a conference; and
– a previous Research Council funded project and Lancaster being aware that EDF wanted to remain an active participant in UK research.

» Lancaster considered that one of the reasons it reached an agreement with EDF, rather than other would-be collaborators, was its speed of responsiveness to the ESPRC/ESRC call. They later learned that EDF had been approached by 3 other institutions.

» EDF's commitment to DEMAND includes the provision of 6 researchers and access to networks, conferences and contacts.

» The benefits cited by the partners include:

- Access to data from EDF;
- Access to ideas from Lancaster;
- Advice on how to communicate research in a way that engages industry.

» The work has led to changes in the way EDF models demand. Amongst other things, this helps them comply with EC directives associated with reducing energy consumption / emissions reduction.

Points raised by others

» Another interviewee (University of Oxford) noted that they are approached by industry to conduct experiments within social science. They did not necessarily seek out new industry partners as it is hard to identify who could benefit from their specific research techniques.

5.4. Conclusions

In this section we set out the conclusions we draw from the discussions we had. In presenting the conclusions, we are mindful of the limitations of our research set out above – and rather than seeking to make specific 'policy recommendations' we instead set out the 'issues for consideration' that we think our research raises. We have organised our conclusions by the factors set out above.

5.4.1. Initiating and maintaining a commercial relationship

As set out in the introduction to this section and as found by previous research, key to collaboration and therefore leverage is initiating and maintaining a commercial relationship. Although we heard that there were challenges associated with this, our interviewees had all formed productive relationships.

The issues we think our discussions raise here are:

» ***Establishing strategic-relationships.*** Our interviews suggest that strategic alliances can be a helpful way of increasing the speed and efficiency with which 'smaller scale' research is undertaken. While our interviews do not suggest that there are 'too few' strategic alliances happening, further research could explore whether there are impediments to implementing strategic alliances and whether anything can and should be done to increase their prevalence.

» ***Moving between industry and academia.*** There were mixed views on whether REF had (or could) discourage individuals moving from industry to academia. Further research could be undertaken to examine whether the 'research labour market' had changed in this dimension since REF had been introduced.

» ***Encouraging multi-partner collaboration.*** A number of 'Catapults' give industry partners the opportunity to guide the research undertaken as a benefit of funding the research. Inherent in this approach is the need to give researchers autonomy and, at the same time, industry partners some say over how their funding is used (and reflect the views of different industry partners). Further research could usefully explore the different approaches to managing this issue to help facilitate the dissemination of best practice / lessons learned.

5.4.2. Agreeing commercial terms and conditions

A number of interviewees said that agreeing commercial terms and conditions could be challenging – specific issues raised relate to IP ownership / use and contract design (i.e. liability and unlimited indemnity).

To put these issues into context, we did not hear of specific examples where otherwise 'good to go' collaborations had failed due to inability to reach an agreement on commercial terms and conditions. Also, it is perhaps unsurprising that these issues present challenges given the type of service that is being 'traded' i.e. it is highly complex, uncertain and where IP has a value to others outside of the relationship. Put simply, a 'no difficulties / no challenge' scenario is hard to envisage.

» ***Agreeing commercial terms and conditions.*** Notwithstanding the above, the interviews do raise the questions: can and should anything be done to facilitate agreeing commercial terms and conditions more easily / cost effectively? Further research to understand the details of the typical contracting 'stumbling blocks' and whether they are associated with particular types of research and/or circumstances may shed further light on this.

5.4.3. Leveraging different sources of funding

The results of our interviews are consistent with the conclusion that different sources of funding are used to meet different objectives i.e. funding mix as well as level is important.

» ***Funding by SMEs.*** We heard that SMEs can be easier to engage with than larger companies, in some circumstances. We also heard that they did engage. The question raised by the interviews is: whether a relative lack of resources prevents SMEs engaging in collaborative research to the extent they should? Further research could be undertaken to examine the extent of SME involvement and whether there is anything that can and should be done to address impediments they may face.

- ***Leveraging funding via social sciences.*** It was suggested that there were fewer 'natural occasions' for social sciences to 'meet' with industry. Is there a difference between the social and other sciences in terms of the opportunities to meet, and could something be done to create more opportunities in a cost effective manner?

6. Recommendations

This section sets out a number of recommendations for BIS to consider.

Our main recommendations are:

(i) That BIS considers our high level suggestions for further research into the factors than help / hinder leverage set out in the previous section of this report.

(ii) To improve the measurement and monitoring of leverage changes to the way that data on in-kind contributions are collected could be made.

Based on the research conducted for this report we make a number of recommendations and suggestions for further research. Specifically:

- We provide ***recommendations relating to how to increase the level of private investment*** in R&D.
- We make ***recommendations regarding how leverage can be better measured and monitored***.
- Finally, we ***identify areas for potential future research***.

The sections below address each of the above points.

6.1. Recommendations as to how to increase the level of private investment

The previous section of this report set out various high level suggestions of further research that could be undertaken that would lead to a better understanding of the factors that help / hinder leverage. We recommend that BIS considers these suggestions as it develops its research priorities for the coming years.

6.2. Recommendations regarding how leverage can be better measured and monitored

Overall the quality of data in relation to public and private funding of UK R&D is relatively comprehensive and complete. ONS data records, through various surveys, funding that can be attributed to the public and private sectors, along with separate elements of these. With the exception of in-kind contributions, as discussed below, ONS data is adequate for measuring and monitoring the relationship between public and private investment in R&D. If more up-to-date data was required, the timing and frequencies of the different surveys could be revised. However, the value of frequent monitoring is not clear. As we know, the effects of investment in R&D can take years to arise and therefore periodic monitoring should be sufficient.

Furthermore, HESA data provides a holistic picture of the income streams of HEIs. It identifies the source of income which can be attributed to either the public or private sector.

We understand that the recording of RC funding, and particularly the outcomes of it has changed significantly in the last several years with the use of the online system Researchfish, which enables the collection of consistent and comprehensive information on the outputs, outcomes and impacts of research. In order to conduct a more detailed analysis of the relationship between RC and private sector funding, and of further funding, this data collection should be continued to allow for a more complete dataset to build up for future analysis. Particularly, it may give insights as to the characteristics of awards that best attract further funding from the private sector.

In the following section we make a number of recommendations regarding how the collection of data on in-kind contributions could potentially be improved.

6.2.1. Recommendations on collection of in-kind data

Existing data suggests that in-kind contributions provide significant value in collaborations between HEIs and external partners. Although measuring the value of in-kind contributions is inherently difficult, we make a number of suggestions which may potentially improve the data collection process.

- The ONS could adjust its BERD survey to take account of: (i) business spending (cash) on research conducted within HEIs; and (ii) the value of in-kind contributions that it makes. An important aspect for the value of in-kind contributions will be the apportionment of resources between research conducted within businesses and HEIs. For example, if a business has invested in a research facility and allows an HEI to use the premises, the specific allocation of costs will determine the estimated value of in-kind contributions. Businesses are best placed to estimate the value of their in-kind contributions because they are aware of the costs that feed into the contributions. Similarly, charities could be asked about their cash spend and in-kind contributions in the biennial PNP survey.
- Whilst the HEBCI survey measures HEI income (including in-kind contributions) from non-academic sources, it does not fully distinguish between public and private sectors. In order to accurately estimate the value of in-kind contributions from the private sector such a distinction should be made in the collection of data.
- Additional guidance could be given in terms of how in-kind contributions should be valued in the HEBCI survey. Inconsistencies between institutions should be investigated to ensure accuracy of data. Furthermore, additional information could be recorded as to the type of in-kind contributions (for example staff time, data, access to facilities) and specific parameters relating to these, for example, hours of staff time. The additional administrative burden to record this type of information would have to be weighed

up against the benefits of additional monitoring information.

- As per the MRC data presented in section 4.7, more granular data with respect to the type of in-kind contributions (e.g. staff time or facilities) may give rise to more accurate estimates. Specifically, if the number of hours of staff time was collected, a standard approach could be used to estimate the value of such a contribution i.e. multiplying it by a standardised wage rate. This may lose some of the specificity of the self-reported value (for example, the HEI may be more informed about the appropriate wage rate) but would gain in transparency and consistency.

6.3. Further research in general

We have identified a number of areas in which further research could be conducted:

- evaluation of funding mechanisms;
- drivers of private sector R&D department location; and
- extensions to the analysis of further funding.

These are set out in the sections below.

6.3.1. Evaluation of funding mechanisms

An evaluation and comparison of public sector funding mechanisms that facilitate direct private sector funding could be undertaken. This would look specifically at mechanisms which aim to attract private sector funding, such as RPIF, rather than other funding mechanisms such as QR funding, which may have a less direct impact on private funding.

The characteristics of public sector funding mechanisms that we have identified could be used to compare between the mechanisms.

The research could include:

- Identification of UK public funding mechanisms which aim to generate leverage. This would include: RPIF; HEIF; Catalyst Fund; Catapults; IPS; and specific calls from RCs.
- A review of the aims, objectives, approach and size of each mechanism. This would allow for a qualitative comparison between mechanisms and the identification of any overlaps or potential gaps.
- Data collection and analysis related to the mechanisms identified above. This would be to identify the relevant public and private investment associated with each scheme and would give an indication of the effectiveness of each mechanism.
- Temporal comparisons to establish which funding mechanism characteristics are most effective at attracting private funding. This could include, for example, Regional Development Agencies.
- Qualitative interviews with the academic and private sector organisations involved with collaborations that have used the identified mechanisms. Furthermore, valuable insights may be gained from interviewing those that started discussions regarding utilising a mechanism, but decided against it.

The research would need to take account of the environment in which the mechanisms work and any linkages between mechanisms would need to be recognised. For example, a partnership may be first formed through one mechanism, which later leads to the use of another mechanism. As with any such evaluation study, attributing effects to specific initiatives will need to be undertaken carefully.

The research could build on previous evaluations, including:

- 'A Review of QR Funding in English HEIs', PACEC, 2014; and
- 'Evaluation of Research Capital Funding (SRIF2006-08) to Higher Education Institutions 2006-2008', PACEC, 2012.

6.3.2. Extensions to analysis of further funding

There are three areas in which we see value for further analysis of the MRC data: additional controls; taking account of the probability of receiving further funding; and estimating the speed at which further funding is received. We discuss each of these later in this section.

There are, however, two limiting factors to conducting these extensions. Firstly, significant resource will be needed to construct the relevant datasets. Information will have to be gathered from different sources which don't necessarily align. For example, original award spend is collected within internal MRC processes, whereas further funding data is self-reported by PIs.

Relatedly, the second limiting factor is the completeness and accuracy of the data. Due to a proportion of the information being self-reported by PIs, we understand that, for example, not all instances of further funding are reported. Furthermore, some information may not be correctly reported.

Despite these limitations, we still see value in conducting the potential extensions to the analysis that are set out below. Furthermore, all the analysis set out in this section could be replicated using data from other RCs, depending on the data available to them. We now turn to the potential extensions to the MRC data analysis.

Additional controls

In the analysis detailed in section 4.7, we have controlled for the start date of the original award and the amount of public further funding that was received (as a proxy for other drivers of further funding in general). Where possible, we see merit in also controlling for the factors listed below.

- ***Type of research***. Some types of research may naturally attract higher levels of further funding due to there being more reasonable extensions of the work, or the further work being more expensive to conduct. For analysing MRC data, the HRCS codes (which specify the type (basic to applied) and area of research) may be a suitable control variable.
- ***Source of original funding***. Within our analysis we made the simplifying assumption that all MRC managed award spend was from the public sector, and did not differentiate between different public sector sources. In reality, we know that there are some private sector co-funders. Further analysis could therefore differentiate between sources of original award spend i.e. exclude private sector spend or include different explanatory variables for different sources.
- ***Characteristics of the PI***. PIs differ in the amount of private sector relations that they have, and potentially also their ability/desire to interact with the external organisations. The individual PI is therefore likely to affect the level of private further funding that is received. The number of previous awards, or awards that have received further funding, could be used as a proxy for these characteristics.
- ***Research organisation***. The research organisation in which the original research is conducted in influences the amount of private sector further funding that is received. This could be due to, for example, the reputation of the institution or the mechanisms that they have in place (e.g. an industry engagement office).

All of these additional controls should be feasible to include in an analysis of MRC data.

Taking account of the probability of receiving further funding

The analysis that we have conducted has focused on the effect of public expenditure on the level of private further funding in cases where some private further funding has been received. When considering the effect of public expenditure however there are two relevant concepts:

- the probability of receiving further funding; and
- the value of the further funding if it is received.

Our analysis has focused on this latter concept.

Further analysis could consider the probability of receiving further funding, especially private further funding, in isolation. Similar controls to those used and suggested in this report would be appropriate to include. Those factors that affect the value of further funding are also likely to affect the probability of receiving further funding. The dependent variable in such regressions would be a binary variable denoting whether further funding had been received or not. Standard OLS models could be used, or alternatively models such as probit or logit could be used to take account of the binary dependent variable.

More complex models could also be constructed that take into account both the probability of receiving further funding and the value of further funding. Typically a tobit model would be used in this case.

Speed of further funding

Another concept that an extension to the existing analysis could consider is the speed at which further funding is received. The speed of further funding may be important because the sooner research is conducted the sooner its benefits can be realised.

The speed at which further funding is received may be a function of, for example, the source of original funding. It could be that investment by the private sector in the original research increases the speed at which further funding is received. Distinctions could be made between the source of the original funding and the source of the further funding.

7. Annex A – Analytical benefits and challenges

This annex discusses the pros and cons of our different analytical approaches.

This annex discusses the challenges and benefits in relation to the different pieces of econometric analysis that we have conducted. These have been identified through:

- the literature review presented in section 4.2;
- our understanding of econometric techniques; and
- conducting the actual analysis.

In line with our main pieces of analysis, we categorise the analytical benefits and challenges in terms of: single country macro analysis; multi-country macro analysis; and micro analysis.

7.1. Single country macro analysis benefits and challenges

We have used time series econometric methods with ONS data to estimate the effect of public expenditure on private expenditure at the UK level. The benefits and advantages of such analyses are discussed below.

Benefits

The benefits of analysing additionality at the UK level using ONS data are:

» All spillover effects within the country are taken account of.

» Public funding can be considered exogenous.

These advantages are discussed in more detail below.

All spillover effects within the country are taken account of

If public investment in one area results in private investment in another, analysis at levels of aggregation lower than the UK level may not capture all the spillover effects. Furthermore, if public funding in one area resulted in private investment substituting away from another a micro study may pick up a positive effect whereas at the aggregate level the effect is neutral. As such, the main benefit of macro level analysis is that all spillover effects are accounted for.

Public funding can be considered exogenous

Another advantage is that public funding can be considered as exogenous with respect to private funding. At the firm level, for example, public expenditure may not be allocated randomly and as such the assumption of exogeneity is questionable. The public sector may fund projects that otherwise would have performed better than their counterparts – see Czarnitzki and Fier (2001) and Wallsten (2000), for example. This would lead to overstating the effect of public funding, without further adjustments. A positive and significant relationship between a firm's R&D and the public funds it received cannot be taken as evidence of the efficiency of public support. This argument may also apply, though to a lesser degree, to cross-industry studies since R&D subsidies are mainly directed towards R&D intensive industries. At the macro level, the exogeneity assumption is more acceptable.

Challenges

The main challenges that we face with the macro analysis using the ONS data are:

» Controlling for the relevant drivers of private sector investment.

» Accounting for the lag effects of public investment.

» Using the appropriate dependent variable.

» Accounting for time series issues.

We discuss each of these four challenges in more detail below.

Controlling for the relevant drivers of private sector investment

Guellec and van Pottelsberghe de la Potterie (2003) identified that both business and government expenditure may be influenced by common factors that cannot be controlled for, which would bias the estimated relationship. Two factors are likely to be important:

» First, changes in the business cycle could affect the returns to investment and financial constraints of government and businesses. To account for this problem in their paper, the authors use GDP growth as an explanatory variable for business funded R&D.

» Second, changes in the cost of R&D may affect both sectors. For instance, wages and other input prices may increase when the public sector expands its spending, leading to a growth in business spending but no change in quantity of research funded. This factor is examined by accounting for the reaction of R&D prices to demand, as estimated by Goolsbee (1998). This is discussed further in the box overleaf.

Box 3. Adjustment for wage inflation

Guellec and van Pottelsberghe de la Potterie (2003), whilst estimating the impact of public funding on private R&D expenditure, make an adjustment to their elasticity to account for rising wages.

Goolsbee (1998) uses 1968–94 CPS data on wages of US scientific personnel and shows that government R&D spending raises wages significantly. The paper concludes that previous estimates of effects of government R&D spending may be overstated by as much as 30 to 50%.

Goolsbee (1998) estimates the elasticity of the R&D worker wage with respect to government spending is 0.09 in the long term. Guellec and van Pottelsberghe de la Potterie (2003) subtract this price effect from their coefficients, leading to an elasticity of -0.01 for direct funding in the long term and therefore making government funding neutral with respect to business R&D. However, they point out that Goolsbee's estimate is based partly on a period when government spending was a much higher proportion of total R&D than in the period that they are studying (between 50 and 60% until 1980, compared with 33% in 1996 – Guellec and van Pottelsberghe de la Potterie (2003) use the period 1981-1996). They therefore conclude that Goolsbee's estimate must be an overstatement for their purpose.

Contrary to the above, Jaumotte and Pain (2005) found that even though increased public expenditure on R&D can push up wages, it is more than offset by a positive impact on the efficiency of labour in the private sector that arises through the public investment in basic research. This would suggest that although the cost per employee rises, the cost of labour per unit of output effectively remains constant. If wages exactly reflect productivity, it could reasonably be argued that no adjustment for wage inflation would be needed.

Goolsbee (1998) and David and Hall (1999) argue that the major effect of government R&D funding is an increase of the wage of researchers. When faced with higher research costs, firms will shift their funding to alternative investments – thus crowding-out privately funded research. However, when looking at the statistics this negative effect may be masked by the fact that higher prices result in the appearance of more research. As the quantity of research is measured in monetary terms, even when adjusted for general inflation, increased wages may result in the amount of research appearing to have increased. Whether the 'real' amount of research increases or decreases as a result of increased wages will depend on firms' price elasticity of demand for its inputs.

As per the above discussion, it is important that the right control variables are included within our models, and that we address issues of endogeneity.

Accounting for the lag effects of public investment

In principle the impact of R&D can take many years to take effect. Guellec and van Pottelsberghe de la Potterie (2003) start by exploring the lag structure of the determinants of private R&D expenditure by conducting simple regressions. They regress private R&D expenditures on the time lags (i.e. *t*, *t-1*, *t-2*, etc.) of government funding. They find that government funded R&D has a positive and significant effect, but only with one and two-year lags.

Many papers that use a dataset that includes a time element have accounted for lagged effects in some form. For example, and as discussed earlier, Haskel et al. (2014) use both lagged private funding and lagged public funding to estimate private funding.

Using the appropriate dependent variable

Some papers have used 'alternative' measures as either dependent or independent variables. Becker and Pain (2007) use the proportion of R&D undertaken by businesses and funded by government as an independent variable. Such a measure has the advantage of being independent of inflation but does not specify the absolute level of public spending. Other studies, such as Haskel et al. (2014), have used total factor productivity (TFP) as the dependent variable. This approach goes a step further than measuring the effect of public expenditure on the amount of private expenditure and estimates the productive gain from increased public investment in R&D.

A choice also needs to be made whether to use 'real' or 'nominal' measures of spending. Real measures take account of inflation and nominal measures reflect the cash amounts that have been spent.

Using a nominal measure can lead to the appearance that quantity is increasing more than it is in practice. As price levels tend to rise over time, even if the quantity remains constant a £ measure will increase. One way to control for this is to include measures of inflation as explanatory variables. Alternatively, measures can be adjusted from nominal to real – that is, measures can be deflated by a price index to be expressed in a common base. Diamond (1998), for example, transformed all nominal dollar amounts to real 1992 dollars using the GDP implicit price deflator.

One issue with using real measures instead of nominal measures is that the 'correct' price level to deflate by is unknown and unobservable. RPI and CPI, the commonly used measures of inflation, relate to a basket of goods and are unlikely to reflect the inflation rate of the inputs into research.

Our preference is to define variables in nominal terms, but to include price levels as independent variables. This is because deflating measures by a price index imposes a constraint on the effect of inflation, whereas including it as an independent variable allows its effect to be determined within the model. Our main models are defined in nominal terms and we conduct sensitivity analysis by including inflation as an explanatory variable.

Accounting for time series issues

Time series models can experience a number of technical econometric issues. These issues violate the assumptions needed for the model to produce unbiased estimates.

Firstly, the residuals from a time series model can be serially correlated. This occurs when, for example, there is a correlation between the model residual e_t and e_{t-1}. This can occur when the appropriate explanatory variables are not included in the model. Visually inspecting the model residuals can show such autocorrelation, and there are multiple statistical tests which we can use to check our models.

A solution to this issue is to include the lagged dependent variable as an explanatory variable, or specify the dependent variable in first differences (i.e. the difference between expenditure in time *t* and *t-1*).

Another common issue with macro time series is that the variables can be 'non-stationary'. This is where a variable continues to grow without reverting to a mean level. For example, measures of GDP are commonly found to be non-stationary. There are a number of solutions to this issue. Firstly, models can be defined in first differences (if the first difference is stationary). Secondly, if variables are found to be 'cointegrated' unbiased estimates of long-run effects can be estimated using traditional techniques and dynamic models, such as an error correction model (ECM), can be specified to estimate short and long-run effects.

7.2. Multi country macro analysis benefits and challenges

Primarily as a cross-check to the results of our ONS analysis, we also analyse Eurostat data. This contains similar information to the ONS dataset but across multiple countries. It brings with it its own benefits and challenges, as discussed below.

Benefits

The advantages of using the Eurostat dataset over and above the ONS analysis are:

- The additional observations in a multi country dataset may allow us to produce more robust estimates of additionality.
- The panel structure of the dataset allows us to use more sophisticated regression techniques, which may in turn also lead to more robust results.

The benefits are discussed more below.

Additional observations

Using a dataset with more observations gives more degrees of freedom, and as such allows us to include more control variables. In essence, more variation in the observations may allow us to better isolate and identify the impact of public expenditure on private expenditure.

Panel data approaches

Panel data approaches allow us to essentially use country observations as controls for themselves. There are two main types of panel data models: fixed effects (FE); and random effects (RE). The FE estimator allows each country to have its own dummy variable that does not change over time. This can take account of, for example, differences in politics that do not change over time and cannot be easily accounted for with a 'direct' measure.

The RE model treats the error terms as comprising of two components: a country specific random element which does not change over time; and an error term that accounts for statistical noise. One benefit of the RE model is that it can estimate the impact of variables that do not change over time within a country. However, it requires an assumption about the correlation between the individual error components and the explanatory variables. If this assumption is violated the coefficients will be biased and the FE model should be preferred. The Hausman test is typically used to test the assumption and choose between a RE and FE model.

Challenges

The additional challenges posed by a multi country macro approach are:

- Controlling for the additional variation.
- Selecting appropriate countries to include in the analysis.

These two issues are closely related to each other and discussed below.

Controlling for additional variation

Although additional observations can allow for more control variables to be included, the additional variation from multi-country datasets may be caused by more factors that need to be controlled for. That is, differences in private sector investment between countries may be driven by additional factors that need to be controlled for. For example, one major difference between countries may be the tax regime. Guellec and van Pottelsberghe de la Potterie (2003) quantified the aggregate net effect of government funding on business R&D in 17 OECD Member countries over the period 1983 to 1996. To control for differences in fiscal incentives between countries the authors used the 'B-index' designed by Warda (1996) – as described in more detail in the box below.

Box 4. B-index

The B-index is a measure of fiscal generosity towards R&D, as designed by Warda (1996). The more favourable a country's tax treatment of R&D, the lower its B-index. Specifically:

$$B\text{-}index = \frac{1-A}{1-\tau}$$

Where: A = the net present discounted value of depreciation allowances, tax credits, and special allowances on the R&D assets; and τ = statutory income tax rate.

The B-index is similar to the marginal effective tax rate (METR) computed for eight OECD countries by Bloom et al. (2001).

There may also be differences between countries due to unobservable factors, such as culture or politics. It may also be that, for a number of reasons, some countries have historically had a higher proportion of private sector investment than others. To this point, we are most interested in determining what the marginal effect of public expenditure is. Analytically we want to isolate what the impact of the public sector increasing its spend is on private sector spend. One way to do this is to use panel data approaches, as discussed above.

Selecting appropriate countries

Related to the above, ideally we would include countries that are relatively 'similar' to each other. If a county is substantially different to the UK it would not seem sensible trying to identify the drivers of difference between them for the purpose of this project. This selection process is subject to judgement and we identify a number of factors that are important to consider:

- ***Availability of data***. Ideally we will have consistent time series for all comparator countries for the same time period.
- ***Size***. Size of the total economy is likely to be a strong determinant of the amount of private sector R&D expenditure. It may not be sensible to include small countries such as Malta and Latvia in the analysis. Size can however be controlled for in regression models.
- ***Political and economic situation***. China, for example, may exhibit very different drivers.
- ***Competitor of overseas investment***. Some countries are seen as close competitors in terms of research output, and increasingly, for overseas investment. For example, the US, Germany and Japan are world renowned research centres which would be interesting to compare the UK with. Also, contrary to the above factor, China is becoming of increasing interest due to the scale of research it is conducting.

7.3. Micro analysis benefits and challenges

We have conducted micro level analysis on a number of datasets, specifically ones from: HESA; HEBCI; and MRC. This analysis considers additionality at the level of HEIs and individual awards. The benefits and challenges of this type of analysis are discussed below.

Benefits

The benefits of such analysis are:

- Additional observations that can lead to more robust estimates of additionality.
- Additionality at the level at which we are concerned with can be analysed.

These points are discussed below.

Additional observations

As per the discussion of multi-country macro analysis, micro datasets can provide more observations from which more robust estimates of additionality may be computed. Similarly, panel data approaches may be used on appropriate datasets.

Additionality at the level we are concerned with

Micro analysis allows us to study additionality at different levels of aggregation. For example, we may be interested in the effect of public spending on private spending at the HEI level or at the award level. This may provide insights as to the scale of spillover effects at different levels.

Challenges

The challenges faced by micro analysis are:

- Controlling for potential selection bias.
- Appropriately reflecting the spillover effects.

These points are discussed below.

Selection bias

As discussed by Correa at al. (2013), studies at the micro level can be subject to selection bias. Public funding is likely to be targeted at those projects with the highest expected social return – which may also be the most attractive for private investors. In such a case both public and private investment will be driven by characteristics of the project, but there may appear to be a causal relationship between the types of funding if the right analytical techniques are not used.

A number of approaches can be used to address the selection bias issue. For example:

- Almus and Czarnitzki (2003) and Czarnitzki and Lopes Bento (2011) use non-parametric matching methods to compare like-for-like.
- González et al. (2005) control for the probability of obtaining a subsidy based on a set of observable firm characteristics (e.g. size, age, industry, location, capital growth).
- Görg and Strobl (2007) combine a matching method with Difference-in-Differences (DiD) estimation.
- Lichtenberg (1988) uses an instrumental variables (IV) approach.

A selection bias may be less of an issue for us, as some datasets include all possible observations. For example, the HESA data includes all HEIs. As such, we would not face a selection bias in terms of the sample. We will still have to be sure however that we are appropriately controlling for all the factors that determine how much public funding is received.

Appropriately reflecting spillover effects

A limitation of micro studies is that measures of additionality are limited to the population under consideration. Put simply, if we focus on one area we may observe that public funding attracts in more private research, but that will only take into account the area being analysed. Private funding could be being diverted from other areas and therefore at a total UK level additionality may not be positive. The 'universe' under consideration needs to be kept in mind when considering results.

8. Annex B – UK Analysis

This annex presents our analysis of the ONS dataset.

This annex sets out our analysis of UK Gross Domestic Expenditure on Research and Development (GERD) based on data compiled by the Office for National Statistics (ONS). In particular, it:

- Provides an overview of the UK GERD data;
- Examines key facts and figures relating to UK GERD over time; and
- Provides an analysis of the link between private and public expenditure on R&D.

8.1. Overview of the UK GERD data[26]

The ONS uses the definition of R&D defined by the Organisation for Economic Cooperation and Development (OECD), as published in the Frascati Manual: "*…creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications*".

UK GERD is the sum of expenditure by Business Enterprise (BERD), Higher Education (HERD), Government including Research Councils (GovERD) and Private Non-Profit (PNP) organisations. Expenditure includes operating (or current) and capital spending. The ONS uses surveys and census to gather the data – the table below shows the summary descriptions of these provided by the ONS. We note that the ONS has experienced challenges in gathering data from PNP organisations, although it is not clear what impact, if any, these challenges have on the quality of the data. Annex D sets out the Frascati definitions of each of these expenditure types.

Table A1

Source	Description
BERD	*BERD is a survey conducted annually by ONS, and covers the business sector of the economy which in 2012 performed 63% of total UK R&D expenditure. As part of the 2012 survey, approximately 5,000 questionnaires were sent to businesses known to perform R&D. This included around 400 of the largest R&D spenders, accounting for approximately 80% of the 2012 total business R&D expenditure figure. Smaller R&D performers, and others believed to be performing R&D, were selected using various sampling fractions. Industry product group and business employment size, were used as the stratification variables. Completed questionnaires were returned by 4,488 businesses representing a response rate of 91%.*
GovERD	*GovERD is an annual census of approximately 140 government departments including seven research councils. Government departments are asked to include the expenditure on R&D they perform as part of their total estimated expenditure on R&D. This includes estimates of R&D performed by local authorities and NHS trusts.*
HERD	*HERD data are provided by the Higher Education Funding Councils for England, Scotland and Wales, the Department for Education in Northern Ireland and the seven UK research councils. These bodies also provide data on external research funding from overseas, non-profit organisations and businesses. The timeliness of these data is the main reason for the delay in the publication of GERD. Data are provided to ONS during February of a given year, approximately one month before the GERD release is published. It is important to note that R&D funding provided to the higher education sector from government departments, research councils and HEFCs are collected as part of the GovERD survey.*
PNP	*PNP data are collected in a biennial survey which was introduced in 2011 with approximately 200 organisations being selected. The estimates from this survey were used in the compilation of the 2011 GERD publication, the first time since the 2003 reference year. Previously, estimates had been based on a number of different sources. Identifying exactly who carries out R&D in this sector is a challenging task. A letter was despatched in 2010 to 344 organisations which were classified as private non–profit bodies, asking if they undertake R&D activities. The response rate was 50%, with 14% of all organisations surveyed responding positively, confirming that they perform R&D. More in depth analysis of these responses indicated that only a few industries were identified as performing R&D in this sector. Activities*

[26] *ONS (2014), "UK Gross Domestic Expenditure on Research and Development, 2012".*

	included library and archive activities, botanical and zoological gardens and nature reserve activities, engineering and design activities and technical testing and analysis. In 2011, all 690 organisations in these industries were sent a letter to further identify R&D performers. The response rate was 60% with 18% indicating positively. All these identified R&D performers together with known performers from earlier surveys, were sent a questionnaire to collect their totals for 2011. The PNP survey is run biennially, so this survey did not run in 2013 to collect 2012 data. The next survey will run in 2014 to collect 2013 data from an updated list of R&D performers in this sector. Results for the PNP sector as a performer in 2012 have therefore been estimated.

Source: ONS

The data shows both expenditure by funding sector (e.g. whether businesses or Research Councils made the funds available for R&D) and by performing sector (i.e. whether businesses or Research Councils undertook the R&D).[27]

The data also splits expenditures by: product group (in the case of business) – e.g. pharmaceuticals, computer programming and information service activities etc.; by civil and defence spending; and by country and region.

8.2. Key facts and figures relating to UK GERD

This section sets out the key facts and figures relating to UK GERD. We first examine how expenditure in 2012 is split between different bodies funding and performing R&D. We then examine the trends in expenditure over time.

a) Expenditure in 2012

The tables below shows expenditure on R&D in the UK by performing and funding sectors in 2012. It shows that out of a total of £27 billion spent on R&D in the UK:

- Business Enterprise was the largest performer and funder of R&D – performing 63% and funding 46% of the total.
- Defining the 'public sector' as Government, Research Councils (RC), Higher Education Funding Councils (HEFC) and Higher Education (HE) and the 'private sector' as everything else, the private sector performed 65% and funded 70% of the total.[28]
- Most R&D expenditure relates to civil activities (93%).

[27] *We have contacted ONS to find out how, in the context of collaboration, the split between different performing sectors is estimated using the above surveys.*

[28] *Note that some (non-UK) public expenditure may be included in the 'overseas' component of private expenditure.*

Table A2

Current prices	Sector performing the R&D						£ million
	Government	Research Councils	Higher Education	Business Enterprise	Private Non-Profit	**Total**	Overseas
Sector providing the funds							
Government	948	103	406	1,346	67	**2,871**	481
Research Councils	68	578	1,955	2	85	**2,688**	206
Higher Education Funding Councils	-	-	2,185	-	-	**2,185**	-
Higher Education	2	10	284	-	14	**310**	-
Business Enterprise	243	28	292	11,666	88	**12,317**	2,243
Private Non-Profit	4	44	1,022	37	170	**1,277**	-
Overseas	96	49	1,068	4,055	91	**5,358**	-
TOTAL	**1,360**	**813**	**7,211**	**17,107**	**515**	**27,006**	**-**
of which:							
Civil	1,210	813	7,178	15,518	513	**25,232**	-
Defence	150	-	34	1,588	2	**1,774**	-

Source: Office for National Statistics

- denotes nil, figures unavailable or too small to display.

Table A3

EXPENDITURE ON R&D IN THE UK BY PERFORMING AND FUNDING SECTORS, 2012

Current prices	Sector performing the R&D					
	Government	Research Councils	Higher Education	Business Enterprise	Private Non-Profit	**Total**
Sector providing the funds						
Government	70%	13%	6%	8%	13%	11%
Research Councils	5%	71%	27%	0%	17%	10%
Higher Education Funding Councils			30%			8%
Higher Education	0%	1%	4%		3%	1%
Business Enterprise	18%	3%	4%	68%	17%	46%
Private Non-Profit	0%	5%	14%	0%	33%	5%
Overseas	7%	6%	15%	24%	18%	20%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
of which:						
Public	75%	85%	67%	8%	32%	30%
Private	25%	15%	33%	92%	68%	70%

Source: Office for National Statistics

The table below shows the product groups for which R&D performed by Business Enterprise relates to. It shows that the "Pharmaceuticals" product group accounts for 25% of the total and is more than twice the size of the next largest product group, "Computer programming and information service activities".

Table A4

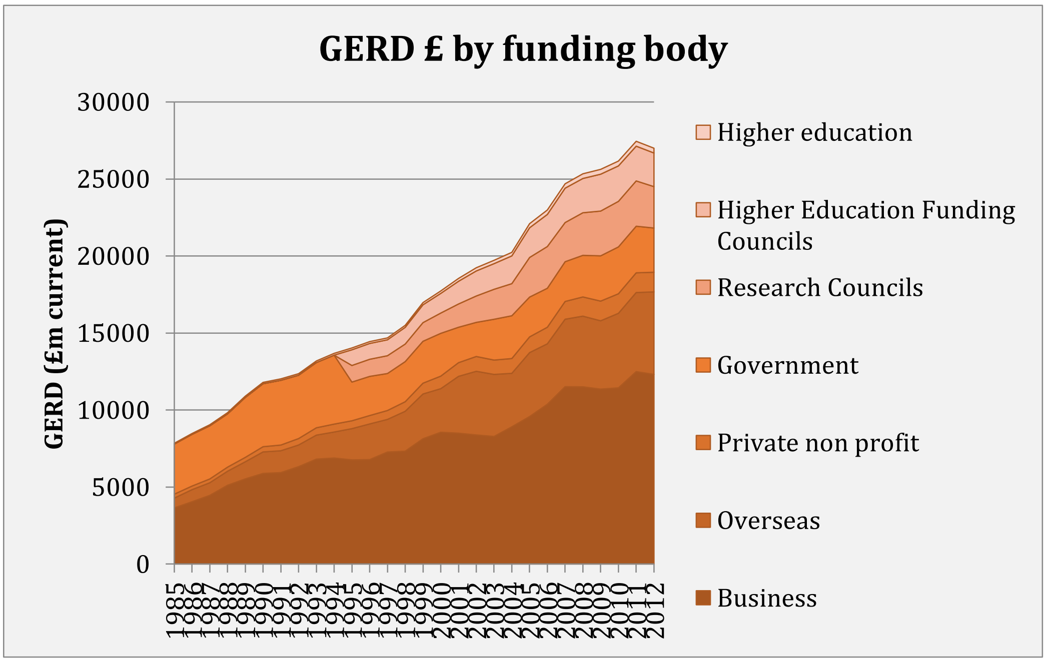
	£ billion	%
Pharmaceuticals	4.2	25
Computer programming and information service activities	1.9	11
Motor vehicles and parts	1.7	10
Aerospace	1.5	9
Machinery and equipment	1.0	6
Telecommunications	0.9	5
Consumer electronics and communication equipment	0.7	4
Miscellaneous business activities; Technical testing and analysis	0.7	4
Precision instruments and optical products; Photographic equipment	0.6	4
Other	3.9	23
Total	17.1	

Source: Office for National Statistics

b) Trends in expenditure

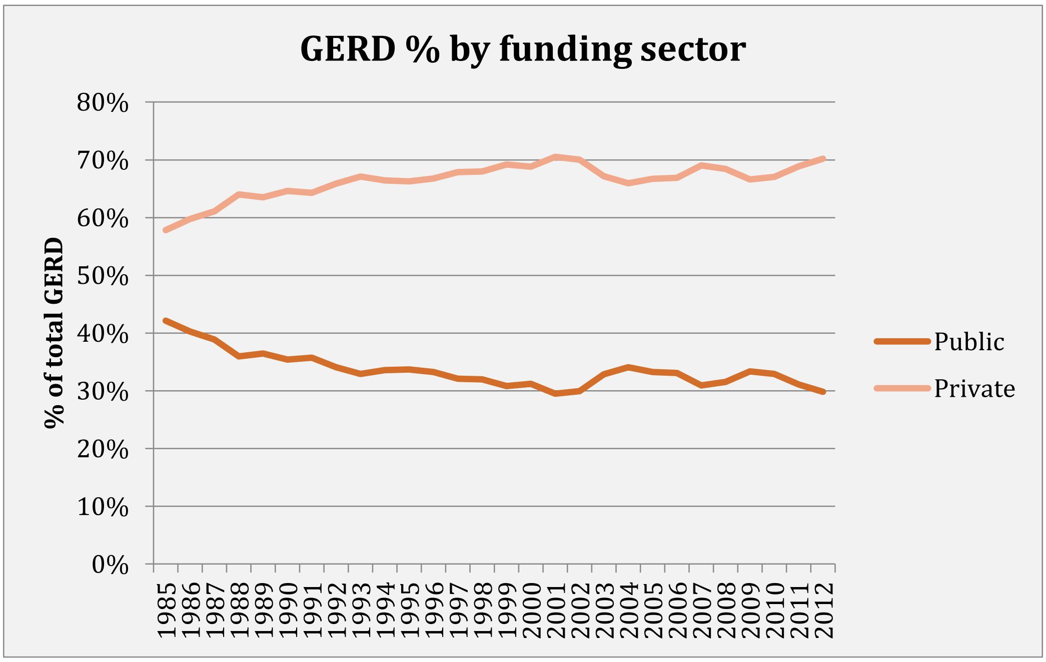
The figure below shows the trend in UK GERD by funding body since 1985 in current prices. It shows that expenditure has increased from around £8bn in 1985 to £27bn in 2012.

Figure A1



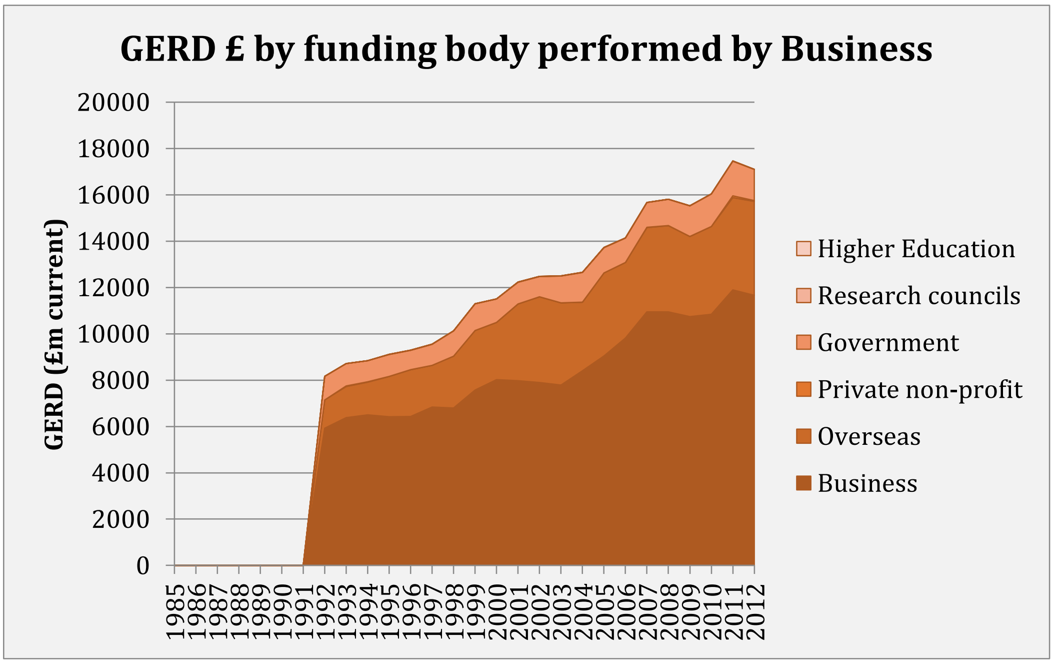
Most of the increase in expenditure is attributable to an increase in funding from the private sector, especially Business and Overseas. This is illustrated by the figure below, which shows that the private sector accounted for just under 60% of funding in 1985 and this has increased to around 70% in 2012. Much of this increase occurred in the period 1985 to 2000 and it has fluctuated around 70% since.

Figure A2



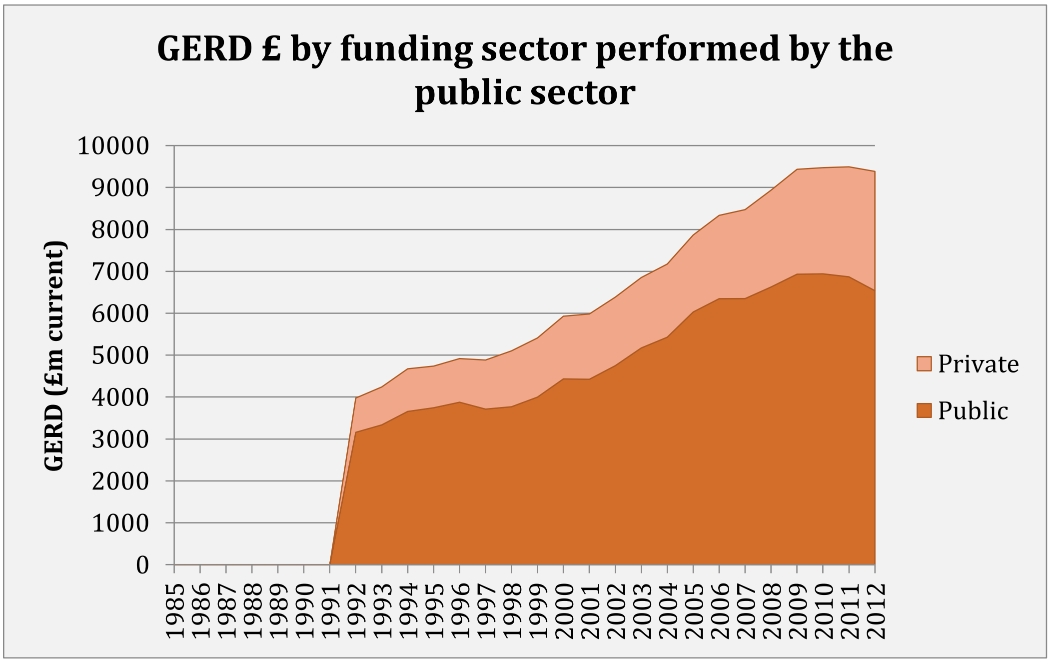
As noted above, around 63% of GERD is accounted for by R&D performed by Business. The figure below shows the trend in R&D expenditure performed by Business and also the sources of funding it. The figure shows that the majority of this expenditure is funded by Business, followed by Overseas and then the Government. The figure also shows that the increase in expenditure is attributable to an increase in funding from Business and Overseas, with Government expenditure remaining relatively stable in cash terms. According to the data, very little is funded by PNPs, RCs or HEs.

Figure A3



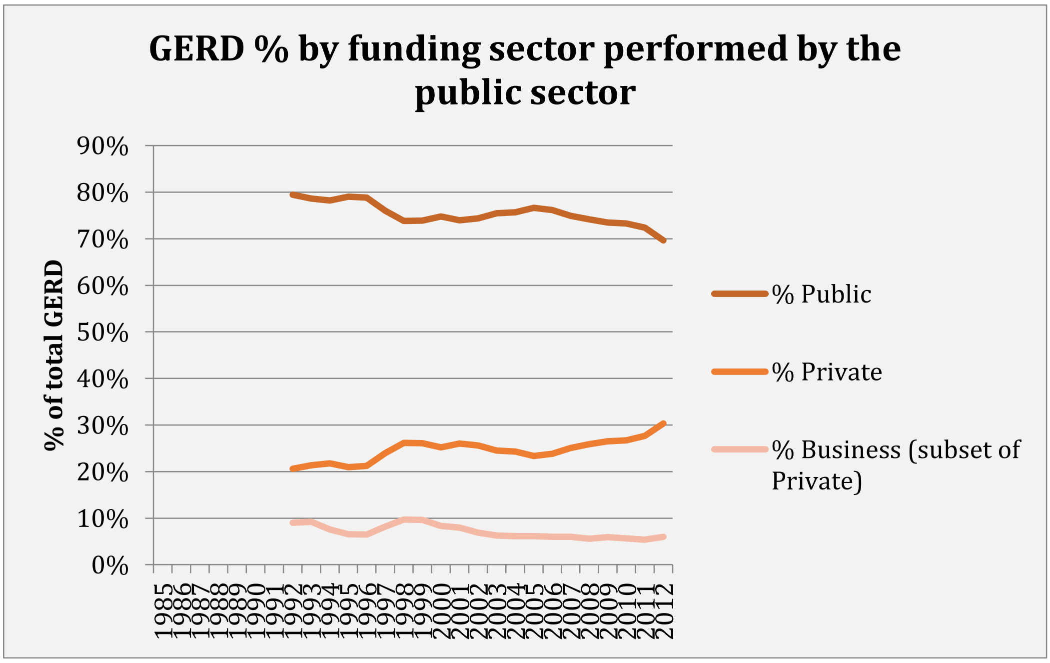
Most of the remaining of GERD is accounted for by R&D performed by the public sector – i.e. Government, Research Councils and Higher Education – 35% of the remaining 37%. Similar to the above, the figure below shows the trend in R&D expenditure performed by the public sector and also the sources of funding of it. It shows that the majority of this expenditure is funded by the public sector, and that funding from both the public and private sources has plateaued since 2009.

Figure A4



The figure below shows that the private sector now contributes around 30% of the funds for R&D performed by the public sector, up from around 20% in the early 1990s. The figure also shows that the increase is not directly attributable to domestic business. The implication is that the increase is related to PNP and Overseas funding.

Figure A5



Overall, these basic trends in UK GERD over the past 20 to 30 years highlight the growing contribution of the private sector. For research performed in Business, domestic and overseas businesses have contributed to the increase in funding. For research performed in the public sector, overseas businesses and the not-for-profit sector are mostly responsible for the increase in funding.

8.3. The relationship between private and public expenditure on R&D

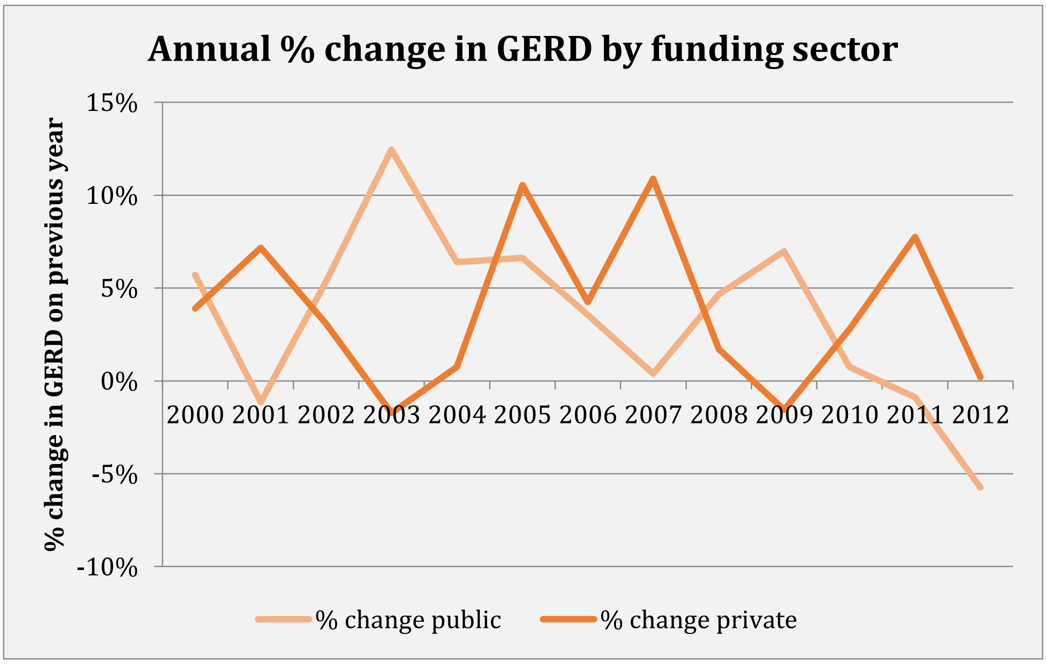
This section set out our preliminary analysis of the relationship between private and public expenditure on R&D using the UK GERD data described above. We begin by looking at private and public expenditure in totality and then investigate how the relationship varies by the different sources of private and public expenditure.

a) Aggregate analysis

i) Graphical analysis

The figure below shows how the annual percentage change in private and public sector funding (in totality, i.e. irrespective of where the research is performed) has evolved since 2000. As can be seen from the figure, there is not a strong positive correlation between the two. In fact, the figure indicates that private funding falls (rises) when public funding rises (falls) sometimes i.e. there is a negative relationship between the two variables.

Figure A6



Taken at face value, this could indicate that public funding crowds out private funding. However, such a conclusion would be premature, as there are various other possibilities for this pattern in the data, which we explore further.

The first possibility is that any effect of public funding on private funding takes time to be seen because it takes time for public funding to 'attract' private funding. This could be for various reasons, including that: (a) it may take time for the R&D activities supported by the public funding to be implemented and therefore represent something 'investable' for the private sector; and/or (b) private funding may, in the shorter-term, be committed to other activities or more generally slow to respond due to operational factors (such as business planning processes).

To illustrate the importance of a possible 'lag', the figures below show the annual percentage change in private and public sector funding, but where public sector funding has been lagged by one and two years. They show a stronger and positive correlation between the two variables.

Figure A7

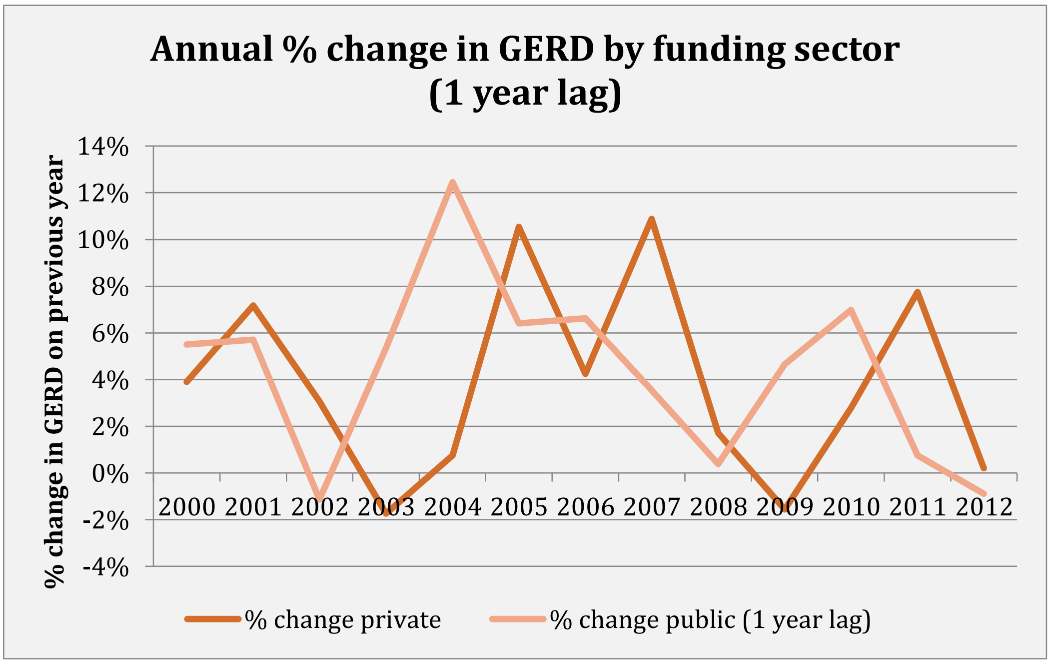
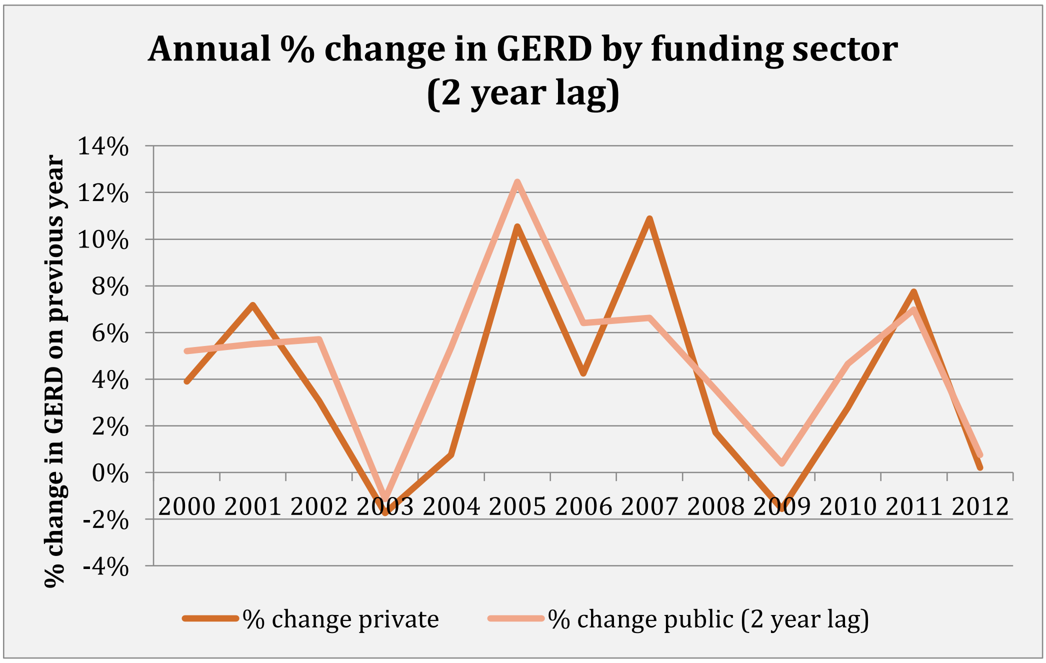


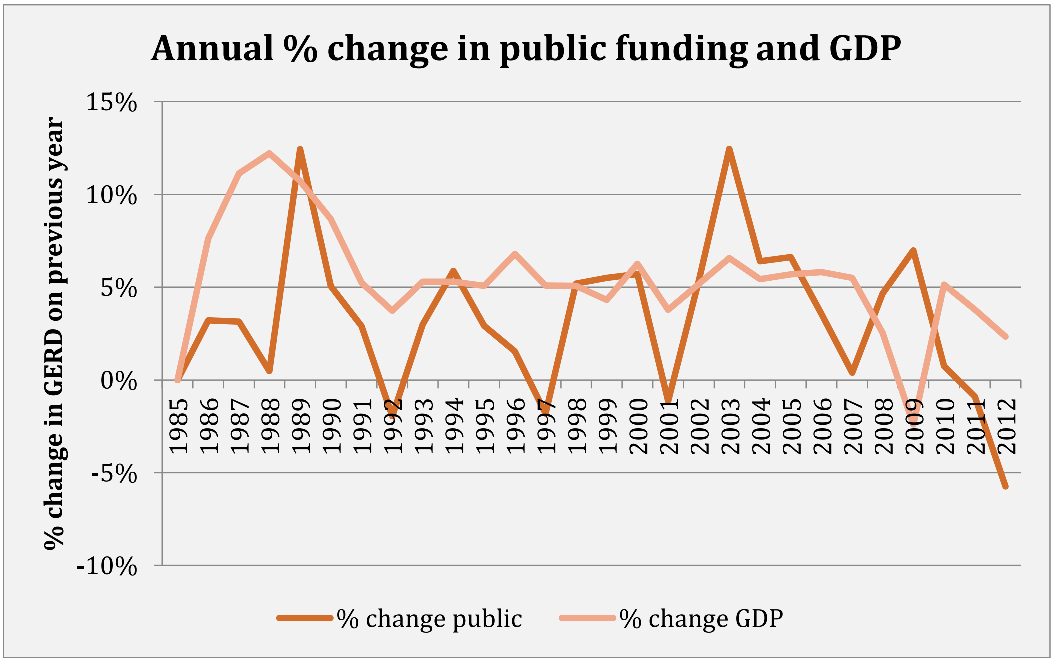
Figure A8



The second possibility is that factors other than the level of public funding have a bearing on the level of private funding and, by failing to control for them adequately, the true relationship between public funding and private funding is masked. As discussed in the main body of this report, there are good reasons to think that the level of private funding made available to R&D will be affected by various factors that influence the actual and perceived revenues and costs associated with such investments.

The third possibility is that policy makers tend to increase public funding of R&D when private funding is scarce, i.e. they seek to fill any 'investment gaps' by spending through the economic cycle. The data could show that private spending tends to be low when public spending is high due the above behaviour, not crowding-out or a lack of crowding in. As indicated by the figure below, this behaviour is not particularly evident in the data. Also, as discussed in the main body of this report, a tendency for public funding R&D to rise and fall in this way may, in fact, increase the risk of crowding out subsequent private expenditure.

Figure A9



The above possibilities suggest that, although informative, the graphical analysis set out above has its limitations and could risk under or overstating the extent of leverage. The next section provides the results of various econometric analyses intended to address the above issues and, in doing so, arrive at more robust estimates of the relationship between public and private funding of R&D.

ii) Econometric analysis

This section sets out the results of our econometric analysis using the UK GERD data described above, combined with other publically available data. The time period for our analysis is from 1997 to 2012 inclusive. The data is measured at an annual frequency.

Our general specification is as set out below:

$$\ln(private\ funding)_t = a + b.\ln(public\ funding)_t + c.controls + e_t \quad (1)$$

Assuming that the equation is properly specified, the parameter b measures the elasticity of private funding with respect to public funding i.e. the % change in private expenditure brought about by a 1% change in public expenditure, other things being equal.

Without any controls, the elasticity is estimated to be 0.91 i.e. the data suggests that a 1% increase in public funding gives rise to a 0.91% increase in private funding of R&D (see Model 1 in Table A4). However, for the reasons set out above, this model fails to take account of the other factors that drive private funding, and so is likely to be biased. Moreover and unsurprisingly, the model performs poorly statistically, with evidence that the model has omitted variables and serially correlated residuals (see Addendum 1).

To address these deficiencies, we make various changes to the analysis.

- Model 2 includes a measure of UK gross fixed capital formation to control for other factors that are likely to influence the level of private funding (this choice is discussed in the main body of this report). It also includes the previous year's level of private expenditure, partly to help capture possible 'memory' in private spending.

- Model 3 is the same as Model 2 except that the previous year's level of public funding is included instead of the current year's level in order to recognise and capture any possible 'delay' in its effect on private funding.[29]

Both Model 2 and Model 3 still suggest that an increase in public funding is correlated with an increase in private funding. The table shows that the estimated coefficient on public funding falls from 0.91 to 0.16 in Model 2 and 0.29 in Model 3. Note, however, that Model 2 and Model 3 include a lagged dependent variable and so an adjustment must be made to the coefficient to calculate the equivalent 'long-run elasticity'.[30] This implied 'long-run' elasticity is shown in the final row of the table. It shows that the elasticity falls from 0.91 to 0.54 and 0.68 respectively.[31] This is perhaps unsurprising as the control variable (UK gross fixed capital formation) is economically large (~0.40) and statistically significant – and so the public funding variable is likely to have erroneously captured the effect of other factors in Model 1.

Consistent with the findings of previous studies, a comparison of Model 2 and Model 3 suggests that the contemporaneous effect of public funding is smaller than the lagged effect of public funding. Indeed, the coefficient on public funding is statistically insignificant in Model 2.

Table A5

	Model 1	Model 2	Model 3
Time period	1997-2012	1997-2012	1997-2012
$\ln(\text{public funding})_t$	0.91*** (0.07)	0.16 (0.10)	
$\ln(\text{public funding})_{t-1}$			0.29** (0.12)
$\ln(\text{fixed capital})_t$		0.43*** (0.14)	0.42*** (0.11)
$\ln(\text{private funding})_{t-1}$		0.71*** (0.10)	0.57*** (0.12)
R-squared	0.91	0.98	0.98
Implied long-run elasticity	0.91	0.54	0.68[32]

Statistically significant at the 10% level, 5% level** and 1%***.*

The table below shows the results of three sensitivity analyses around Model 3.

- Model 4 includes UK GDP as a control variable in addition to UK gross fixed capital formation.
- Model 5 estimates the model in levels rather than logarithms.

[29] *Note we will include a fuller discussion of time series issues in our final report.*

[30] *For example, in Model 2 the long-run elasticity is 0.16/(1-0.71)=0.54. In the long-run y(t)=y(t-1)=y(t-2)…=y(t-n) and so in the model y(t)=a+bx(t)+cy(t-1) the long-run effect of x on y is estimated as b/(1-c). The statistical significance of this expression can be estimated using a Wald test.*

[31] *Addendum E includes an error-correction-model as an additional sensitivity. The implied long-run elasticity from this model is 0.64 i.e. close to the results implied by Model 3.*

[32] *This estimate is statistically significant at the 1% level with an estimated standard error of 0.12 and a confidence interval of [0.45, 0.91].*

- Model 6 examines the effect of using only the later time period in the analysis (2002-2012 inclusive).[33]

The table shows that the long-run elasticity implied by these models is somewhat higher than Model 3. Model 5 suggests that the long-run elasticity is somewhat higher at 0.71 based on a model in levels rather than logarithms. Similarly, Model 6 suggests that the elasticity is also somewhat higher at 0.73. Interestingly, Model 4 suggests that the elasticity is higher again at 1.09 – but the estimated coefficient is statistically insignificant. This lack of significance could be linked to the fact that UK GDP and public funding are highly correlated with one another in these data (0.99). This high correlation, combined with the relatively low number of observations in the dataset, mean that multicollinearity could be inflating the standard errors of the elasticity estimates (and may mean that the elasticity estimates themselves are unreliable).

Overall, the sensitivity analyses indicate that Model 3 and the associated elasticity of around 0.68 is reliable, within the strengths and weaknesses of using UK GERD data (discussed further below). [34]

Table A6

	Model 3	**Model 4**	**Model 5** ***Levels#***	**Model 6**
Time period	1997-2012	1997-2012	1997-2012	2002-2012
ln(public funding)$_t$				
ln(public funding)$_{t-1}$	0.29** (0.12)	0.40 (0.27)	0.36*** (0.12)	0.33* (0.14)
ln(fixed capital)$_t$	0.42*** (0.11)	0.48** (0.20)	0.42*** (0.15)	0.39** (0.13)
ln(private funding)$_{t-1}$	0.57*** (0.12)	0.63*** (0.18)	0.50*** (0.13)	0.55*** (0.14)
ln(gdp)$_t$		-0.19 (0.40)		
R-squared	0.98	0.98	0.98	0.98
Implied long-run elasticity	0.68	1.08	0.72	0.73

Statistically significant at the 10% level, 5% level** and 1%***.*
 # Elasticities are calculated at the means of the dataset.

b) Disaggregated analysis

As noted above, there are different types of private funding and public funding within the aggregates used above. It is possible that the effect of public funding on private funding vary by these types and, in addition, it is possible that the other drivers of private funding vary by these types.

[33] *The split is largely arbitrary, except insofar as the later time period is arguably of greater interest than the earlier.*

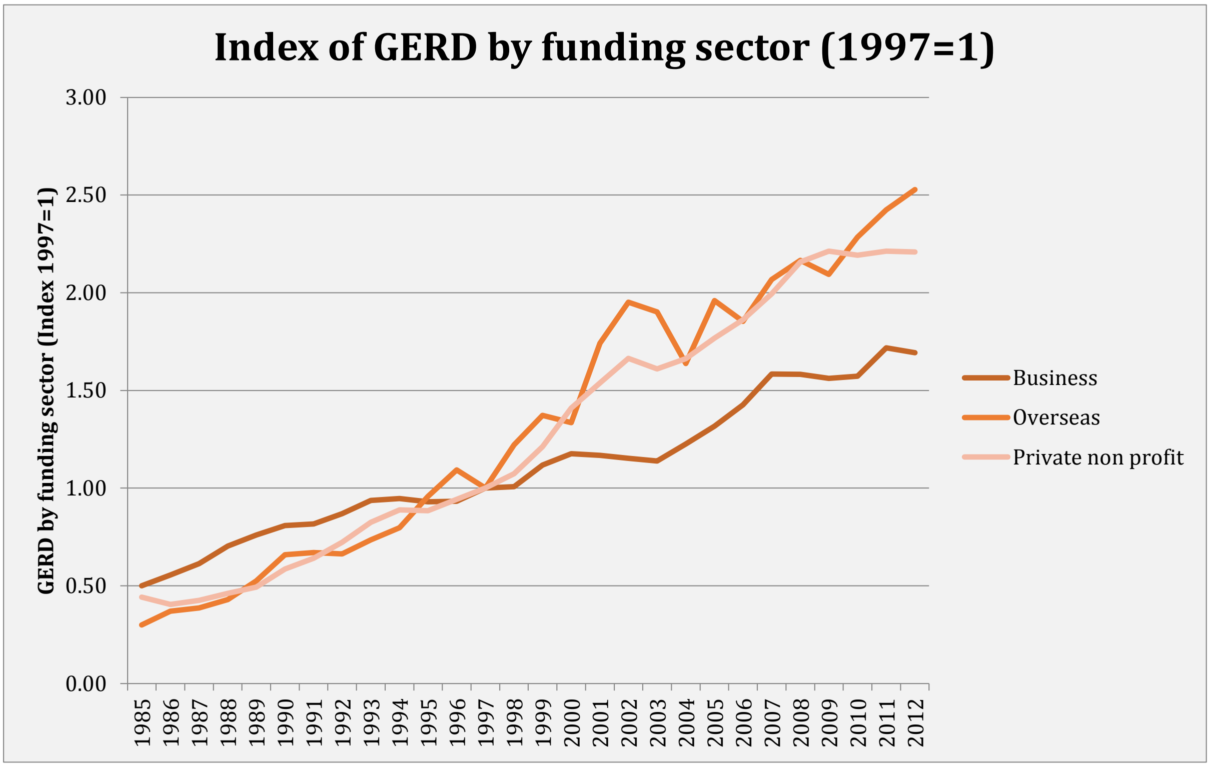
[34] *These regressions use expenditure measured at current not constant / real prices – i.e. they are not adjusted for general inflation. In principle, it is not clear to us that general inflation is a sensible deflator for R&D expenditure. In practice, Addendum D shows that the estimated effect of public funding on private funding does not vary significantly whether the variables are measured in current or constant prices.*

i) Analysis by type of private funding type

The figure below show that, within private funding, the pattern in funding levels vary between Business, Overseas and Private Non-Profit. That is, although they generally follow an upward trend, there are the following points of difference:

- First, Business funding has grown more slowly than Overseas and Private Non-Profit funding.
- Second, Overseas funding is generally more volatile than Business and Private Non-Profit funding.
- Third, they follow different trends at different points in time – for example, business funding 'plateaued' from around 2007 onwards, whereas Private Non-Profit funding continued to rise.

Figure A10



These facts suggest that: (a) the drivers of the different forms of funding may differ; and (b) their relationship with the level of public funding may differ too.

To start exploring these possibilities, we re-estimated Model 3 above but separately for the different types of private funding i.e. business funding, overseas funding and private non-profit funding (between 1997-2012 these accounted for 66.5%, 26.7% and 6.8% of total private funding respectively). The results of these analyses are set out in the table below. The results suggest that the association between public funding and private funding is strongest for business funding and weakest for private non-profit funding, specifically:

- The estimated long-run elasticity for business funding is 0.72 and is statistically significant at the 1% level.
- The estimated long-run elasticity for overseas funding is lower at 0.55 and is not statistically significant. Neither is the control variable.
- The estimated long-run elasticity for private non-profit funding is small and negative and is not statistically significant.

Table A7

	Business	Overseas	PNP
Time period	1997-2012	1997-2012	1997-2012
ln(public funding)$_{t-1}$	0.45*** (0.10)	0.21 (0.29)	-0.03 (0.21)
ln(fixed capital)$_t$	0.35* (0.16)	0.86 (0.49)	0.42** (0.16)
ln(dependent var.)$_{t-1}$	0.37** (0.13)	0.62** (0.22)	0.87*** (0.16)
R-squared	0.97	0.88	0.98
Implied long-run elasticity	0.72	0.55	-0.24

Statistically significant at the 10% level, 5% level** and 1%***.*

These results are consistent with the following two hypotheses. The first is that only business funding is affected by public funding. The second is that the model does not adequately capture the drivers of overseas and PNP funding. Indeed, it is possible that overseas and PNP funding are likely to be driven by different factors to business funding. For example, the level of overseas funding may be influenced by factors that make the UK relatively attractive to other countries.

To examine this last possibility we included the GBP:Euro and GBP:US exchange rates as control variables in the Overseas model in Table A7 above. This had the effect of increasing the estimated elasticity for Overseas funding and its statistical significance, although it and the estimated coefficients on exchange rates were statistically insignificant.

ii) Analysis by type of public funding

We also analysed whether the elasticity of private funding with respect to public funding varied according to the type of public funding received, i.e. Government funding, Higher Education funding, RC funding or HEFCs funding (between 1997-2012 these accounted for 39.1%, 3.5%, 31.2% and 26.3% of total public funding respectively).

An empirical challenge associated with conducting this analysis using this dataset is that the different types of non-Government public funding are highly correlated with one another over time and so separating the effect of one type of funding from another is a challenge, as shown by the correlation matrix below.

Table A8

	Government	Higher Education	RCs	HEFCs
Government	1.00			
Higher Education	0.54	1.00		
RCs	0.55	0.99	1.00	
HEFCs	0.51	0.99	0.98	1.00

Therefore, for the purpose of this analysis, we have split public funding into two – Government funding and 'other public funding' (of course, most of the latter is RC and HEFC funding). The table below shows the results of the analysis with respect to total private funding and business funding. The results of the analysis suggest that the elasticities with respect to Government funding are somewhat higher than the elasticities with respect to other public funding. Also we note that However, it is important not to over interpret these differences, as the results of our statistical analysis (see Addendum C) show that the elasticities are not statistically significantly different from one another.

Table A9

	Private	**Business**
Time period	1997-2012	1997-2012
ln(Govn. funding)$_{t-1}$	0.32** (0.13)	0.54*** (0.12)
ln(Other funding)$_{t-1}$	0.25 (0.15)	0.42*** (0.12)
ln(fixed capital)$_{t}$	0.42*** (0.13)	0.34*** (0.18)
ln(dependent var.)$_{t-1}$	0.60*** (0.14)	0.38** (0.15)
R-squared	0.98	0.98
Implied long-run elasticity Govn.	0.44	0.51
Implied long-run elasticity Other.	0.36	0.37

Statistically significant at the 10% level, 5% level** and 1%***.*

8.4. Further sensitivity analysis

This section sets out further sensitivity analyses around Model 3 to take account a number of statistical issues. Recall that the specification underpinning Model 3 (and the 0.68 elasticity estimate) is:

$$\ln(private\ funding)_t = a + b.\ln(public\ funding)_{t-1} + c.\ln(fixed\ capital) + d.\ln(private\ funding)_{t-1} + e_t \quad (2)$$

There are various econometric issues associated with this type of specification that could affect the accuracy of the elasticity estimate. They include:

- The possibility of omitted variable bias caused by other factors that could drive private funding (and public funding) to increase and that may not be adequately captured by the other control variables included – in particular, the cost of labour used in R&D.
- The possibility that the cost of labour used in R&D is endogenous – i.e. because greater demand for private would put upward pressure on labour costs.
- The possibility that inclusion of the lagged dependent variable may (i) not be justified theoretically and/or (ii) induce an endogeneity problem.
- The possibility that public funding is endogenous and in part determined by the amount of private funding – either directly (say through a policy response to a reduction / increase in private funding) or indirectly (say through the upward / downward pressure on labour costs).

(a) Possible omitted variable bias

The solution to the first problem is to include more control variables. Of course, the size of the dataset limits how many one can reasonably include. Therefore, for the purpose of this analysis, we have gathered information that serves as a proxy for the cost of labour.

The Office of National Statistics gathers salary information via its Annual Survey of Hours and Earnings. Within this dataset is a subcategory called 'Professional occupations'. This is available from 1997 to 2014 (although the 2013 and 2014 results are provisional). The 'professional occupations' category includes a wide range of occupations, from 'biological scientists and biochemists' to 'chartered and certified accountants'. From 2002 onwards, this sub-category was reorganised and split into further sub-sub-categories: 'Science, research and engineering professionals', 'Health professionals', 'Teaching and education professionals' and 'Business, media and public professionals'.

For the purpose of this analysis, we have decided to use the mean salary of all those occupations included in the 'Professional occupations' category for three main reasons. The first is a practical one: the sub-category exists prior to 2002 and so allows us to include the complete time series in the analysis. The second is that we do not have granular information on the labour mix used to create R&D and so it is not clear cut which occupations should be excluded or included from the wage variable, accordingly, we have erred on including more rather than less. The final reason is that, even if we did have granular information on the labour mix, it may still be relevant to include other related occupations as there may be some input substitutability between occupations.

Our first sensitivity simply added a ln(*wage*) variable to specification (2) above. The results are shown in the table below under Model 7. The implied elasticity estimate fell slightly from ***0.68*** to ***0.64***, however, the ln(*wage*) variable was statistically insignificant. This could be for a number of reasons, including that: the other control variable adequately captures the wage effect or – as noted in the literature – the inclusion of the lagged dependent variable 'picks up' some or all of the effect of potentially relevant independent variables. This may particularly be an issue in relatively short time series datasets, as we have here.

To examine the latter possibility we ran the same regression, but excluded the lagged dependent variable. The results of this regression are shown under Model 8 below. It shows that the elasticity falls to ***0.48***.

Table A10

	Model 3	**Model 7**	**Model 8**
Time period	1997-2012	1997-2012	1997-2012
ln(public funding)$_t$			
ln(public funding)$_{t-1}$	0.29** (0.12)	0.28* (0.15)	0.48** (0.18)
ln(fixed capital)$_t$	0.42*** (0.11)	0.42*** (0.12)	0.50** (0.17)
ln(private funding)$_{t-1}$	0.57*** (0.12)	0.56*** (0.13)	
ln(wage)$_t$		0.03 (0.22)	0.50* (0.25)
R-squared	0.98	0.98	0.97
Implied long-run elasticity	0.68	0.64	0.48

(b) Possible endogeneity problems

It is possible that the public funding, wage and lagged dependent variables are endogenous and this could bias the estimated elasticity. We think that the former issue is best addressed using a panel dataset. To help explore the latter two issues we used an instrumental variables approach.

- First, in Model 7, we instrumented current wages with the first lag of wages. We found that this increased the estimated elasticity increased somewhat to 0.50, but that the instrumented wage variable was statically insignificant. We also tried the second lag of wages and the estimated elasticity increased again somewhat to 0.53, with the instrumented wage variable remaining insignificant.
- Second, in Model 3, we instrumented the lagged dependent variable with its rank order. We found that this had little effect on the results, with the elasticity remaining at 0.68.

Although we take some comfort that the results do not vary markedly with these adjustments, we are careful not to over interpret them. There may be superior or different instruments to those we have selected and, in addition, it is well known that instrumental variables estimation may not perform well in small samples.

Addendum A

Model 1

```
Linear regression                                      Number of obs =      16
                                                       F(  1,    14) =  181.94
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9064
                                                       Root MSE      =  .06406

------------------------------------------------------------------------------
             |               Robust
    lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |   .9129358   .0676824    13.49   0.000     .7677716      1.0581
       _cons |   1.531384   .5945507     2.58   0.022     .2561992    2.806568
------------------------------------------------------------------------------


Durbin-Watson d-statistic(  2,    16) =  .9947305


Ramsey RESET test using powers of the fitted values of lprivate
       Ho:  model has no omitted variables
                  F(3, 11) =      2.32
                  Prob > F =      0.1313


Dickey-Fuller test for unit root                   Number of obs   =        27

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -2.733            -3.736            -2.994            -2.628
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0684
```

Model 2

```
Linear regression                                      Number of obs =      16
                                                       F(  3,    12) =  244.00
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9781
                                                       Root MSE      =  .03347

-------------------------------------------------------------------------------
              |               Robust
     lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
      lpublic |   .1569204   .0993949     1.58   0.140    -.0596424    .3734832
lfixedcapital |   .4329704    .139985     3.09   0.009     .1279693    .7379714
              |
     lprivate |
          L1. |   .7117654   .0952239     7.47   0.000     .5042903    .9192406
              |
        _cons |  -3.740414   1.518404    -2.46   0.030    -7.048731    -.432096
-------------------------------------------------------------------------------
```

Model 3

Linear regression

Number of obs	16
F(3, 12)	271.20
Prob > F	0.0000
R-squared	0.9836
Root MSE	.02897

lprivate	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpublic						
L1.	.2927997	.1151821	2.54	0.026	.0418395	.5437599
lfixedcapital	.4243687	.1143277	3.71	0.003	.1752701	.6734674
lprivate						
L1.	.5695124	.1175663	4.84	0.000	.3133574	.8256674
_cons	-3.469806	1.284631	-2.70	0.019	-6.268777	-.6708346

Model 4

Linear regression

Number of obs	16
F(4, 11)	186.23
Prob > F	0.0000
R-squared	0.9839
Root MSE	.03

lprivate	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpublic						
L1.	.4024663	.2682984	1.50	0.162	-.1880545	.992987
lgdp	-.1854928	.4040937	-0.46	0.655	-1.074897	.7039114
lfixedcapital	.4838709	.2044859	2.37	0.037	.0338006	.9339413
lprivate						
L1.	.6305594	.1756236	3.59	0.004	.2440144	1.017104
_cons	-3.117318	1.481072	-2.10	0.059	-6.377135	.1424994

Model 5

```
      Source |       SS       df       MS              Number of obs =      16
-------------+------------------------------           F(  3,    12) =  244.52
       Model |   123245376     3  41081792.1           Prob > F      =  0.0000
    Residual |   2016157.5    12  168013.125           R-squared     =  0.9839
-------------+------------------------------           Adj R-squared =  0.9799
       Total |   125261534    15  8350768.93           Root MSE      =  409.89

------------------------------------------------------------------------------
     private |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      public |
         L1. |   .7856615    .261817     3.00   0.011     .2152113    1.356112
             |
fixedcapital |   .0419054    .014776     2.84   0.015     .0097112    .0740995
             |
     private |
         L1. |    .522606      .1312     3.98   0.002     .2367459    .8084662
             |
       _cons |  -4024.147   1837.169    -2.19   0.049    -8026.995   -21.29972
------------------------------------------------------------------------------


Elasticities after regress
      y  = Fitted values (predict)
         =  14665.438
------------------------------------------------------------------------------
variable |      ey/ex    Std. Err.     z    P>|z|  [    95% C.I.   ]      X
---------+--------------------------------------------------------------------
L.public |   .3554959      .11849    3.00   0.003   .123254  .587738   6635.81
fixedc~l |   .4170234      .14707    2.84   0.005   .128765  .705282    145944
L.priv~e |   .5018775      .12604    3.98   0.000   .254834  .748921   14083.8
------------------------------------------------------------------------------
```

Model 6

```
Linear regression                                      Number of obs =      11
                                                       F(  3,     7) =   68.15
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9668
                                                       Root MSE      =  .02972

-------------------------------------------------------------------------------
             |               Robust
    lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+-----------------------------------------------------------------
     lpublic |
         L1. |   .3285228   .1434211     2.29   0.056    -.0106142    .6676597
             |
lfixedcapital |   .3942308   .1317222     2.99   0.020     .0827574    .7057043
             |
    lprivate |
         L1. |   .5472617   .1378427     3.97   0.005     .2213155    .8732079
             |
       _cons |  -3.215855   1.841072    -1.75   0.124    -7.569298    1.137588
-------------------------------------------------------------------------------
```

Addendum B

Business funding

```
Linear regression                                      Number of obs =      16
                                                       F(  3,     12) =  176.07
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9748
                                                       Root MSE      =  .03284

------------------------------------------------------------------------------
             |               Robust
   lbusiness |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |   .4504017   .1047936     4.30   0.001     .2220761    .6787273
             |
lfixedcapital |   .3454709   .1611705     2.14   0.053    -.0056896    .6966313
             |
   lbusiness |
         L1. |   .3721317   .1292899     2.88   0.014     .0904333    .6538301
             |
       _cons |  -2.290115   1.566041    -1.46   0.169    -5.702226    1.121996
------------------------------------------------------------------------------
```

Overseas funding

```
Linear regression                                      Number of obs =      16
                                                       F(  3,     12) =   33.41
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.8775
                                                       Root MSE      =  .10215

------------------------------------------------------------------------------
             |               Robust
   loverseas |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |   .2083372    .288511     0.72   0.484    -.4202742    .8369485
             |
lfixedcapital |   .8618892   .4925115     1.75   0.106    -.2112011     1.93498
             |
   loverseas |
         L1. |   .6208615    .223229     2.78   0.017     .1344874    1.107236
             |
       _cons |  -8.918468    5.36588    -1.66   0.122    -20.60972    2.772781
------------------------------------------------------------------------------
```

Private non-profit funding

```
Linear regression                                      Number of obs =      16
                                                       F(  3,     12) =  371.86
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9849
                                                       Root MSE      =  .03582

----------------------------------------------------------------------------------
                 |               Robust
lprivatenonprofit |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----------------+----------------------------------------------------------------
         lpublic |
             L1. |  -.0318064   .2068069    -0.15   0.880    -.4823999     .418787
                 |
    lfixedcapital |   .4151957   .1614657     2.57   0.024     .0633922    .7669991
                 |
lprivatenonprofit |
             L1. |   .8687703   .1577944     5.51   0.000     .5249658    1.212575
                 |
           _cons |  -3.707859   1.917173    -1.93   0.077    -7.885019    .4693015
----------------------------------------------------------------------------------
```

Exchange rates

```
      Source |       SS       df       MS              Number of obs =      14
-------------+------------------------------           F(  5,     8) =    8.70
       Model |  .396154378     5  .079230876           Prob > F      =  0.0043
    Residual |  .072887937     8  .009110992           R-squared     =  0.8446
-------------+------------------------------           Adj R-squared =  0.7475
       Total |  .469042315    13  .036080178           Root MSE      =  .09545

------------------------------------------------------------------------------
    loverseas |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lpublic |
          L1. |   .4776499   .3266808     1.46   0.182    -.2756773    1.230977
              |
lfixedcapital |   .3249806   .5884644     0.55   0.596    -1.032021    1.681982
              |
    loverseas |
          L1. |   .6721194   .3100873     2.17   0.062    -.0429433    1.387182
              |
         euro |   .3331292   .3422777     0.97   0.359    -.4561645    1.122423
       dollar |  -.2761288   .1813439    -1.52   0.166    -.6943085     .142051
        _cons |  -5.319595   7.400506    -0.72   0.493    -22.38519      11.746
------------------------------------------------------------------------------
```

Addendum C

Private funding

```
Linear regression                                      Number of obs =      16
                                                       F(  4,    11) =  194.26
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9840
                                                       Root MSE      =  .02989

-------------------------------------------------------------------------------------
                    |               Robust
           lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------+----------------------------------------------------------------
        lgovernment |
                L1. |   .3151363   .1280984     2.46   0.032     .0331936     .597079
                    |
lnongovernmentpublic |
                L1. |   .2545268   .1491426     1.71   0.116    -.0737339    .5827875
                    |
      lfixedcapital |   .4170601   .1267122     3.29   0.007     .1381685    .6959517
                    |
           lprivate |
                L1. |   .5963988   .1395929     4.27   0.001     .2891569    .9036408
                    |
              _cons |  -3.780771   1.481789    -2.55   0.027    -7.042166   -.5193759
-------------------------------------------------------------------------------------

( 1)  L.lgovernment - L.lnongovernmentpublic = 0

       F(  1,    11) =    0.24
            Prob > F =    0.6359
```

Business funding

```
Linear regression                                      Number of obs =      16
                                                       F(  4,    11) =  133.88
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9769
                                                       Root MSE      =  .03286

--------------------------------------------------------------------------------------
                     |               Robust
           lbusiness |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------+----------------------------------------------------------------
         lgovernment |
                 L1. |   .5353384    .138093     3.88   0.003     .2313979    .8392789
                     |
lnongovernmentpublic |
                 L1. |   .4176559   .1210075     3.45   0.005     .1513201    .6839916
                     |
       lfixedcapital |    .340146   .1820908     1.87   0.089    -.0606331    .7409251
                     |
           lbusiness |
                 L1. |   .3781658   .1478488     2.56   0.027     .0527529    .7035788
                     |
               _cons |  -2.921654   1.791946    -1.63   0.131    -6.865702    1.022393
--------------------------------------------------------------------------------------


 ( 1)  L.lgovernment - L.lnongovernmentpublic = 0

       F(  1,    11) =    0.93
            Prob > F =    0.3549
```

Addendum D

Private, constant / real values (RPI)

```
Linear regression                                      Number of obs =      16
                                                       F(  3,    12) =   17.66
                                                       Prob > F      =  0.0001
                                                       R-squared     =  0.8420
                                                       Root MSE      =  .03402

--------------------------------------------------------------------------------
               |               Robust
     lcprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
      lcpublic |
           L1. |   .2992637   .1374286     2.18   0.050    -.0001675    .5986948
               |
lcfixedcapital |   .2233381    .113759     1.96   0.073    -.0245214    .4711976
               |
     lcprivate |
           L1. |   .7350309   .1849146     3.97   0.002     .3321365    1.137925
               |
         _cons |  -2.561692   2.710456    -0.95   0.363    -8.467268    3.343885
--------------------------------------------------------------------------------
```

Private, RPI inflation included as control

```
Linear regression                                      Number of obs =      16
                                                       F(  4,    11) =  191.03
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9836
                                                       Root MSE      =  .03026

------------------------------------------------------------------------------
             |               Robust
    lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |   .2911425   .1309531     2.22   0.048     .0029167    .5793684
             |
lfixedcapital |   .4236795   .1222065     3.47   0.005     .1547048    .6926542
             |
    lprivate |
         L1. |   .5681706   .1484643     3.83   0.003     .2414028    .8949383
             |
       index |   .0024457   .1197184     0.02   0.984    -.2610527    .2659441
       _cons |  -3.439284   1.927378    -1.78   0.102    -7.681415     .802847
------------------------------------------------------------------------------
```

Business, constant / real values (RPI)

```
Linear regression                                      Number of obs =      16
                                                       F(  3,    12) =   10.13
                                                       Prob > F      =  0.0013
                                                       R-squared     =  0.7588
                                                       Root MSE      =  .03406

-------------------------------------------------------------------------------
              |               Robust
   lcbusiness |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
     lcpublic |
          L1. |   .4476356   .1333352     3.36   0.006     .1571233     .738148
              |
lcfixedcapital |      .2261    .124988     1.81   0.096    -.0462255    .4984255
              |
   lcbusiness |
          L1. |   .5012666   .1259018     3.98   0.002     .2269501    .7755832
              |
        _cons |  -1.929366   2.690648    -0.72   0.487    -7.791784    3.933053
-------------------------------------------------------------------------------
```

Business, RPI inflation included as control

```
Linear regression                                      Number of obs =      16
                                                       F(  4,    11) =  121.27
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9749
                                                       Root MSE      =  .03425

------------------------------------------------------------------------------
             |               Robust
   lbusiness |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |   .4332146   .1522791     2.84   0.016     .0980505    .7683787
             |
lfixedcapital |   .3415331   .1748218     1.95   0.077    -.0432472    .7263134
             |
   lbusiness |
         L1. |   .3527944   .1526393     2.31   0.041     .0168375    .6887514
             |
       index |   .0274779   .1473864     0.19   0.855    -.2969173    .3518732
       _cons |  -1.972132   2.643267    -0.75   0.471    -7.789923    3.845659
------------------------------------------------------------------------------
```

Addendum E

ECM

```
Linear regression                                      Number of obs =      15
                                                       F(  5,      9) =    6.72
                                                       Prob > F      =  0.0071
                                                       R-squared     =  0.6844
                                                       Root MSE      =   .0291

------------------------------------------------------------------------------
             |               Robust
   D.lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lpublic |
          D1. |  -.3122212   .1711351    -1.82   0.101    -.6993556    .0749133
              |
     lprivate |
          L1. |  -.4844718   .1499225    -3.23   0.010    -.8236199   -.1453236
              |
      lpublic |
          L1. |    .310123   .1319687     2.35   0.043     .0115891    .6086569
              |
lfixedcapital |
          D1. |   .2987138   .1166065     2.56   0.031     .0349317     .562496
          L1. |   .3419855   .1827683     1.87   0.094    -.071465      .755436
              |
        _cons |  -2.113116   1.969398    -1.07   0.311    -6.568202    2.341971
------------------------------------------------------------------------------
```

ADL

```
Linear regression                                      Number of obs =      15
                                                       F(  5,      9) =  100.08
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9838
                                                       Root MSE      =   .0291

------------------------------------------------------------------------------
             |               Robust
     lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lpublic |
          --. |  -.3122212   .1711351    -1.82   0.101    -.6993556    .0749133
          L1. |   .6223442   .1515237     4.11   0.003     .2795738    .9651146
              |
lfixedcapital |
          --. |   .2987138   .1166065     2.56   0.031     .0349317     .562496
          L1. |   .0432717   .1249366     0.35   0.737    -.2393546     .325898
              |
     lprivate |
          L1. |   .5155282   .1499225     3.44   0.007     .1763801    .8546764
              |
        _cons |  -2.113116   1.969398    -1.07   0.311    -6.568202    2.341971
------------------------------------------------------------------------------
```

Addendum F – Section 4 sensitivity analysis

```
Linear regression                                      Number of obs =       16
                                                       F(  3,     12) =  236.05
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9667
                                                       Root MSE      =  .04128

------------------------------------------------------------------------------
             |               Robust
    lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |    .477342    .182502     2.62   0.023     .0797044    .8749797
             |
lfixedcapital |   .5005864   .1700524     2.94   0.012     .1300741    .8710987
       lwage |   .4957823   .2547889     1.95   0.075     -.059355     1.05092
       _cons |  -3.742316   1.810357    -2.07   0.061    -7.686744    .2021128
------------------------------------------------------------------------------
```


```
Linear regression                                      Number of obs =       16
                                                       F(  3,     12) =  236.05
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9667
                                                       Root MSE      =  .04128

------------------------------------------------------------------------------
             |               Robust
    lprivate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     lpublic |
         L1. |    .477342    .182502     2.62   0.023     .0797044    .8749797
             |
lfixedcapital |   .5005864   .1700524     2.94   0.012     .1300741    .8710987
       lwage |   .4957823   .2547889     1.95   0.075     -.059355     1.05092
       _cons |  -3.742316   1.810357    -2.07   0.061    -7.686744    .2021128
------------------------------------------------------------------------------
```


```
Instrumental variables (2SLS) regression               Number of obs =       15
                                                       Wald chi2(3)  =   339.04
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9576
                                                       Root MSE      =  .03646

------------------------------------------------------------------------------
    lprivate |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lwage |   .4575988     .34557     1.32   0.185    -.2197059    1.134903
             |
     lpublic |
         L1. |   .5009403   .2274756     2.20   0.028     .0550963    .9467844
             |
lfixedcapital |   .4392081   .2263798     1.94   0.052    -.0044882    .8829045
       _cons |  -2.973351   2.590264    -1.15   0.251    -8.050174    2.103472
------------------------------------------------------------------------------
Instrumented:  lwage
Instruments:   L.lpublic lfixedcapital L.lwage
```

```
Instrumental variables (2SLS) regression               Number of obs =      14
                                                       Wald chi2(3)  =  256.06
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9481
                                                       Root MSE      =  .03599

------------------------------------------------------------------------------
    lprivate |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lwage |   .3683001   .4925385     0.75   0.455    -.5970576    1.333658
             |
     lpublic |
         L1. |   .5328192   .3059688     1.74   0.082    -.0668687    1.132507
             |
lfixedcapital |   .4210587   .2337881     1.80   0.072    -.0371574    .8792749
       _cons |  -2.461122   2.863931    -0.86   0.390    -8.074324     3.15208
------------------------------------------------------------------------------
Instrumented:  lwage
Instruments:   L.lpublic lfixedcapital L2.lwage
```

```
Instrumental variables (2SLS) regression               Number of obs =      16
                                                       Wald chi2(3)  =  950.88
                                                       Prob > chi2   =  0.0000
                                                       R-squared     =  0.9836
                                                       Root MSE      =  .02509

------------------------------------------------------------------------------
    lprivate |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lprivate |
         L1. |   .5751452   .1336369     4.30   0.000     .3132217    .8370687
             |
     lpublic |
         L1. |   .2878175    .123871     2.32   0.020     .0450347    .5306003
             |
lfixedcapital |   .4231765   .1346435     3.14   0.002       .15928     .687073
       _cons |  -3.465592   1.395126    -2.48   0.013    -6.199988   -.7311955
------------------------------------------------------------------------------
Instrumented:  L.lprivate
Instruments:   L.lpublic lfixedcapital L.rank
```

9. Annex C – Reconciliation of BIS budget with ONS data

This annex presents a comparison of the BIS budget with ONS data.

9.1. ONS data

Part of our analysis relies on ONS "Gross Expenditure on Research and Development" (GERD) data. As set out in further detail in Annex B, the GERD data is compiled in line with the international standards set out in the OECD's Frascati manual. The data shows the following "sectors" which fund R&D in the UK:

1. Government
2. Research Councils
3. Higher Education Funding Councils
4. Higher Education
5. Business Enterprise
6. Private Non-Profit.[35]

The table below shows the funding provided by each sector in 2011 and 2012.

Table 1

Sector	**2011 (£ million)**	**2012 (£ million)**
Government	3,028	2,871
Research Councils	2,942	2,688
Higher Education Funding Councils	2,257	2,185
Higher Education	317	310
Business Enterprise	12,498	12,317
Private Non-Profit	1,279	1,277
Total	**27,459**	**27,006**

Note that in our analysis, we have defined "public" expenditure as the sum of sectors 1-4 and "private" expenditure as the sum of sectors 5 and 6. Also in our analysis, we have defined "government" public expenditure as sector 1 and "non-government" public expenditure as sectors 2-4.

9.2. BIS budget

BIS allocates funding to the Research Councils, the Higher Education Funding Council for England and smaller sums to various other public bodies. As well as being split between the different public bodies, the budget is further split between "resource", "depreciation and impairment" and "capital" expenditure. These splits are set out in the table in Table 3.

The table below shows the budget for 2011 and 2012 (note that the budget is produced on a FY basis and so we have converted the figures into calendar years for comparison with the ONS data).

Table 2

Sector	**2011 (£ million)**	**2012 (£ million)**
Research Councils	3,029	2,969

[35] *ONS states that "The private non-profit sector includes registered charities and trusts. Those performing R&D in this sector specialise mainly in health and medical research. Some of the largest of these are based in the UK. This sector includes, for example, a number of cancer charities that carry out extensive research into types of cancer prevention, from drug development to clinical trials."*

Higher Education Funding Councils (HEFCE in brackets)	1,874 (1,857)	1,852 (1,839)
Other	443	400
Total	**5,346**	**5,221**

9.3. Comparison

i) Research Councils

A comparison of the data in Table 1 and Table 2 shows that, for Research Councils, the ONS GERD data is a similar order of magnitude to the BIS budget data (around £3 billion).

We note that the BIS figures are somewhat higher than the ONS figures. One possible reason for this is that there may be may be differences between when the budget is allocated and when expenditure is actually incurred. For example, the Research Councils receive funding to cover "depreciation and impairment" and "capital" expenditure, such that they are in a position to finance investments in new assets when needs arise – clearly, these needs may arise at a different times to those implied by the budget.

Given the above and our understanding of the data, we consider that it is appropriate to interpret 100% of the research identified as being funded by "Research Councils" in the ONS GERD data as stemming from the BIS budget.

ii) Higher Education Funding Councils

For Higher Education Funding Councils, the funding level implied by the ONS data is higher than the BIS figures (between 18% and 20%, depending on the year). This difference could, in part, be due to the timing-related reason set out above. However, of greater potential importance, is that the BIS figures relate primarily to its funding of HEFCE, whereas the ONS data also includes the funding received (and spent) by the funding bodies in Scotland, Northern Ireland and Wales, primarily from sources other than BIS.

To illustrate this point, the table below provides a breakdown of the £2,257m and £2,185m figures relating to HEFC in Table 2. It implies that around 20% of the funding relates to the funding bodies outside of England.

Table 3

Sector	**2011 (£ million)**	**2012 (£ million)**
HEFCE	1,821	1,736
SFC	296	312
DELNI	59	57
HEFCW	82	80
Total	**2,257**	**2,185**
HEFCE % of total	81%	79%
Other funding bodies	19%	21%

Comparing the BIS HEFCE figures in Table 2 to the ONS HEFCE figures in Table 3, shows that they are relatively close – with the ONS figures only being somewhat lower than the BIS figures (between 2% and 6%, depending on the year).

Therefore, given the above and our understanding of the data, we consider that it is appropriate to interpret 80% of the research identified as being funded by "Higher Education Funding Councils" in the ONS GERD data as stemming from the BIS budget.

iii) Other

In addition to the budget allocated to Research Councils and HEFCs, BIS allocates budget to "Other" public bodies – these include but are not limited to the UK Space Agency and the National Academies. Table 2 shows that the budget was £443m in 2011 and £400m in 2012 – around 8% of the total budget.

Our research suggests that this sum is included in "Government" sector in the ONS GERD data. Therefore, it would account for around 14-15% of the total "Government" sector and this would seem to be an appropriate figure to interpret as stemming from the BIS budget.

Table 4

Source: BIS (December 2010), "The Allocation of Science and Research Funding 2011/12 to 2014".								Source: ONS (March 2014), "UK Gross Domestic Expenditure on Research and Development, 20			
								http://www.ons.gov.uk/ons/dcp171778_355583.pdf			
RC	**2010-11**	**2011-12**	**2012-13**		**2011**	**2012**		**2011**	**2012**		
Resource	2,549,353	2,596,196	2,573,678		2,584,485	2,579,308					
Depreciation and impairment	130,706	178,472	180,440		166,531	179,948					
Capital	393,438	239,821	199,393		278,225	209,500					
Total	**3,073**	**3,014**	**2,954**		**3,029**	**2,969**		2,942	2,688	97%	91%
Excluding depreciation and impairment					*2,863*	*2,789*				103%	96%
HEFCE	**2010-11**	**2011-12**	**2012-13**		**2011**	**2012**		**2011**	**2012**		
Resource	1,731,300	1,662,112	1,699,578		1,679,409	1,690,212					
Depreciation and impairment	-	-	-		-	-					
Capital	325,372	128,369	155,347		177,620	148,603					
HEI Capital HEFCE	166,952	75,170	90,970		98,116	87,020					
HEI Research Capital England	158,420	53,199	64,377		79,504	61,583					
Total	**2,057**	**1,790**	**1,855**		**1,857**	**1,839**		1,821	1,736	98%	94%
Other HEFC	**2010-11**	**2011-12**	**2012-13**		**2011**	**2012**		**2011**	**2012**		
Resource	-	-	-		-	-					
Depreciation and impairment	-	-	-		-	-					
Capital	31,431	11,531	13,953		16,506	13,348					
HEI Research Capital Scotland	23,622	8,620	10,431		12,371	9,978					
HEI Research Capital Wales	6,031	2,113	2,557		3,093	2,446					
HEI Research Capital N. Ireland	1,778	798	965		1,043	923					
Total	**31**	**12**	**14**		**17**	**13**		437	449	4%	3%
Other BIS funding	**2010-11**	**2011-12**	**2012-13**		**2011**	**2012**		**2011**	**2012**		
Resource	295,253	317,598	302,650		312,012	306,387					
National Academies	87,832	87,465	86,547		87,557	86,777					
Other Programmes	43,616	24,496	24,140		29,276	24,229					
UK Space Agency	163,805	205,637	191,963		195,179	195,382					
Depreciation and impairment	-	-	-		-	-					
Capital	122,380	134,279	80,307		131,304	93,800					
Large Facilities Capital Fund	103,380	115,279	61,307		112,304	74,800					
UK Space Agency	19,000	19,000	19,000		19,000	19,000					
Total	**418**	**452**	**383**		**443**	**400**		646	729	146%	182%
Total BIS funding	**2010-11**	**2011-12**	**2012-13**		**2011**	**2012**		**2011**	**2012**		
RC+HEFC	5,162	4,817	4,822		4,903	4,821		5,199	4,873	106%	101%
RC	3,073	3,014	2,954		3,029	2,969		2,942	2,688	97%	91%
HEFC	2,088	1,802	1,869		1,874	1,852		2,257	2,185	120%	118%
Other BIS	418	452	383		443	400		646	729	146%	182%
Total	**5,579**	**5,268**	**5,205**		**5,346**	**5,221**		5,845	5,602	109%	107%

10. Annex D – Eurostat analysis

This annex develops our analysis regarding public funding leverage using Eurostat data.

This annex sets out our analysis of European and Overseas Gross Domestic Expenditure on Research and Development (GERD) based on data compiled by Eurostat. In particular, it:

- Provides an overview of the Eurostat GERD data;
- Examines key facts and figures relating to Eurostat GERD over time; and
- Provides an analysis of the link between private and public expenditure on R&D.

10.1. Overview of the data[36]

Eurostat compiles R&D data following the guidelines laid out in the Frascati Manual (OECD) and the Regional Manual (Eurostat). According to the Frascati Manual, *"[r]esearch and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications*".[37]

Basic R&D indicators reported by Eurostat are R&D expenditure and R&D personnel (by sectors of performance and source of funds/ fields of science), at the national and regional level, whereby national data refers to distinct countries (e.g. UK or Germany) and regional data refers to a *supra-national level of aggregation* (e.g. Euro-area, EU15 or EU28). For the purpose of this report, we will only look at the R&D expenditure data by sectors of performance and source of funds at a national level.

Intramural expenditures are all expenditures for R&D performed within a statistical unit or sector of the economy, whatever the source of funds (GERD). Expenditures made outside the statistical unit or sector but in support of intramural R&D (e.g. purchase of supplies for R&D) and both current and capital expenditures are included. Internal expenditure is broken down by institutional sector – the sector in which the R&D is performed. There are four main sectors: Business Enterprise (BES), Government (GOV), Higher Education (HES) and Private Non-Profit institutions (PNP). There is also another major sector as a source of funding, namely Abroad (ABR). What is included in each sector (following the Frascati Manual) is summarised in the table below. For the purpose of our analysis we will classify BES, PNP and ABR as the "private sector" and GOV and HES as the "public sector".

Table 23 Coverage of R&D sectors

Sector	Description
BES	*All firms, organisations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price; the private non-profit institutes mainly serving them.*
GOV	*All departments, offices and other bodies, which furnish but normally do not sell to the community those common services, other than higher education, which cannot otherwise be conveniently and economically provided and administer the state and the economic and social policy of the community (public enterprises are included in the business enterprise sector); non-profit institutes controlled and mainly financed by government.*
HES	*All universities, colleges of technology and other institutes of post-secondary education, whatever their source of finance or legal status. It also includes all research institutes, experimental stations and clinics operating under the direct control of or administered by or associated with higher education establishments.*

[36] *Eurostat (2012), "Research and Development expenditure and personnel – Methodological references".*

[37] *R&D statistics should be used with caution, as the Frascati Manual underlines: "R&D statistics are only a summary quantitative reflection of very complex patterns of activities and institutions. For this reason it can be dangerous to use them "neat". They should, as far as possible, be analysed in light of any relevant qualitative information. Particularly in the case of international comparisons the size, aspirations, economic structure and institutional arrangements of the countries concerned should be taken into consideration."*

PNP	*Non-market, private non-profit institutions serving households (i.e. the general public); private individual or households.*
ABR	*All institutions and individuals located outside the political borders of a country, except vehicles, ships, aircraft and space satellites operated by domestic entities and testing grounds acquired by such entities. All international organisations (except business enterprises), including facilities and operations within the country's borders.*

Source: Frascati Manual

We focus on the split by sector **performing** the R&D and sector **funding** the R&D. R&D expenditure by source of funding are broken down into:

- Business enterprise sectors (BERD)
- Government sector (GovERD)
- Private non-profit sectors (PNP)
- Higher education sector (HERD)
- Abroad
    - Foreign business enterprises
    - Other national governments
    - Higher education
    - PNP
    - European Commission
    - International organisations
    - N.E.C.

Below, we summarise the sources of Eurostat's R&D indicators by sector of performance and country.

a) BES

Eurostat obtains data from all enterprises known or supposed to perform R&D. Almost all countries carry out a dedicated R&D survey, whereas three countries combine the R&D with the CIS survey. The table below presents the survey types in the 2009 data collection, the frame population and the sample size.

Country	Survey type	Frame population size	Population covered by sampling	Sample size
Belgium	Combination of census/ sample	23,629	19,488 (82.5%)	6,940
Bulgaria	Census	414	-	414
Czech Republic	Census	2,594	-	2,594
Germany	Census	22,800	22,052 (96.7%)	4,968
Estonia	Combination of census/ sample	26,744	-	26,744
Ireland		1,810	110 (6.21%)	1,721
Spain	Combination of census/ sample	3,484	-	3,484
Cyprus	Census	197,917	178,582 (90.0%)	49,280
Latvia	Sampling	250	-	250
Lithuania	Combination of census/ sample	66,944	-	3,678

Luxembourg	Combination of census/ sample	14,832	14,366 (96.9%)	1,488
Hungary	Census	5,363	-	5,363
Malta	Census	99	-	99
Netherlands	Combination of census/ sample	55,000	50,000 (90.0%)	15,000
Austria	Census	5,972	-	5,972
Poland	Census	3,958	-	3,958
Portugal	Census	9,679	-	9,679
Romania	Census	940	-	940
Slovenia	Census	718	-	718
Slovak Republic	Census	225	-	173 (leaving out inactive enterprises included in the sampling frame)
Finland	Combination of census/ sample	12,500	8,408 (67.6%)	5,410
Sweden	Combination of census/ sample	32,000	No information available	7,619
United Kingdom	Combination of census/ sample	26,000	No information available	4,010
Norway	Combination of census/ sample	10,835	8,458 (78.1%)	4.841

b) GOV

Most countries follow the recommendations of the Frascati Manual in terms of scope and coverage. Germany, Finland and Norway incorporate R&D statistics on the PNP sector into the R&D statistics on the GOV sector. Hungary incorporates PNP in both the GOV and BES. The target population comprises in most countries all units under the Government sector (including the municipal ones) known or assumed to perform R&D activities. The frame population includes all possible R&D performing units in the GOV sector, such as: (i) Central Government (ministries, departments); (ii) local councils; (iii) Government research institutes, public research centres; (iv) non-profit semi-government organisations; (v) National banks, museums, libraries and public benefit companies.

The identical target and frame population sizes that are apparent for most of the countries reveal the good quality of the established frame population on the one hand and the satisfactory coverage of all R&D performing units (known or assumed to perform R&D activities) in the target population on the other hand. In addition, the majority of the countries conduct a survey every year

c) HES

Again, most countries follow the recommendations of the Frascati Manual. The target population in all reporting countries was in line with the Manual's specifications, and in all reporting countries the R&D survey for HES is conducted on an annual compulsory basis, except for Austria, Belgium, Ireland, Sweden and Norway, in which the full survey is conducted biennially. R&D surveys on HES are census surveys except for Sweden where a combination of census and sample survey is used.

d) PNP

In most cases the PNP is included in one of the other sectors. Denmark, Finland and the Netherlands report that they incorporate the PNP in the GOV sector. Hungary incorporates PNP into both BES and GOV sectors, whereas Lithuania incorporates it into BES. Only Cyprus and Portugal report that its share in total R&D expenditure is more than 5% (13.7% and 8.9% respectively).

All potentially R&D performing non-market units controlled and mainly financed by non-profit institutions serving households (professional and learned societies, charities, associations of research institutions, clubs, groups with R&D activity), as well as private individuals and households are targeted by the survey. In most cases, only non-profit associations are covered, as the number of individuals and households engaged in R&D activities is very small. The reporting countries perform annual or biennial census surveys of the PNP sector.

Deciding on comparator countries

Eurostat provides R&D data for the 28 countries of the European Union plus Iceland, Norway, Switzerland, the countries applying for EU membership (Montenegro, Serbia, Turkey), Russia, the United States, China (except Hong Kong), Japan and South Korea. For the purpose of this analysis we have decided to use a subset of those. For ease of comparison, we have examined the eleven countries first joining the Euro in 1999 (BE, DE, IE, ES, FR, IT, LU, NL, AT, PT, FI) – henceforth the Euro-countries - the UK, the US, China (except Hong Kong) and Japan.

Including these Euro-countries and the overseas countries ensures we have a good mix of countries for our comparative analysis and to identify trends and strengths and weaknesses in the different nations. Eurostat provides data on GERD as a percentage of GDP, which are summarised in the table below, and which reinforces the good mix of countries represented in our analysis.

Country	GERD to GDP (%) in 2012	Rank
Finland (FI)	3.43	1
Sweden (SE)	3.28	2
Switzerland (CH)	3.13	3
Denmark (DK)	3.03	4
Germany (DE)	2.88	5
Austria (AT)	2.81	6
United States (US)	2.81	7
Slovenia (SI)	2.58	8
Belgium (BE)	2.24	9
France (FR)	2.23	10
Estonia (EE)	2.16	11
China (except Hong Kong) (CN)	1.98	12
Netherlands (NL)	1.97	13
Czech Republic (CZ)	1.79	14

Norway (NO)	1.65	15
United Kingdom (UK)	1.63	16
Ireland (IE)	1.58	17
Portugal (PT)	1.37	18
Spain (ES)	1.27	19
Hungary (HU)	1.27	20
Italy (IT)	1.26	21
Luxembourg (LU)	1.16	22
Russia (RU)	1.13	23
Turkey (TR)	0.92	24
Serbia (RS)	0.91	25
Lithuania (LT)	0.9	26
Poland (PL)	0.89	27
Malta (MT)	0.87	28
Slovakia (SK)	0.81	29
Croatia (HR)	0.75	30
Greece (EL)	0.69	31
Latvia (LV)	0.66	32
Bulgaria (BG)	0.62	33
Romania (RO)	0.48	34
Cyprus (CY)	0.43	35

Source: Eurostat, Economic Insight analysis

Including the countries in bold above in our analysis, we have come across certain issues, regarding some countries (IT, LU, NL, AT and CN), where total GERD is available for some years, but it is not split out by sectors (i.e. we have the total GERD performed by Business Enterprises, but no data regarding the different sources of funding). Nonetheless, we have still used the total figures, so that our analysis would be as complete as possible.

10.2. Key facts and figures relating to the EU GERD data

This section sets out the key facts and figure relating to the GERD across different European and overseas countries. We first examine how expenditure is split between different bodies funding and performing R&D across different countries. We then examine the trends in expenditure over time across countries.

a) GERD in 2012

The table below shows expenditure on R&D in the Euro-countries by performing and funding sectors in the year 2012. It shows that out of a total of €184 billion spent on R&D in the Euro-countries:

- Business Enterprise was the largest funder and performer of R&D - funding 58% and performing 64% of the total.

- Defining the 'public sector' as Government and Higher Education, and the 'private sector' as Business Enterprises, Private Non-Profits, and Abroad, the private sector funded 66% and performed 64% of the total.

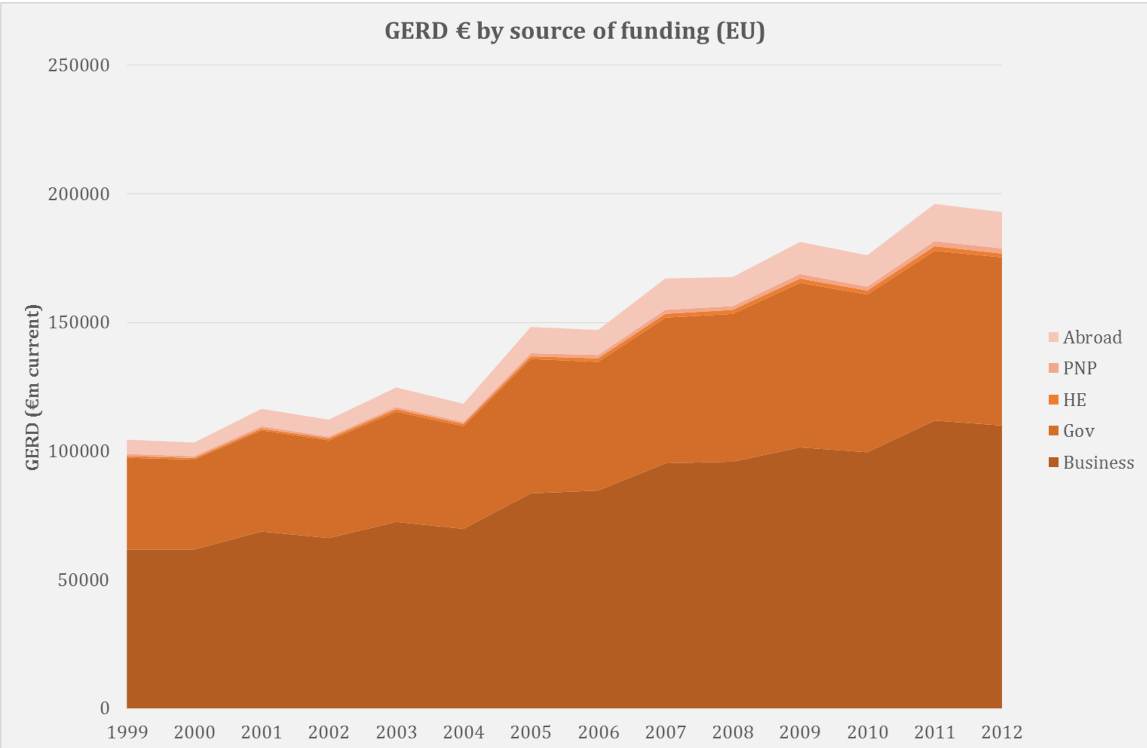
€m	*Sector performing the R&D*				
	Government	Higher Education	Business Enterprises	Private Non-Profit	**Total**
Sector providing the funds					
Government	20,954	33,204	7,263	515	**61,936**
Higher Education	91	1,307	54	9	**1,462**
Business Enterprises	2,234	2,993	100,720	126	**106,073**
Private Non-Profit	603	603	338	699	**2,007**
Abroad	1,662	2,047	8,783	154	**12,645**
Total	**25,308**	**40,154**	**117,158**	**1,503**	**184,123**

Source: Eurostat, Economic Insight analysis

b) Trends in expenditure

The figure below shows the trend in GERD by funding body (irrespective of who performs the R&D) since 1999 in current prices for the Euro-countries, for the UK, for the US, China (ex HK) and Japan.

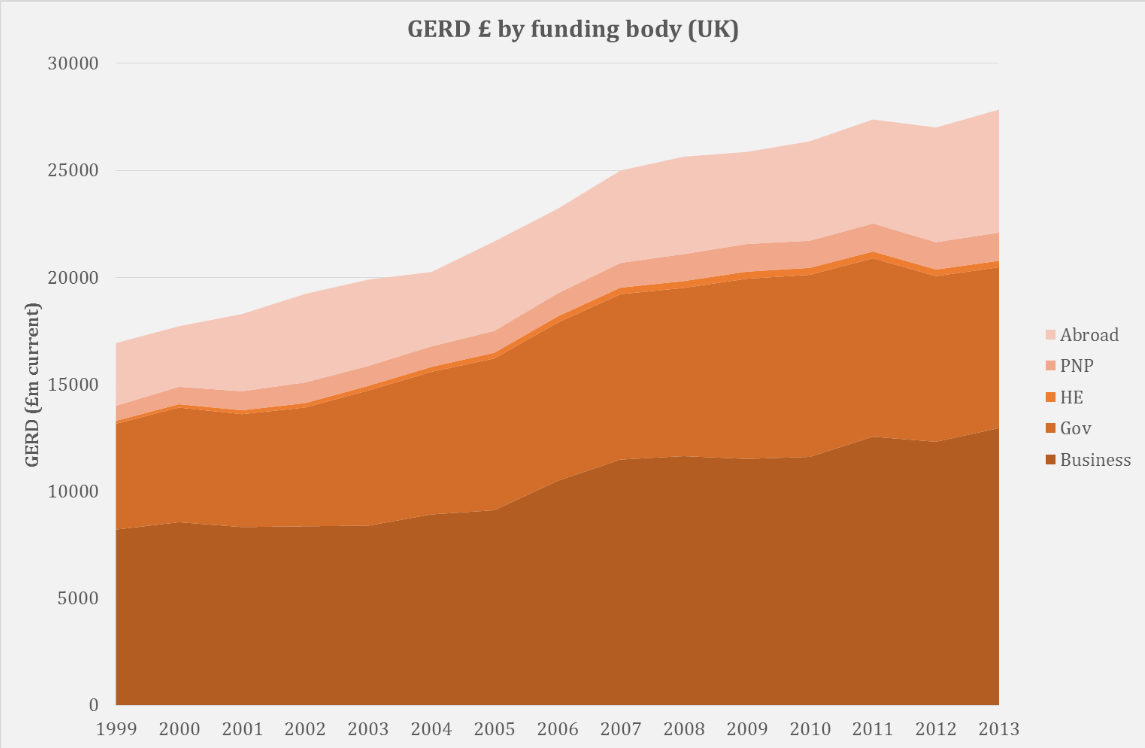
Figure 49 GERD € by source of funding (EU)



Source: Eurostat, Economic Insight analysis

It shows that expenditure has increased from €105bn in 1999 to €193bn in 2012. In 13 years GERD almost doubled. There was a drop in GERD from 2009-10, possibly reflecting a lagged effect of the 2008 financial crisis. Similarly, in the UK GERD has increased from £17bn (€22bn) in 1999 to £28bn (€34bn) in 2012.

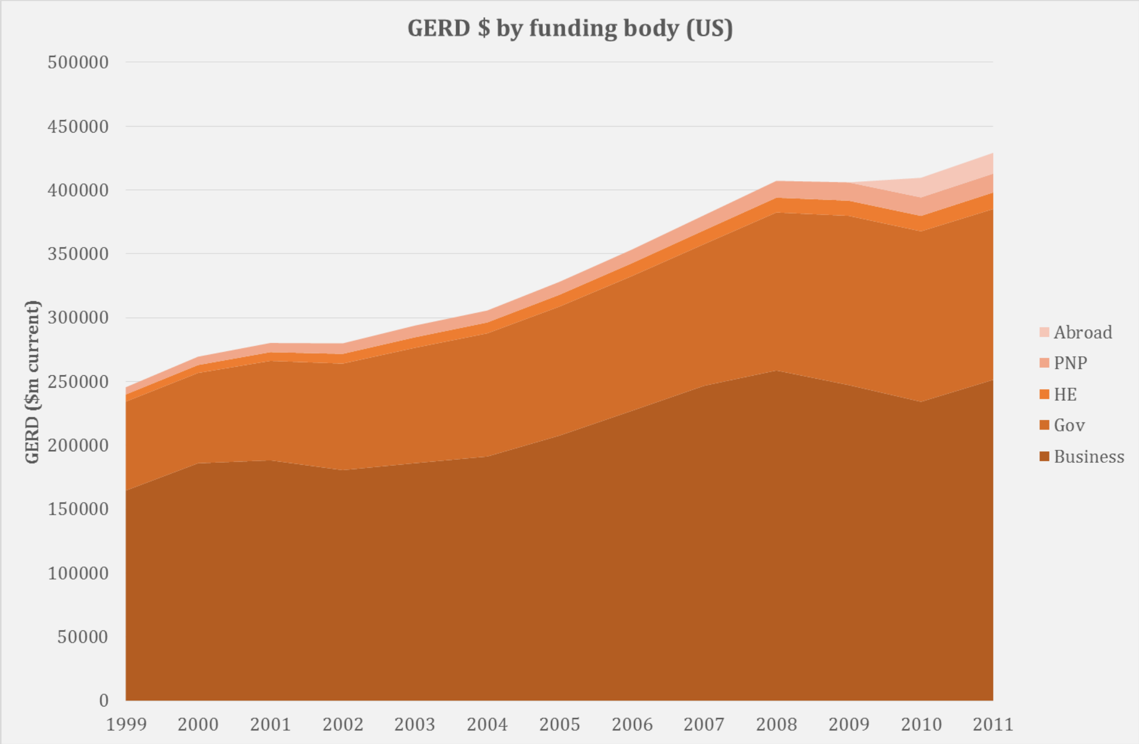
Figure 50 GERD £ by source of funding (UK)



Source: Eurostat, Economic Insight analysis

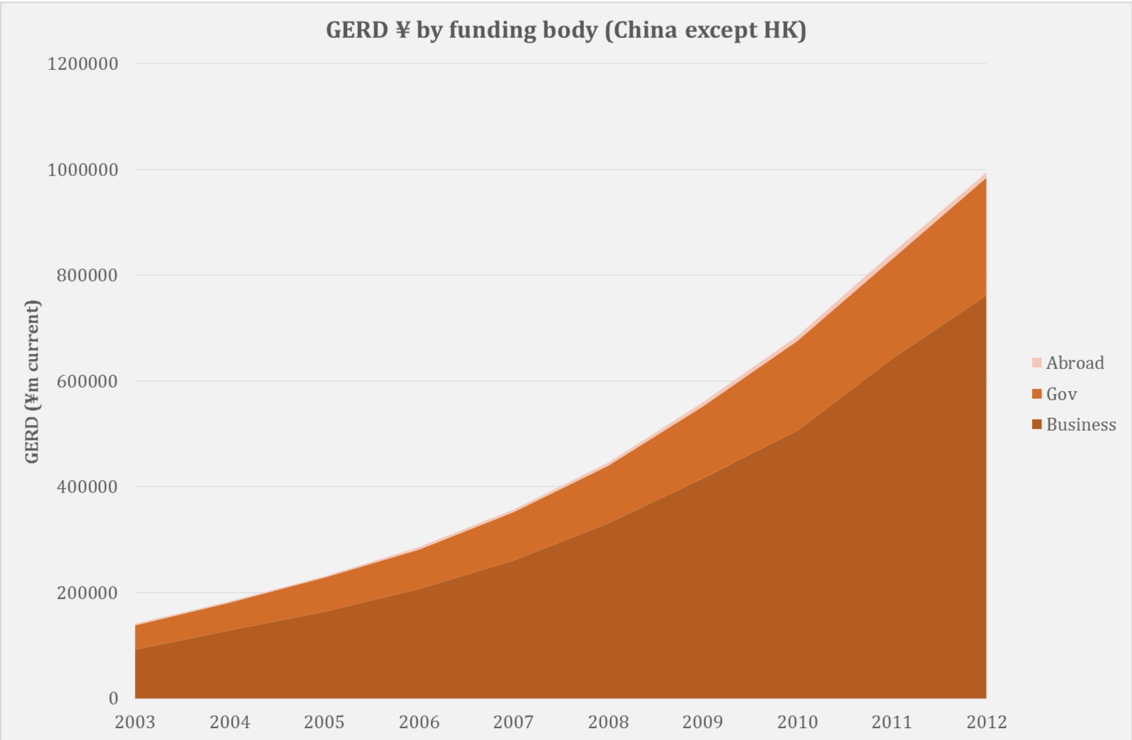
In the US, GERD has increased from US$246bn (€199bn) in 1999 to US$454bn (€368bn) in 2012, whereas China's GERD has increased sevenfold from CN¥142bn (€19bn) in 2003 to CN¥995bn (€131bn) in 2012 and Japan's from JP¥15,033bn (€102bn) in 1999 to JP¥15,945bn (€108bn) in 2011. Most of these increases were due to increased private sector funding, as can be seen in the charts below.

Figure 51 GERD US$ by source of funding (US)



Source: Eurostat, Economic Insight analysis

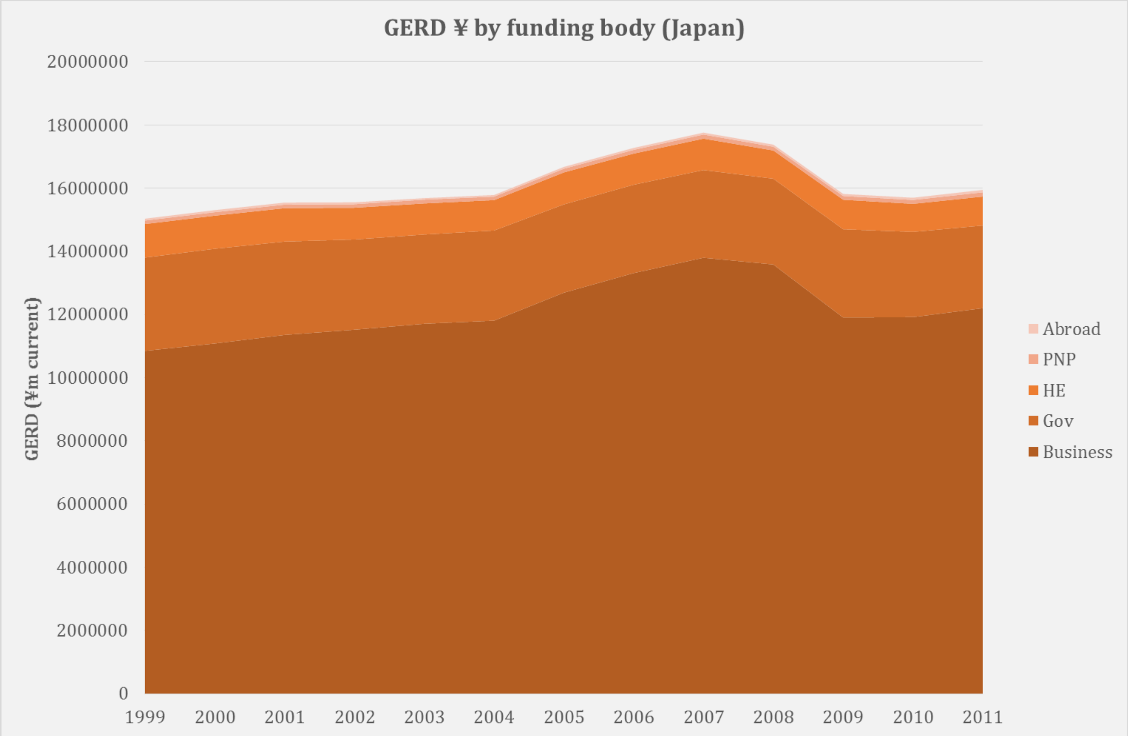
Figure 52 GERD CN¥ by source of funding (CN)



Source: Eurostat, Economic Insight analysis

In Japan one can clearly observe the effects of the 2008 financial crisis on GERD, with a sharp decline in expenditure between 2008-09. Total GERD dropped by 9% from 2008 to 2009 and has been slowly recovering since.

Figure 53 GERD JP¥ by source of funding (JP)

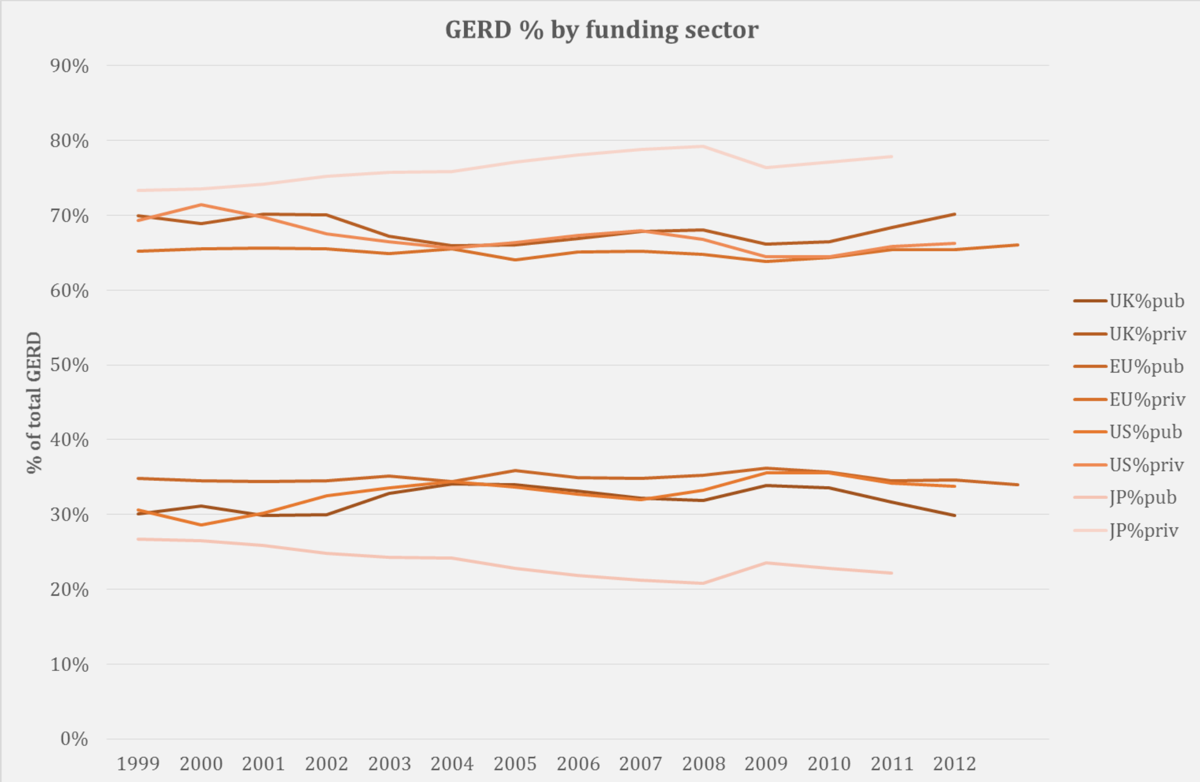


Source: Eurostat, Economic Insight analysis

The following figure depicts the percentage of total GERD attributable to the private and to the public sector in the Euro-countries, the UK, the US and Japan since 1999. As can be seen, private investment R&D expenditure accounted for 65% of total GERD in the EU in 1999, and to 66% in 2012. Similarly, in the UK, private GERD accounts for 70% of the total both in 1999 and 2012. There was a slight drop in the mid-2000s, but it has been relatively steady. In the US, on the other hand, private GERD has decreased from 69% of the total in 1999 to 66% in 2012, whereas in Japan it increased from 73% in 1999 to 78% in 2011.

Overall, public R&D expenditure has been declining over time, whereas private expenditure has been increasing.

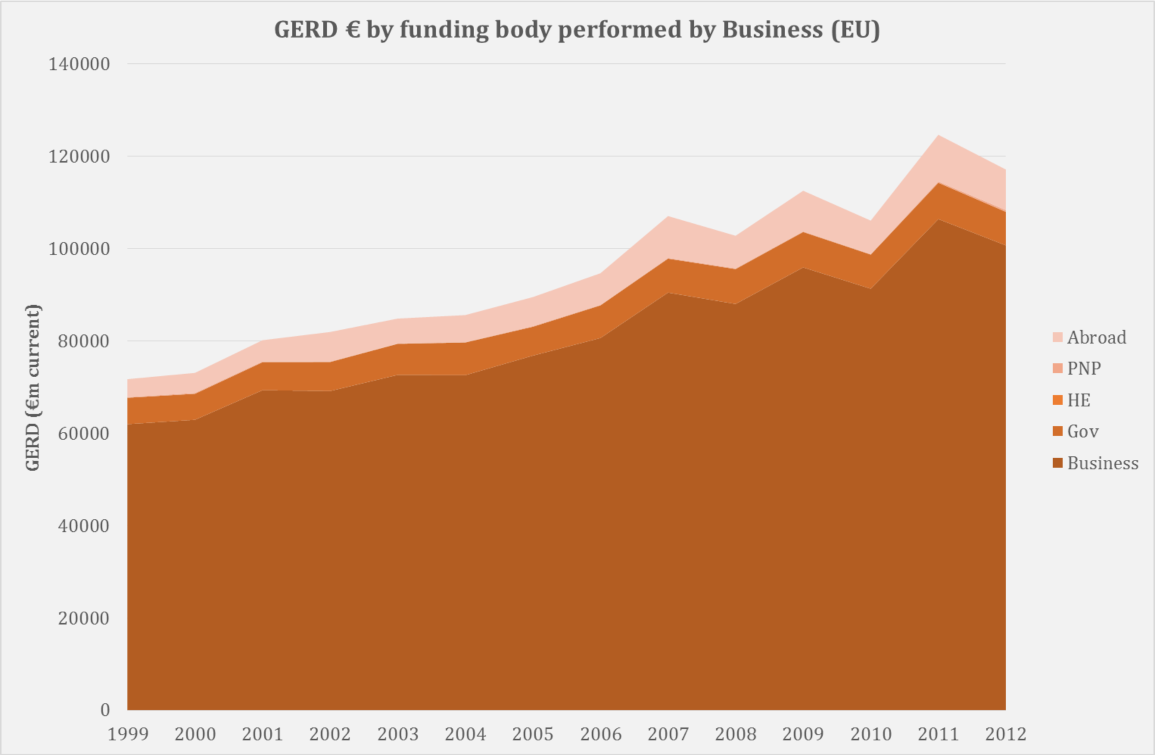
Figure 54 GERD % by funding sector



Source: Eurostat, Economic Insight analysis

As mentioned earlier, around 64% of GERD is accounted for R&D performed by Business for the Euro-countries. The figures below show the trend in R&D expenditure performed by Business from all different sources of funding. It shows that the majority of this expenditure is funded by Business, followed by Abroad and then the Government. The data shows that very little is funded from the Higher Education and PNP sectors.

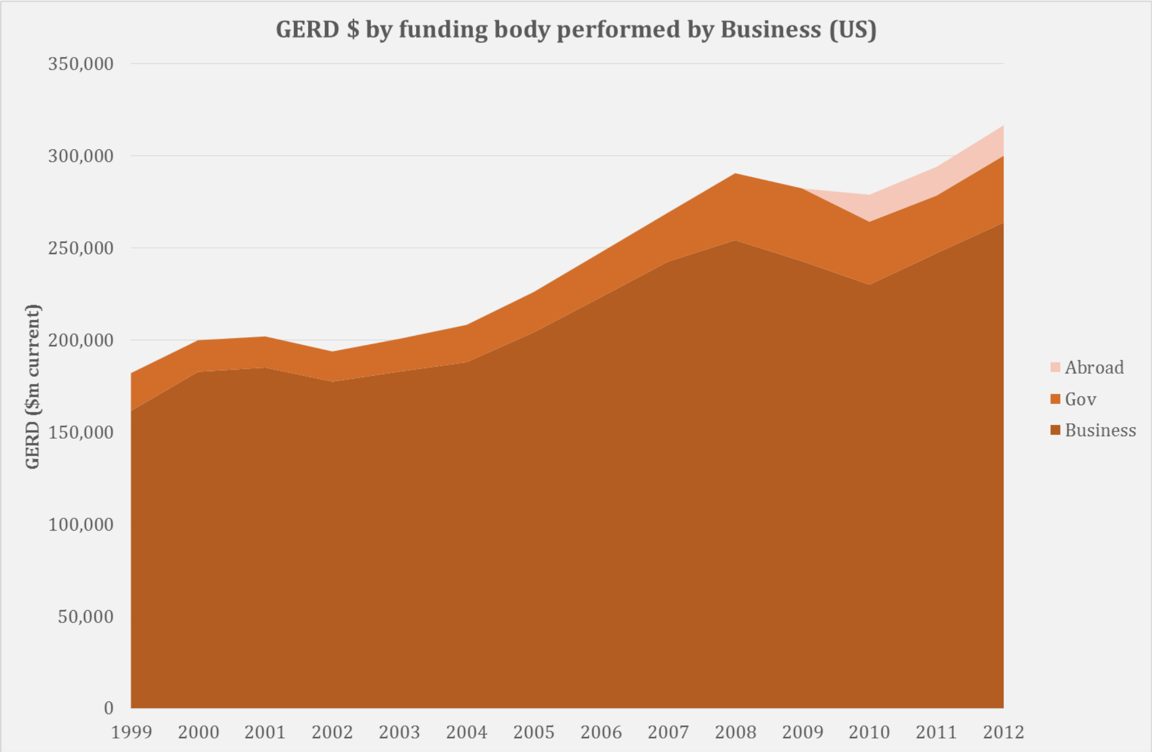
Figure 55 GERD € by funding body performed by Business (EU)



Source: Eurostat, Economic Insight analysis

Of interest in the figure below is that, Abroad has become an important funding source from 2009 onwards in the US. This is important, as it may overestimate the importance of Abroad funding in the later years of our dataset, and special care should be taken when analysing this source of funding.

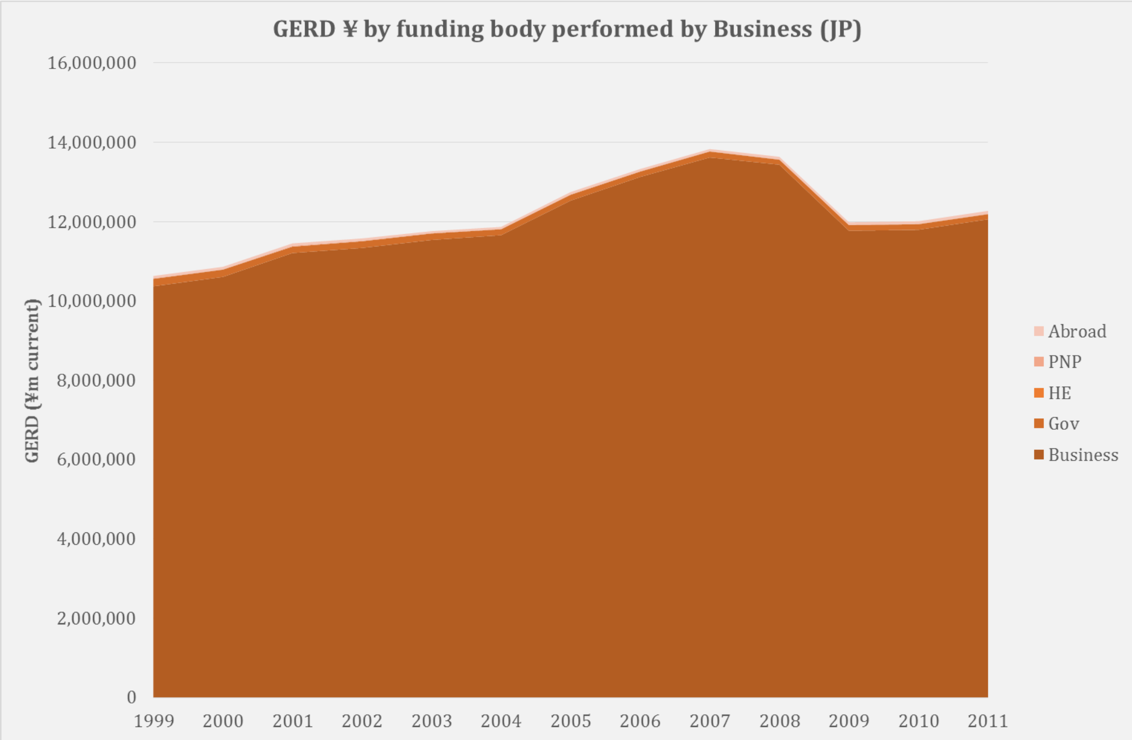
Figure 56 GERD US$ by funding body performed by Business (US)



Source: Eurostat, Economic Insight analysis

Again, similarly as with total GERD, one can see the effects of the 2008 financial crisis on Japan's GERD performed by Business in the figure below.

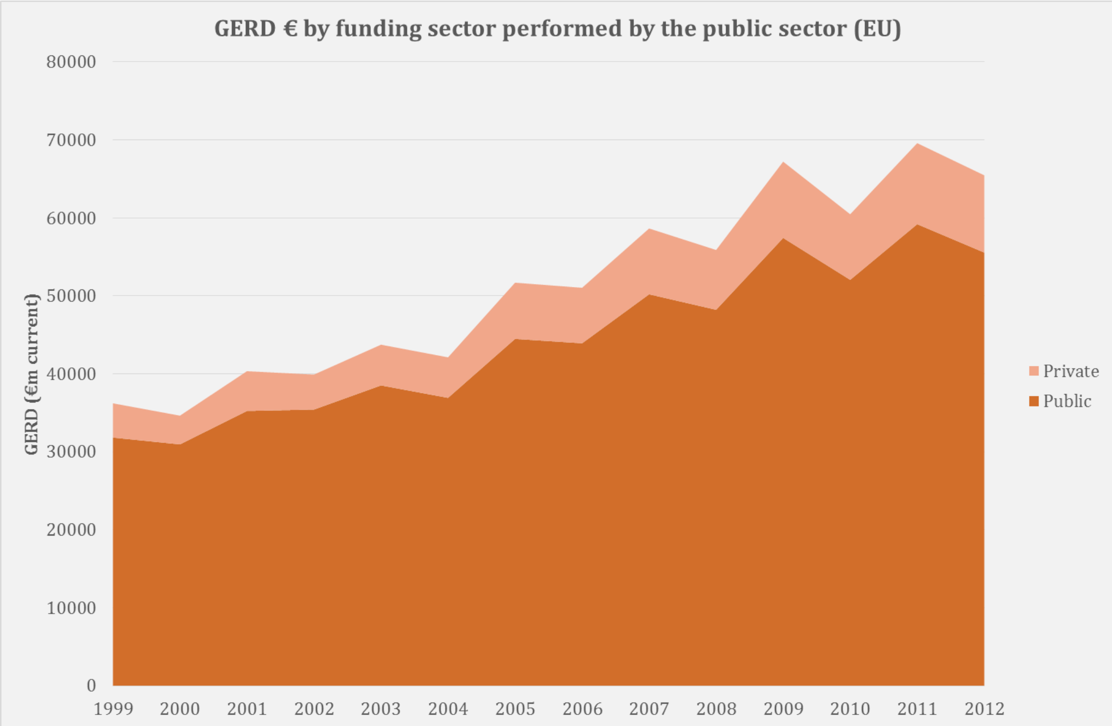
Figure 57 GERD JP¥ by funding body performed by Business (JP)



Source: Eurostat, Economic Insight analysis

Most of the remaining GERD is accounted for by R&D performed by the public sector (Government and Higher Education), namely 35% of the remaining 36%. Similarly to above, the figures below show the trend in R&D expenditure performed by the public sector and the sources funding it. It shows that the majority of this expenditure is funded by the public sector.

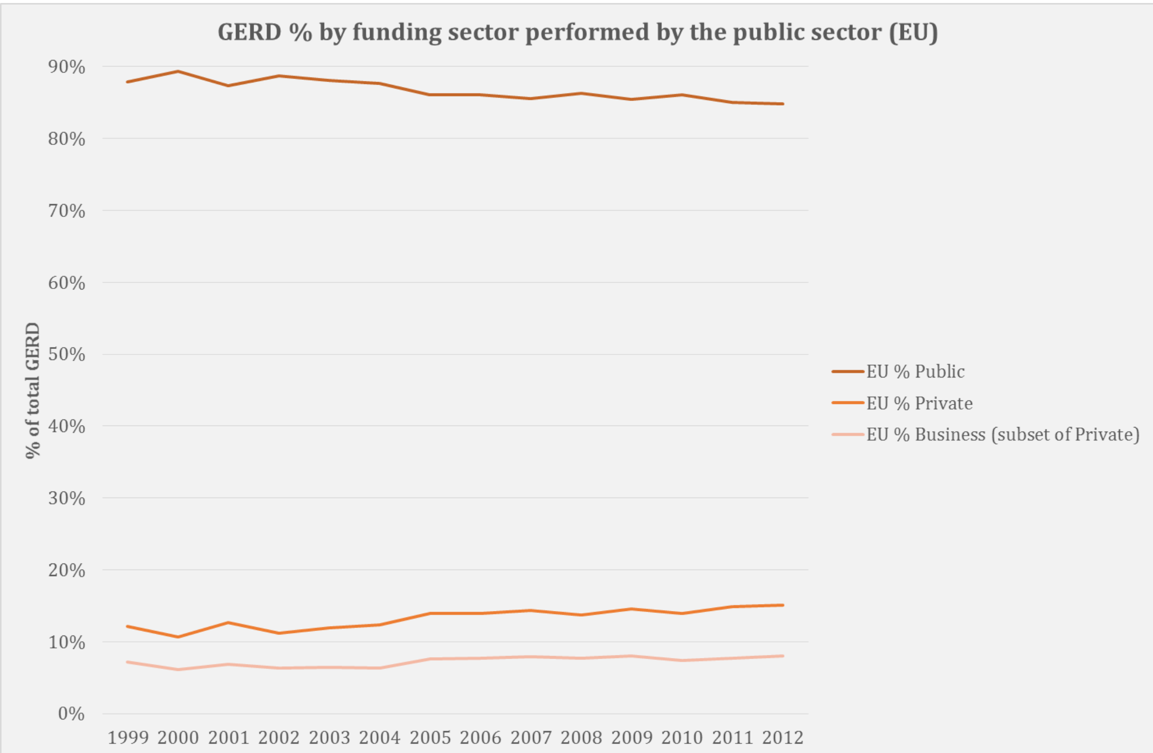
Figure 58 GERD € by funding sector performed by the public sector (EU)



Source: Eurostat, Economic Insight analysis

The chart below shows that around 15% of the funds for R&D performed by the public sector come from the private sector in the Euro-countries, up from around 12% in 1999. It also implies that the increase is not only attributable to Business Enterprises, but rather to PNP and Abroad.

Figure 59 GERD % by funding sector performed by the public sector (EU)



Source: Eurostat, Economic Insight analysis

10.3. The relationship between private and public expenditure on R&D

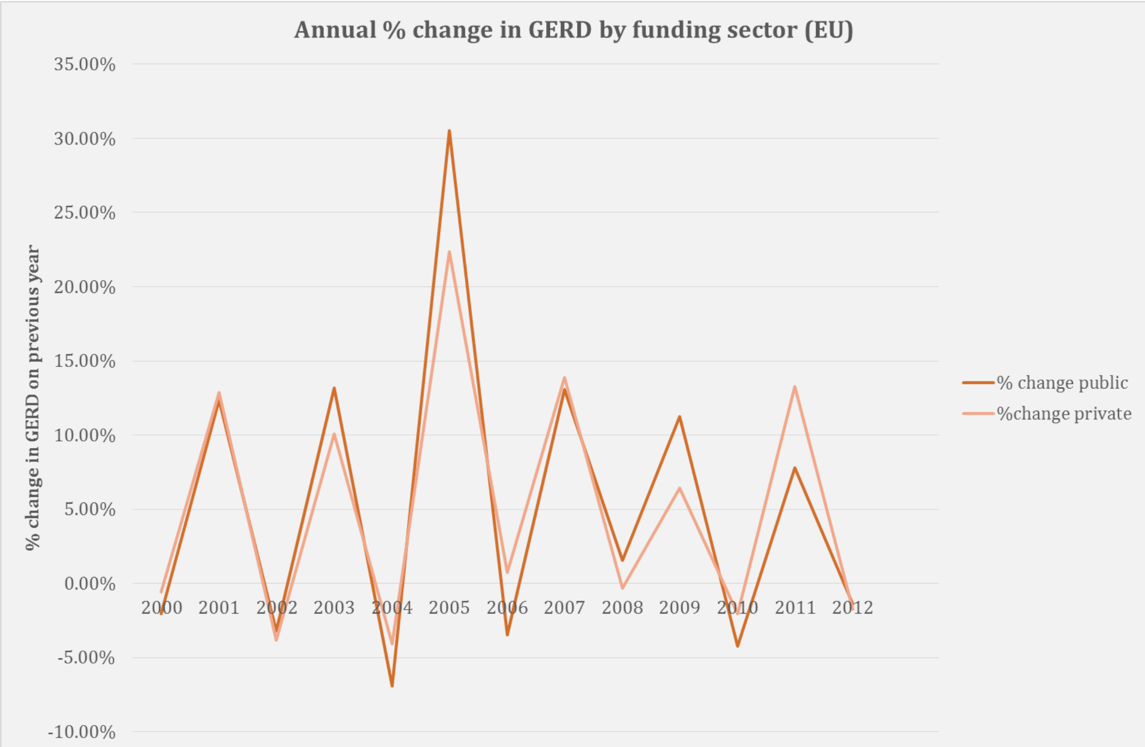
This section sets out the relationship between private and public R&D expenditure using the Eurostat dataset. We begin by looking at the private and public sector expenditure in totality and then investigate how the relationship varies by the different sources of private and public expenditure.

a) *Aggregate analysis*

i. *Graphical analysis*

In the figure below we can see GERD changes from year to year in the public and the private sector funding (as defined earlier), irrespective of where the R&D is performed for the Euro-countries since 2000. As can be seen from the figure, there seems to be a strong positive correlation between the two, i.e. private funding rises (falls) when public funding rises (falls), indicating a positive relationship between these two variables.

Figure 60 Annual % change in GERD by funding sector



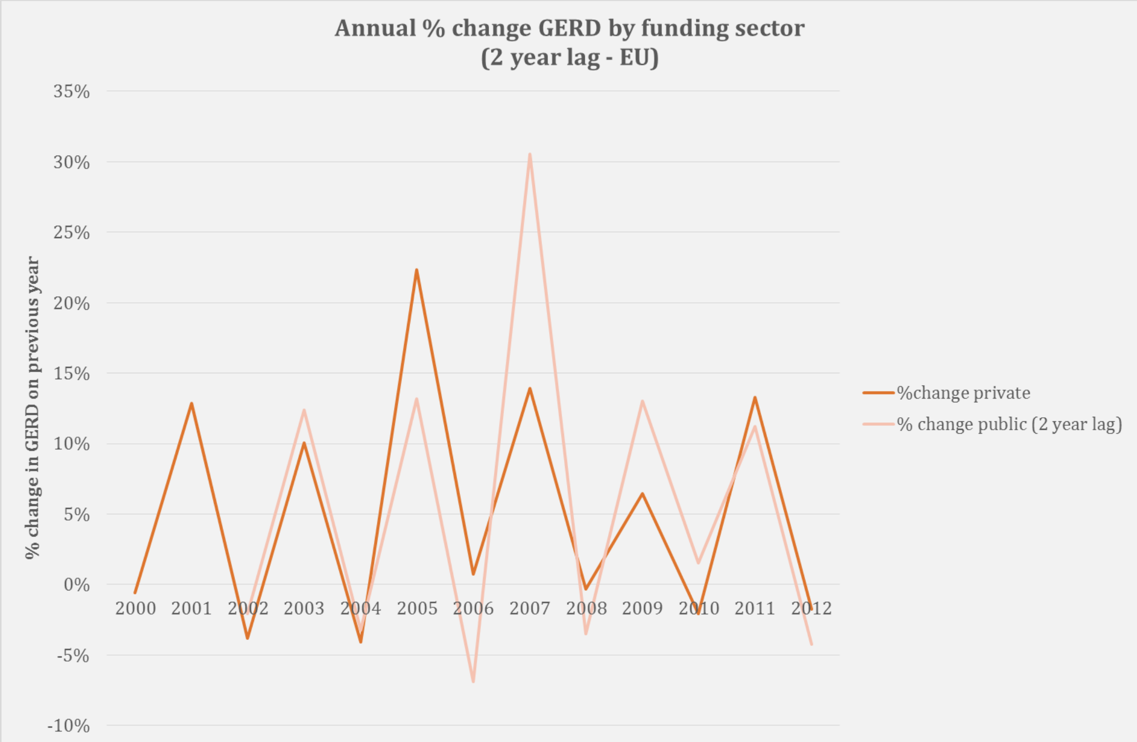
Source: Eurostat, Economic Insight analysis

This could indicate that public funding ***crowds in*** private funding. Nevertheless, there could be other reasons for this pattern in the data, which we explore in the following paragraphs.

It has been widely recognised in the literature that any effect of public funding on private funding takes time to be seen, as it requires time for public funding to 'attract' private funding. There are many reasons for this to be the case, for instance: (a) it may take time for the R&D activities supported by the public funding to be implemented and therefore represent something 'investable'; and/ or (b) private funding may, in the shorter-term, be committed to other activities or more generally slow to respond due to operational factors (such as business planning processes).

In order to illustrate the effect of a possible 'lag', the figure below shows the annual percentage change in private and public sector funding, but where public sector funding has been lagged by 2 years. Again, there seems to be a strong, positive correlation between the two variables.

Figure 61 Annual % change in GERD by funding sector (2 year lag)

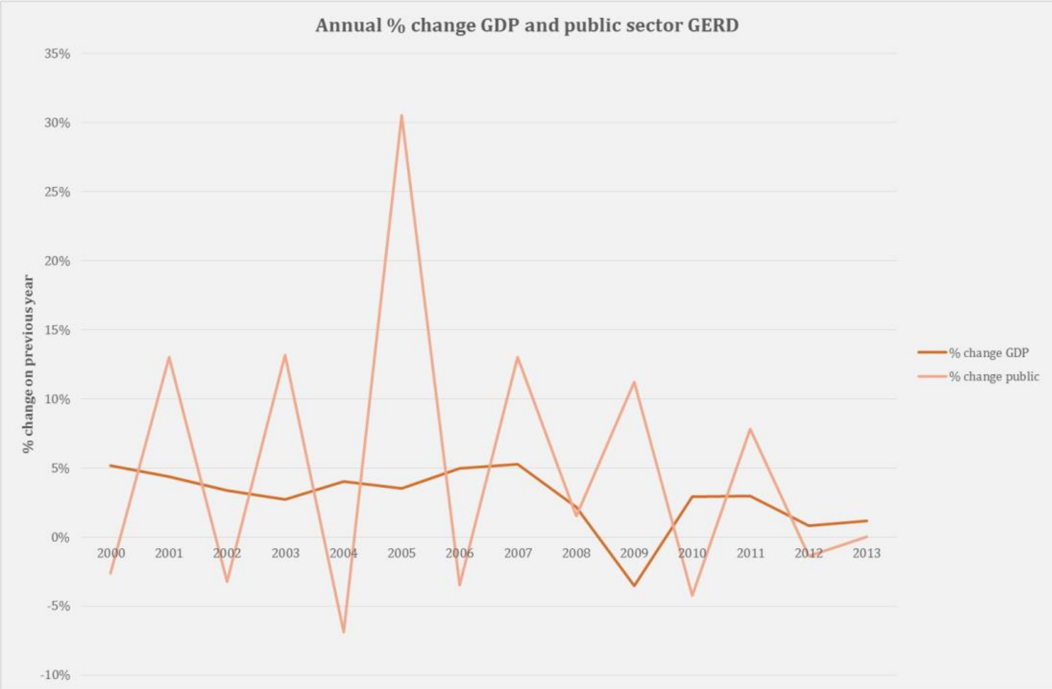


Source: Eurostat, Economic Insight analysis

However, other factors but the level of public sector funding may be influencing the level of private sector funding. By not controlling adequately for them, the true relationship between public and private funding may be masked. The level of private sector funding can be influenced by various other factors that affect the actual and perceived revenues and costs associated with R&D investments. In order to control for those we perform the appropriate econometric analyses in the section below.

A final possibility is that policy makers tend to increase public funding of R&D when private funding is scarce, i.e. they seek to fill any 'investment gaps' by spending through the economic cycle. The figure below illustrates the annual change in public funding compared against the annual change in GDP. One can see that when GDP drops from one year to the other, public sector GERD tends to increase. Hence, the relationship between GERD and GDP will be examined in our econometric analysis below.

Figure 62 Annual % change GDP and public funding



Source: Eurostat, Economic Insight analysis

All these possibilities suggest that, although informative, the graphical analysis set out above has limitations regarding the analysis that it allows. Furthermore, there is a risk of under- or overstating the extent of leverage. Therefore, the next section provides the results of various econometric analyses intended to address the above issues and, in doing so, arrive at more robust estimates of the relationship between public and private funding of R&D.

ii. Econometric analysis

In this section we present the results of our econometric analysis using the Euro-countries plus the UK, the US, China (ex HK) and Japan data described above, combined with other publicly available data. Our analysis comprises the time period between 1999 and 2012 inclusive, where data is measured at an annual frequency. All data has been gathered in the national currency and has been translated into Euros applying the most recent (2013) exchange rate from *Thomson Reuters* Datastream. We deal with exchange rate effects further below.

Our general specification is as set out below:

$$\ln(\textit{private funding})_{it} = a_i + b.\ln(\textit{public funding})_{it} + c.\textit{controls} + \varepsilon_{it} \quad (1)$$

Where a_i contains a constant term and a set of individual- or group-specific variables which may or may not be observed, all of which are taken to be constant over time t. The time period comprises $t = 1,2,\ldots,15$ years and there are $i = 1, 2,\ldots,15$ countries. As we are using longitudinal (panel) data, our analysis will depart from the general specification and explore more specific models, such as pooled regression, fixed and random effects approaches. Assuming that the equation is properly specified, the parameter b measures the elasticity of private funding with respect to public funding i.e. the % change in private expenditure brought about by a 1% change in public expenditure, other things being equal.

As a starting point, we have estimated the relationship between private and public funding without any controls. Both, the fixed and random effects model have high levels of significance and estimate an elasticity of 0.96, i.e. the data implies that a 1% increase in public sector funding will lead to a 0.96% increase in private sector funding of R&D (see Model 1.1 and 1.2 in Table 24). However, for reasons set out previously, these models fail to take account of other factors that might drive private sector R&D

investment decisions and are likely to be biased. To address these deficiencies, we make various changes to the analysis:

- Models 2.1 and 2.1 include a measure of GDP to control for other factors that are likely to influence the level of private funding.
- Models 3.1 and 3.2 are the same as model 2, but they include the previous year's level of private expenditure, partly to help capture possible 'memory' in private spending and they also include the previous year's level of public funding instead of the current year's level of public funding, to capture any possible 'delay' in its effect on private funding.

Models 2.1 and 2.2 suggest that an increase in public funding is correlated with an increase in private funding. Adding the controls the elasticity drops to 0.49 with fixed effects and to 0.58 with random effects. However, the table shows that when adding the lagged variables elasticities we cannot make any definitive conclusions, as the fixed and random effects models give significant and insignificant results respectively. This does not allow us to make an inference regarding the sign or magnitude of the effect of lagged public funding on private funding.

Table 24 Econometric analysis (1)

	Model 1.1 (fe)	**Model 1.2 (re)**	**Model 2.1 (fe)**	**Model 2.2 (re)**	**Model 3.1 (fe)**	**Model 3.2 (re)**
ln(public funding)$_{it}$	0.96*** (0.04)	0.96*** (0.04)	0.49*** (0.11)	0.58*** (0.10)		
ln(public funding)$_{it-1}$					-0.10* (0.05)	-0.04 (0.04)
ln(gdp)$_{it}$			0.67*** (0.20)	0.46*** (0.15)	0.36*** (0.08)	0.12*** (0.03)
ln(private funding)$_{it-1}$					0.84*** (0.03)	0.92*** (0.02)
R-squared (overall)	0.93	0.93	0.92	0.93	0.99	0.99

Statistically significant at the 10% level, 5% level** and 1% level***.*

As we are dealing with European, UK, US, China (ex HK) and Japan-wide data, we have included exchange rate variables, to capture the effects of exchange rate fluctuations on R&D investment decisions. All the data has been converted into € using this year's exchange rate applied to all previous data points. The exchange rate variables should be able to capture increases/ decreases in GERD solely based on currency appreciation/ depreciation. These variables may also capture fluctuations in GERD due to changes in the attractiveness of investing in different economies that is not already accounted for by GDP.

	Model 2a (fe)	**Model 2b (re)**
ln(public funding)$_{it}$	0.56*** (0.11)	0.41*** (0.11)
ln(gdp)$_{it}$	-0.56** (0.28)	0.45*** (0.15)
ln(gbpeur)$_{it}$	0.08	0.04

	(0.25)	(0.26)
ln(usdeur)it	1.72*** (0.37)	0.71** (0.31)
ln(cnyeur)it	-2.03*** (0.40)	-0.90*** (0.32)
ln(jpyeur)it	0.79*** (0.21)	0.29 (0.18)
R-squared (overall)	0.17	0.92

Statistically significant at the 10% level, 5% level** and 1% level***.*

b) *Disaggregated analysis*

As mentioned earlier, there are different sources of private and public funding within the aggregates used above. It is possible that the effect of public funding on private funding vary by these sources and, in addition it is possible that the other drivers of private funding vary by these sources, too.

i. *Analysis by type of private funding*

To explore these possibilities, we re-estimated Model 2 above, but separately for the different sources of private funding, i.e. business, PNP and Abroad funding. The results are set out in the table below.

Table 25 Analysis by type of private funding

	Business		**PNP**		**Abroad**	
	Model 4.1 (fe)	**Model 4.2 (re)**	**Model 5.1 (fe)**	**Model 5.2 (re)**	**Model 6.1 (fe)**	**Model 6.2 (re)**
ln(public funding)it	0.41*** (0.13)	0.49*** (0.11)	0.38* (0.22)	0.53*** (0.19)	0.58*** (0.19)	0.94*** (0.17)
ln(gdp)it	0.71*** (0.23)	0.55*** (0.16)	1.22*** (0.37)	0.87*** (0.28)	1.14*** (0.34)	0.16 (0.24)
R-squared (overall)	0.91	0.92	0.82	0.82	0.75	0.77

Statistically significant at the 10% level, 5% level** and 1% level***.*

The results from the table above indicate that the elasticities are similar for all disaggregated private funding sources.

ii. *Analysis by type of public funding*

Furthermore, we analyse whether the elasticity of private funding with respect to public funding varies according to the source of public funding, i.e. Government or Higher Education funding.

Table 26 Analysis by type of public funding

	Private	**Business**

	Model 7.1 (fe)	Model 7.2 (re)	Model 8.1 (fe)	Model 8.2 (re)
ln(gov funding)$_{it}$	0.68*** (0.12)	0.72*** (0.10)	0.62*** (0.13)	0.64*** (0.11)
ln(HE funding)$_{it}$	0.18*** (0.03)	0.17*** (0.03)	0.20*** (0.03)	0.20*** (0.03)
ln(gdp)$_{it}$	0.09 (0.19)	0.03 (0.14)	0.07 (0.21)	0.08 (0.16)
R-squared (overall)	0.92	0.92	0.91	0.91

Statistically significant at the 10% level, 5% level** and 1% level***.*

As can be seen from the table above, private and business funding seems to be more sensitive to Government funding than HE funding.

Addendum A – Econometric considerations

As we want the 'best' estimate for *b* – our elasticity measure - we note that a fixed effects model can produce unbiased estimates of *b*, but that those estimates can be subject to high sample-to-sample variability. That's because fixed effects models control for, or partial out, the effects of time invariant variables with time-invariant effects (such as countries in our case). A random effects model, on the other hand, can introduce bias in estimates of *b*, but can greatly constrain the variance of those estimates – leading to estimates that are closer, on average, to the true value in any particular sample.

Performing the Hausman test (c.f. Addendum B) we fail to reject the null hypothesis, and we cannot reject the random effects model in favour of the fixed effects one. Nonetheless, it does not necessarily follow that the random effects estimator is 'safely' free from bias, and therefore to be preferred over the fixed effects one. In most applications, the true correlation between the covariates and unit effects is not exactly zero. Yet, as the Hausman test failed to reject the null hypothesis, it probably does not mean that the true correlation is zero – and, hence, that the random effects estimator is unbiased. Rather, it is that the test does not have sufficient statistical power to reliably detect departures from the null. So, when using the random effects model in the following analysis, there will still be bias (if perhaps negligible) in estimates of *b*, even if the Hausman test cannot reject the null hypothesis. However, a biased estimator (i.e., random effects) is often preferable to an unbiased estimator (i.e., fixed effects), if the former provides sufficient variance reduction over the latter.

Further, we have analysed how the UK compares to all other countries in the panel. We have done this by creating a dummy variable for the UK and interacting this variable with *lnpub*. That is to say, the interpretation of the *interact* coefficient would be that if the country is the UK a 1% increase in public funding would lead to an X% increase in *lnpriv*. However, the coefficient is not significant in a Model 2-type specification with the *interact* variable added. Hence, we can conclude that the UK is not statistically different from the average. And that the general results obtained from the regressions hold for the UK, too.

Moreover, we have performed diagnostic tests, to see whether our results are robust. Performing Wooldridge's (2002) test for autocorrelation in panel data we have to strongly reject the null hypothesis of no first-order autocorrelation in favour of our data being serially correlated.

We have performed the Phillips-Perron test for unit-roots, as our data is serially correlated and this test is robust to serial correlation. From the results we have to reject the null hypothesis of all panels containing a unit root at the 1% level of significance. Hence, most our data is stationary (including panel mean and time trend). As our *N* is relatively small, we have also performed individual Phillips-Perron tests for the individual countries, reporting the test statistics below. This confirms the first result and shows in more detail, which countries we can be certain about to be stationary, and which not.

Table 27 Phillips-Perron test statistics

Country	Phillips-Perron test statistic ρ / t	Unit root / stationary
BE	0.488 / 0.360	Cannot reject H_0
DE	0.445 / 0.837	Cannot reject H_0
IE	-0.821 / -1.871	Cannot reject H_0
ES	-1.912 / -2.969	Reject at 5% level of significance: **stationary**
FR	0.334 / 0.592	Cannot reject H_0
IT	-2.303 / -8.779	Reject at 1% level of significance: **stationary**
LU	.	.
NL	.	.
AT	-1.101 / -3.555	Reject at 1% level of significance: **stationary**
PT	-1.685 / -1.491	Cannot reject H_0
FI	-2.415 / -2.635	Reject at 10% level of significance: **stationary**
UK	-0.456 / -0.530	Cannot reject H_0
US	-0.744 / -0.650	Cannot reject H_0
CN	-0.453 / -4.661	Reject at 1% level of significance: **stationary**
JP	-3.907 / -1.676	Cannot reject H_0

Addendum B

Hausman test

```
                     ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed        random        Difference          S.E.
-------------+----------------------------------------------------------------
       lnpub |   .9581531     .9647272       -.0065741         .022642
------------------------------------------------------------------------------
                         b = consistent under Ho and Ha; obtained from xtreg
          B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(1) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        0.08
                Prob>chi2 =      0.7715
```

Model 1.1

```
Fixed-effects (within) regression               Number of obs      =       185
Group variable: country                         Number of groups   =        15

R-sq:  within  = 0.7499                         Obs per group: min =         6
       between = 0.9408                                        avg =      12.3
       overall = 0.9337                                        max =        14

                                                F(1,169)           =    506.82
corr(u_i, Xb)  = 0.2165                         Prob > F           =    0.0000
```

lnpriv	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpub	.9581531	.0425605	22.51	0.000	.8741345	1.042172
_cons	1.034168	.3606354	2.87	0.005	.3222376	1.746099
sigma_u	.42085271					
sigma_e	.16837134					
rho	.86202622	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(14, 169) =     73.78           Prob > F = 0.0000
```

Model 1.2

```
Random-effects GLS regression                   Number of obs      =       185
Group variable: country                         Number of groups   =        15

R-sq:  within  = 0.7499                         Obs per group: min =         6
       between = 0.9408                                        avg =      12.3
       overall = 0.9337                                        max =        14

                                                Wald chi2(1)       =    716.62
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnpriv	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnpub	.9647272	.036038	26.77	0.000	.8940941	1.03536
_cons	.9868853	.3212518	3.07	0.002	.3572434	1.616527
sigma_u	.43202763					
sigma_e	.16837134					
rho	.86814264	(fraction of variance due to u_i)				

Model 2.1

```
Fixed-effects (within) regression               Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6959                         Obs per group: min =         6
       between = 0.9328                                        avg =      12.4
       overall = 0.9220                                        max =        14

                                                F(2,146)           =    167.08
corr(u_i, Xb)  = -0.4263                        Prob > F           =    0.0000
```

lnpriv	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpub	.4894069	.115567	4.23	0.000	.2610065	.7178073
lngdp	.6711282	.2022876	3.32	0.001	.2713381	1.070918
_cons	-4.120225	1.866915	-2.21	0.029	-7.809895	-.4305556
sigma_u	.50796051					
sigma_e	.15886805					
rho	.91089883	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(12, 146) =     81.03             Prob > F = 0.0000
```

Model 2.2

```
Random-effects GLS regression                   Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6939                         Obs per group: min =         6
       between = 0.9362                                        avg =      12.4
       overall = 0.9262                                        max =        14

                                                Wald chi2(2)       =    490.36
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnpriv	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnpub	.5798776	.1013861	5.72	0.000	.3811645	.7785906
lngdp	.460517	.1488605	3.09	0.002	.1687558	.7522781
_cons	-2.05185	1.260658	-1.63	0.104	-4.522694	.4189935
sigma_u	.43917237					
sigma_e	.15886805					
rho	.88428366	(fraction of variance due to u_i)				

Model 3.1

```
Fixed-effects (within) regression               Number of obs      =       139
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.9562                         Obs per group: min =         1
       between = 0.9955                                        avg =      10.7
       overall = 0.9938                                        max =        13

                                                F(3,123)           =    895.91
corr(u_i, Xb)  = -0.6897                        Prob > F           =    0.0000

------------------------------------------------------------------------------
      lnpriv |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lngdp |   .3646076   .0787851     4.63   0.000     .2086574    .5205579
    lnprivL1 |   .8372908   .0346524    24.16   0.000     .7686984    .9058832
     lnpubL1 |  -.0978749    .050734    -1.93   0.056    -.1982997    .0025499
       _cons |  -2.576015   .7711493    -3.34   0.001    -4.102458   -1.049572
-------------+----------------------------------------------------------------
     sigma_u |  .15648749
     sigma_e |  .05658822
         rho |  .88435676   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(12, 123) =     4.46             Prob > F = 0.0000
```

Model 3.2

```
Random-effects GLS regression                   Number of obs      =       139
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.9522                         Obs per group: min =         1
       between = 0.9993                                        avg =      10.7
       overall = 0.9982                                        max =        13

                                                Wald chi2(3)       =  25484.86
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      lnpriv |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lngdp |   .1209769    .030937     3.91   0.000     .0603414    .1816123
    lnprivL1 |   .9209882   .0220687    41.73   0.000     .8777343    .9642421
     lnpubL1 |  -.0368735   .0363032    -1.02   0.310    -.1080265    .0342795
       _cons |  -.5606547    .200487    -2.80   0.005    -.9536021   -.1677073
-------------+----------------------------------------------------------------
     sigma_u |  .02861712
     sigma_e |  .05658822
         rho |  .20365725   (fraction of variance due to u_i)
```

Model 2a

```
Fixed-effects (within) regression               Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.7625                         Obs per group: min =         6
       between = 0.3858                                        avg =      12.4
       overall = 0.1773                                        max =        14

                                                F(6,142)           =     75.99
corr(u_i, Xb)  = 0.2626                         Prob > F           =    0.0000
```

lnpriv	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpub	.5639791	.1145096	4.93	0.000	.3376152	.790343
lngdp	-.5633731	.2841553	-1.98	0.049	-1.125094	-.0016518
lngbpeur	.0812386	.2472249	0.33	0.743	-.4074783	.5699555
lnusdeur	1.724533	.3755909	4.59	0.000	.9820609	2.467005
lncnyeur	-2.032125	.3966491	-5.12	0.000	-2.816225	-1.248024
lnjpyeur	.7924236	.2087966	3.80	0.000	.3796721	1.205175
_cons	12.10759	3.19333	3.79	0.000	5.794981	18.4202
sigma_u	1.5756915					
sigma_e	.142366					
rho	.99190272	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(12, 142) =    104.03            Prob > F = 0.0000
```

Model 2b

```
Random-effects GLS regression                   Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.7363                         Obs per group: min =         6
       between = 0.9327                                        avg =      12.4
       overall = 0.9229                                        max =        14

                                                Wald chi2(6)       =    537.12
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnpriv	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnpub	.4154623	.1102869	3.77	0.000	.1993039	.6316207
lngdp	.4495072	.1545502	2.91	0.004	.1465943	.75242
lngbpeur	.0423373	.2618385	0.16	0.872	-.4708567	.5555313
lnusdeur	.719307	.3145864	2.29	0.022	.102729	1.335885
lncnyeur	-.9010373	.3183682	-2.83	0.005	-1.525027	-.2770472
lnjpyeur	.2969465	.1851151	1.60	0.109	-.0658725	.6597655
_cons	-.137635	1.478439	-0.09	0.926	-3.035322	2.760052
sigma_u	.42920634					
sigma_e	.142366					
rho	.90088288	(fraction of variance due to u_i)				

Addendum C

Business funding

Model 4.1

```
Fixed-effects (within) regression               Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6027                         Obs per group: min =         6
       between = 0.9258                                        avg =      12.4
       overall = 0.9140                                        max =        14

                                                F(2,146)           =    110.75
corr(u_i, Xb)  = -0.2522                        Prob > F           =    0.0000

------------------------------------------------------------------------------
       lnbus |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnpub |   .4121108   .1334633     3.09   0.002     .1483412    .6758804
       lngdp |   .7155731    .233613     3.06   0.003     .2538731    1.177273
       _cons |  -4.264071   2.156018    -1.98   0.050    -8.525108   -.0030342
-------------+----------------------------------------------------------------
     sigma_u |  .49677258
     sigma_e |  .18346972
         rho |  .87997204   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(12, 146) =    69.46             Prob > F = 0.0000
```

Model 4.2

```
Random-effects GLS regression                   Number of obs      =       161
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6015                         Obs per group: min =         6
       between = 0.9285                                        avg =      12.4
       overall = 0.9173                                        max =        14

                                                Wald chi2(2)       =    363.58
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
       lnbus |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnpub |   .4888475   .1155253     4.23   0.000      .262422    .7152729
       lngdp |   .5479508   .1670514     3.28   0.001     .2205361    .8753655
       _cons |  -2.662238   1.400245    -1.90   0.057    -5.406668    .0821916
-------------+----------------------------------------------------------------
     sigma_u |  .47198467
     sigma_e |  .18346972
         rho |  .86873201   (fraction of variance due to u_i)
```

PNP funding

Model 5.1

```
Fixed-effects (within) regression               Number of obs      =       155
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.5199                         Obs per group: min =         3
       between = 0.8681                                        avg =      11.9
       overall = 0.8179                                        max =        14

                                                F(2,140)           =     75.81
corr(u_i, Xb)  = -0.5265                        Prob > F           =    0.0000
```

lnpnp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpub	.3800162	.2166353	1.75	0.082	-.0482835	.8083158
lngdp	1.224862	.37546	3.26	0.001	.4825575	1.967167
_cons	-14.73394	3.457421	-4.26	0.000	-21.56945	-7.898435
sigma_u	.93821451					
sigma_e	.28969801					
rho	.91295641	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(12, 140) =    93.57             Prob > F = 0.0000
```

Model 5.2

```
Random-effects GLS regression                   Number of obs      =       155
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.5175                         Obs per group: min =         3
       between = 0.8713                                        avg =      11.9
       overall = 0.8214                                        max =        14

                                                Wald chi2(2)       =    219.33
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnpnp	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnpub	.5303451	.1906277	2.78	0.005	.1567218	.9039685
lngdp	.8665316	.2802148	3.09	0.002	.3173207	1.415742
_cons	-11.1324	2.372778	-4.69	0.000	-15.78296	-6.481835
sigma_u	.84063369					
sigma_e	.28969801					
rho	.89384517	(fraction of variance due to u_i)				

Abroad funding

Model 6.1

```
Fixed-effects (within) regression               Number of obs      =       150
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6285                         Obs per group: min =         3
       between = 0.8525                                        avg =      11.5
       overall = 0.7561                                        max =        14

                                                F(2,135)           =    114.19
corr(u_i, Xb)  = -0.8316                        Prob > F           =    0.0000
```

lnabr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnpub	.5781718	.1901779	3.04	0.003	.2020585	.9542851
lngdp	1.140269	.3382042	3.37	0.001	.4714049	1.809133
_cons	-13.0196	3.114479	-4.18	0.000	-19.17908	-6.860114
sigma_u	1.4705957					
sigma_e	.25878789					
rho	.969963	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(12, 135) =     73.69          Prob > F = 0.0000
```

Model 6.2

```
Random-effects GLS regression                   Number of obs      =       150
Group variable: country                         Number of groups   =        13

R-sq:  within  = 0.6067                         Obs per group: min =         3
       between = 0.8627                                        avg =      11.5
       overall = 0.7728                                        max =        14

                                                Wald chi2(2)       =    250.05
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnabr	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnpub	.9423273	.17182	5.48	0.000	.6055663	1.279088
lngdp	.1671541	.246219	0.68	0.497	-.3154263	.6497344
_cons	-3.201674	2.053396	-1.56	0.119	-7.226257	.8229078
sigma_u	.64330293					
sigma_e	.25878789					
rho	.86071173	(fraction of variance due to u_i)				

Addendum D

Private funding

Model 7.1

```
Fixed-effects (within) regression               Number of obs      =       133
Group variable: country                         Number of groups   =        12

R-sq:  within  = 0.8012                         Obs per group: min =         1
       between = 0.9373                                        avg =      11.1
       overall = 0.9176                                        max =        14

                                                F(3,118)           =    158.52
corr(u_i, Xb)  = 0.0411                         Prob > F           =    0.0000

------------------------------------------------------------------------------
      lnpriv |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lngov  |   .6820945   .1189144     5.74   0.000     .4466117    .9175773
       lnhe  |    .178929   .0283272     6.32   0.000     .1228335    .2350246
      lngdp  |   .0945071   .1939345     0.49   0.627    -.2895361    .4785502
      _cons  |   1.105231     1.7611     0.63   0.531    -2.382227    4.592689
-------------+----------------------------------------------------------------
     sigma_u |  .41395396
     sigma_e |   .1344351
         rho |  .90459414   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(11, 118) =   101.40             Prob > F = 0.0000
```

Model 7.2

```
Random-effects GLS regression                   Number of obs      =       133
Group variable: country                         Number of groups   =        12

R-sq:  within  = 0.8009                         Obs per group: min =         1
       between = 0.9397                                        avg =      11.1
       overall = 0.9203                                        max =        14

                                                Wald chi2(3)       =    633.98
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
      lnpriv |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lngov  |   .7294569   .1041229     7.01   0.000     .5253798     .933534
       lnhe  |    .173391   .0277119     6.26   0.000     .1190767    .2277053
      lngdp  |   .0311015   .1461864     0.21   0.832    -.2554186    .3176216
      _cons  |   1.607881   1.234537     1.30   0.193    -.8117666    4.027528
-------------+----------------------------------------------------------------
     sigma_u |  .41910205
     sigma_e |   .1344351
         rho |  .90670628   (fraction of variance due to u_i)
```

Business funding

Model 8.1

```
Fixed-effects (within) regression               Number of obs      =       133
Group variable: country                         Number of groups   =        12

R-sq:  within  = 0.7567                         Obs per group: min =         1
       between = 0.9363                                        avg =      11.1
       overall = 0.9113                                        max =        14

                                                F(3,118)           =    122.30
corr(u_i, Xb)  = 0.2450                         Prob > F           =    0.0000
```

lnbus	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lngov	.6151079	.1307371	4.70	0.000	.3562129	.874003
lnhe	.2041562	.0311435	6.56	0.000	.1424835	.2658288
lngdp	.0732964	.213216	0.34	0.732	-.3489293	.495522
_cons	1.624325	1.936193	0.84	0.403	-2.209865	5.458515
sigma_u	.43886255					
sigma_e	.14780097					
rho	.89813202	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(11, 118) =    89.56          Prob > F = 0.0000
```

Model 8.2

```
Random-effects GLS regression                   Number of obs      =       133
Group variable: country                         Number of groups   =        12

R-sq:  within  = 0.7564                         Obs per group: min =         1
       between = 0.9374                                        avg =      11.1
       overall = 0.9127                                        max =        14

                                                Wald chi2(3)       =    520.58
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000
```

lnbus	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lngov	.6375015	.1135941	5.61	0.000	.414861	.8601419
lnhe	.1967059	.0304641	6.46	0.000	.1369974	.2564145
lngdp	.0845948	.1574613	0.54	0.591	-.2240237	.3932133
_cons	1.321148	1.319737	1.00	0.317	-1.265489	3.907786
sigma_u	.43004694					
sigma_e	.14780097					
rho	.89435852	(fraction of variance due to u_i)				

11. Annex E – HESA analysis

This annex sets out a preliminary analysis of the Higher Education Statistics Agency (HESA) data.

11.1. Overview of the HESA data

The Higher Education Statistics Agency (HESA) collects financial information on the activities of all UK higher education institutions (HEI) via the annual Finance Statistics Return (FSR). Amongst other things, the HESA dataset shows all "*income in respect of externally sponsored research carried out by the institution or its subsidiary undertaking for which directly related expenditure has been incurred*".[38] This income is split by the categories shown in the table below.

Table 28 Categories of research income

Funding Body Grants: *Funding body grants includes those from the Higher Education Funding Council for England (HEFCE), the Higher Education Funding Council for Wales (HEFCW), the Scottish Further and Higher Education Funding Council (SFC), the Teaching Agency (TA) and the Department for Employment and Learning Northern Ireland (DEL(NI)).*	
Recurrent (research)	*This includes the total grant (or main and associated grants) for research as shown in the annual grant letter or additional grant letter from the funding councils.*
Research grants and contracts*: This includes all income in respect of externally sponsored research carried out by the institution or its subsidiary undertaking for which directly related expenditure has been incurred.*	
BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh	*This includes all research grants and contracts income from Research Councils sponsored by the Department for Business, Innovation and Skills (BIS), The Royal Society, British Academy and The Royal Society of Edinburgh, returned to HESA under the following categories:* *Biotechnology and Biological Sciences Research Council (BBSRC)* *Medical Research Council (MRC)* *Natural Environment Research Council (NERC)* *Engineering and Physical Sciences Research Council (EPSRC)* *Economic and Social Research Council (ESRC)* *Arts and Humanities Research Council (AHRC)* *Science and Technology Facilities Council (STFC)* *Other (i.e. sponsored research grants and contracts income not included above).*
UK-based charities	*This includes all research grants and contracts income from all charitable foundations, charitable trusts, etc. based in the UK which are registered with the Charities Commission or those recognised as charities by the Office of the Scottish Charity Regulator (OSCR) in Scotland. Income from UK-based charities is split between those with an open competitive process for the allocation of funds and other charities.*
UK-based charities (open competitive process)	*This includes research grants or contracts income from UK-based charities that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus). Income awarded by the Education Endowment Foundation is included under this heading where funding originated from grants made by non-government sources.*

[38] *Definitions from taken from HESA "Finances of Higher Education Institutions 2012/13".*

UK-based charities (other)	*This includes research grants or contracts income from UK-based charities that does not meet the definition of open competition.*
UK central government bodies, local authorities, health and hospital authorities	*This includes all research grants and contract income from UK central government bodies, UK local authorities and UK health and hospital authorities, except Research Councils and UK public corporations. This includes government departments and other organisations (including registered charities) financed from central government funds. Research grants and contracts from non-departmental public bodies (NDPBs) such as the British Council are also included in this source of income. Income awarded by the Education Endowment Foundation is included under this heading where funding originated from grants made by UK government sources.*
UK industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory organisations with a substantial degree of financial independence) operating in the UK.*
EU government bodies	*This includes all research grants and contracts income from all government bodies operating in the EU, which includes the European Commission, but excludes bodies in the UK.*
EU-based charities (open competitive process)	*This includes research grants or contracts income from EU bodies with exclusively charitable purposes (consistent with the definition set out in the Charities Act 2006 and which exists for the public benefit in a manner which is consistent with the Public Benefit Guidance published by the Charity Commission for England and Wales), that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus).*
EU industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory corporations, with a substantial degree of financial independence) operating in the EU outside of the UK.*
EU other	*This includes all research grants and contracts income from EU-based non-competitive charities and any other EU income not otherwise specified.*
Non-EU-based charities (open competitive process)	*This includes research grants or contracts income from non-EU bodies with exclusively charitable purposes (consistent with the definition set out in the Charities Act 2006 and which exists for the public benefit in a manner which is consistent with the Public Benefit Guidance published by the Charity Commission for England and Wales), that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus).*
Non-EU industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory corporations, with a substantial degree of financial independence) operating outside the EU.*

Non-EU other	*This includes all research grants and contracts income from all non-EU-based non-competitive charities and any other non-EU income not otherwise specified.*
Other sources	*This includes all research grants and contracts income not covered above. This includes income from other higher education institutions (HEIs) where the HEI is the original contractor.*

For the purpose of this analysis we have grouped the categories that relate to '*research income*' into two broad categories:

- ***UK public funding***: which comprises (i) BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh (henceforth referred to as RCs funding), (ii) UK central government bodies, local authorities, health and hospital authorities(henceforth referred to as other government funding), and (iii) QR research related research funding: Funding Body Grants for recurrent (research).
- ***Private funding***: which comprises (i) UK-based charities, (ii) UK-based charities (open competitive process), (iii) UK-based charities (other), (iv) UK industry, commerce and public corporations, (v) EU government bodies, (vi) EU-based charities (open competitive process), (vii) EU industry, commerce and public corporations, (viii) EU other, (ix) Non-EU-based charities (open competitive process), (x) Non-EU industry, commerce and public corporations, (xi) Non-EU other, and (xii) Other sources

For a more detailed analysis we have made further splits of the data, namely:

- ***RC funding***: this is equivalent to (i) BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh income for research grants and contracts
- ***Government funding (non-RC)***: this is equivalent to (i) UK central government bodies, local authorities, health and hospital authorities, and (ii) QR-related research funding.
- ***Business funding***: relates solely to UK business investment, i.e. (i) UK industry, commerce and public corporations
- ***Charities funding***: relates solely to UK charities, namely: (i) UK-based charities, (ii) UK-based charities (open competitive process), (iii) UK-based charities (other).
- ***Overseas funding***: comprises all research income from abroad: (i) EU government bodies, (ii) EU-based charities (open competitive process), (iii) EU industry, commerce and public corporations, (iv) EU other, (v) Non-EU-based charities (open competitive process), (vi) Non-EU industry, commerce and public corporations, (vii) Non-EU other.

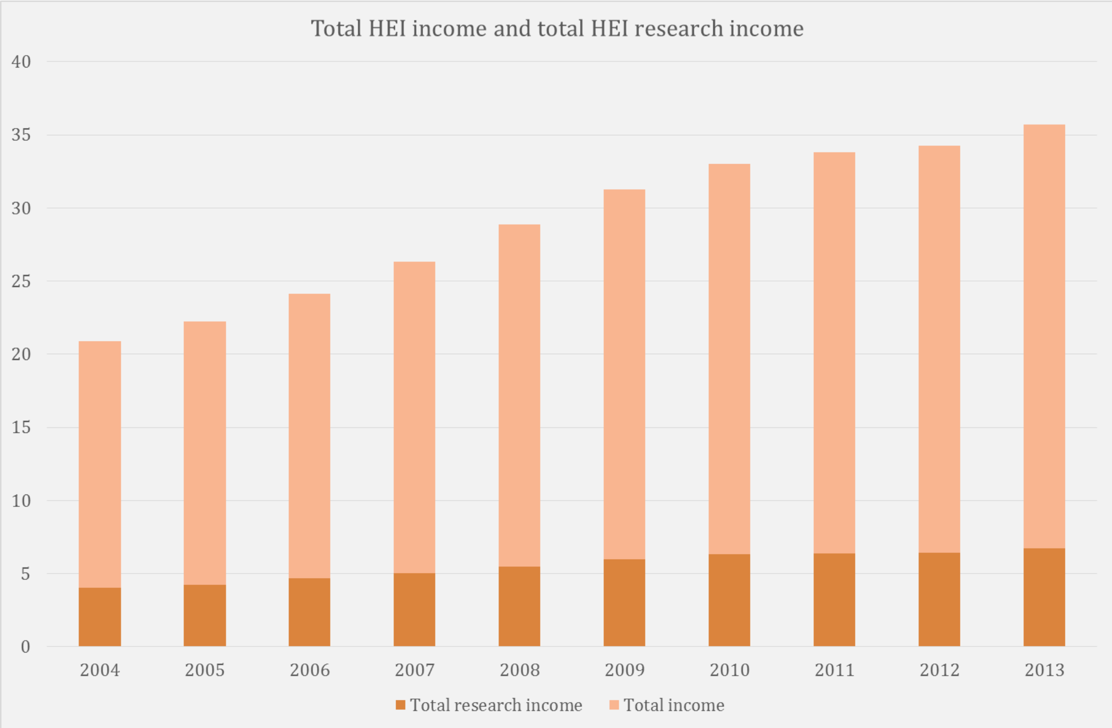
These splits broadly align with the ONS splits and definitions, and make comparisons easier.

11.2. Key facts and figures relating to HESA data

This section sets out the key facts and figures relating to HEIs' R&D income. First, we examine how income in 2012/13 is split between different funding bodies. We then examine the trends in R&D income over time.

As we are interested in the income relating to research that each HEI receives, it is useful to see the proportion of total HEI income that relates to research. On average, total research income tends to account for 24% of total HEI income over this period. Of the £29bn of total income received by all HEIs in 2012/13, £6.7bn (including grants for recurrent research) were specifically for research purposes.

Figure 63

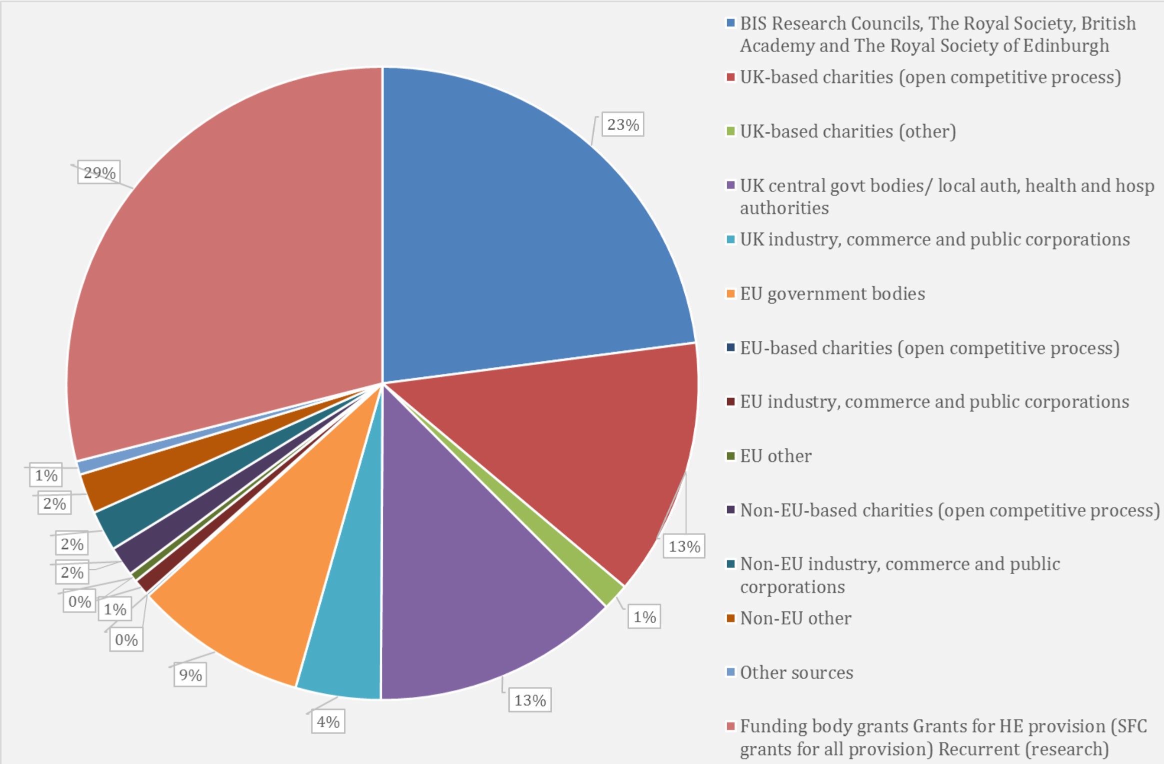


Income in 2012/13

The HESA data shows that the 161 UK HEIs reported income from research grants and contracts and QR-related research income of £6.7 billion in 2012/13 (£42 million per HEI on average). This represents over 70% of £9.4 billion of GERD performed by the public sector.

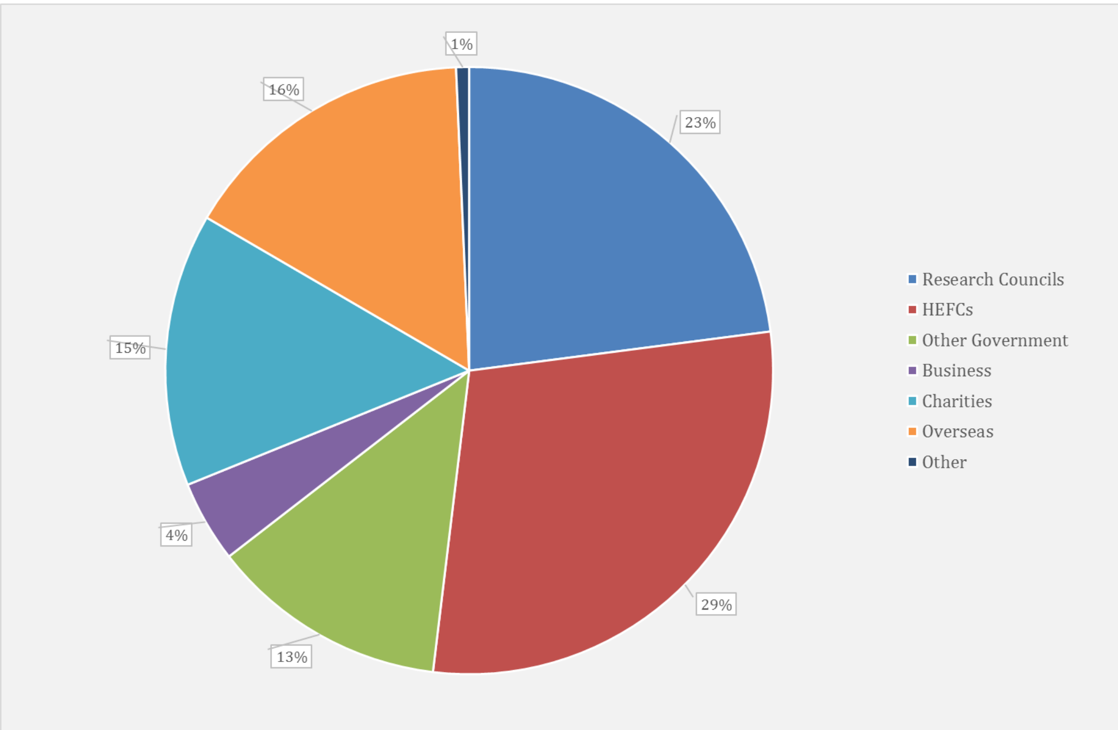
The chart below shows how this is split between the different sources of income shown in Table 28 above. It shows that the largest source of income is QR-related research income (29%), followed by RCs funding (23%), and then by UK-based charities and UK central government (both with 13%).

Figure 64



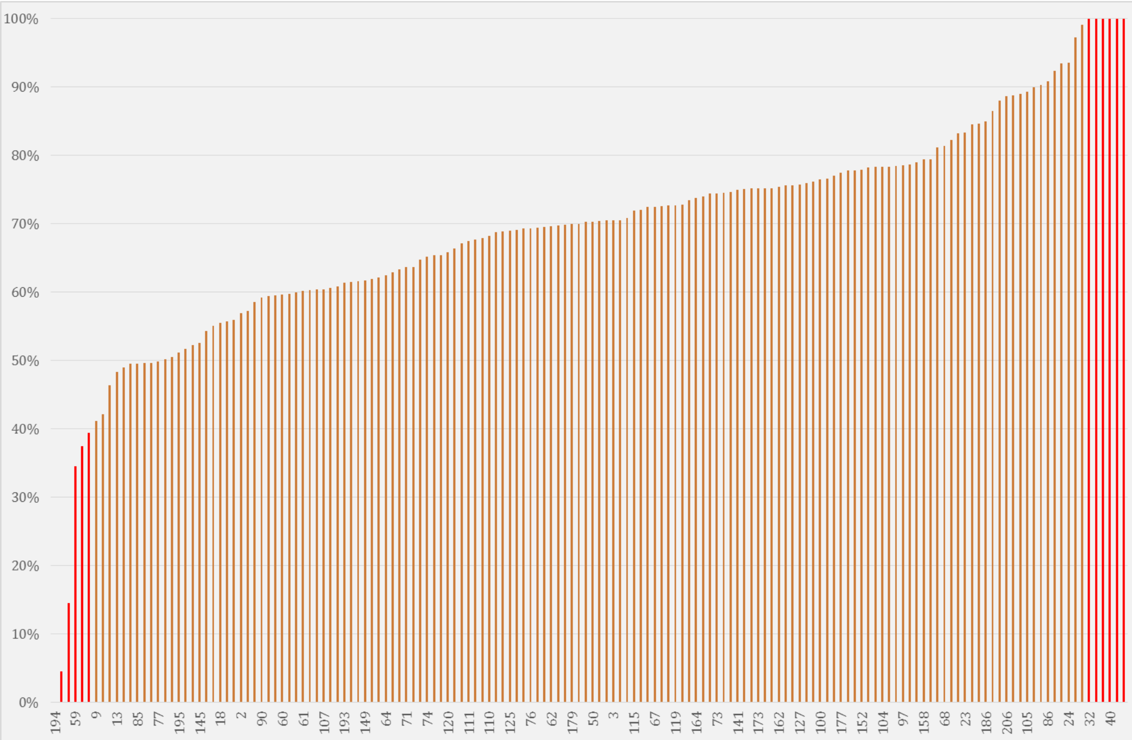
The chart below groups some of the sources of income to align more closely with the definitions used by ONS and Eurostat. Specifically, 'Charities' groups all income from UK-based charities and 'Overseas' groups all income from non-UK sources (irrespective of whether the source is publically or privately owned). The chart shows that 65% of the income is from the UK public sector and 35% is from elsewhere.

Figure 65



This 'average' 65:35 split between income from the UK public sector and elsewhere masks significant variation in the percentage split in different HEIs. The data shows that 5% of HEI's receive less than 40% of their income from the UK public sector and 5% of HEI's receive 100% of their income from the UK public sector.

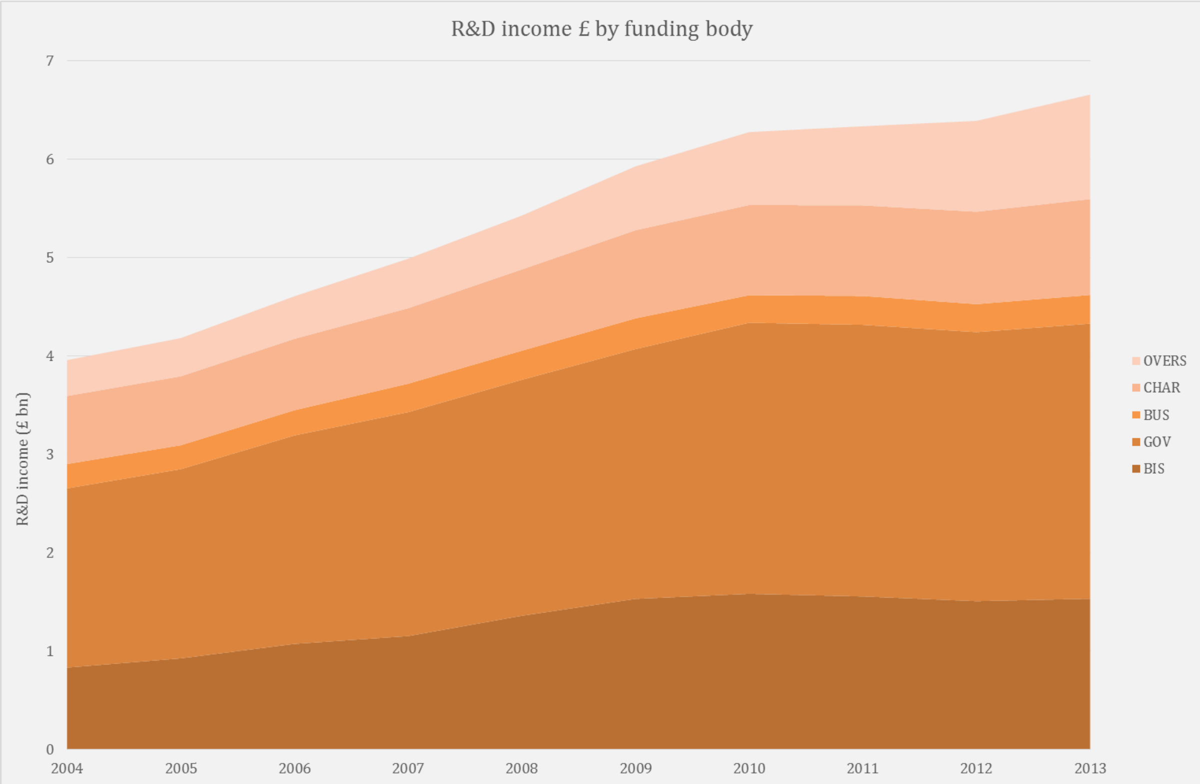
Figure 66 Percentage of HEI's income from UK public sector



Trends in income

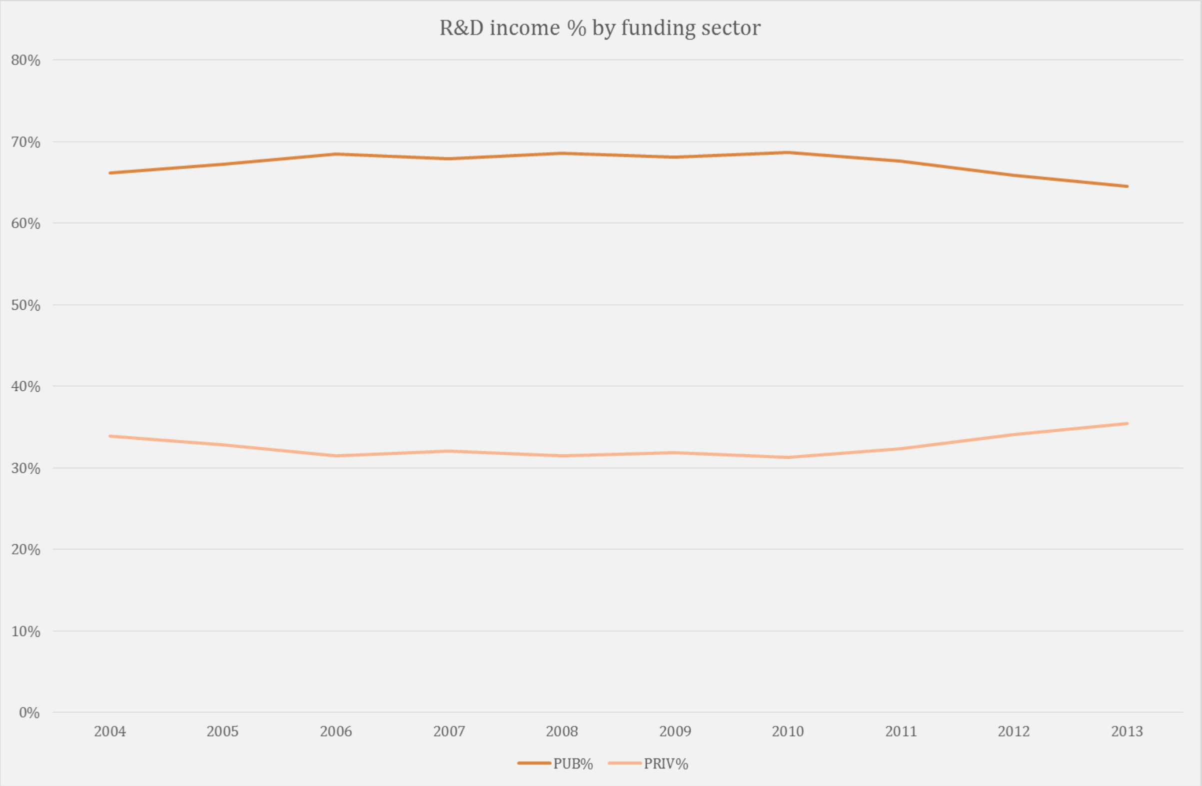
The figure below shows the trend in total HEIs R&D income by funding body since 2003/04. It shows that total R&D income has increased from around £4bn in 2003/04 to around £6.6bn in 2012/13.

Figure 67



Most of this increase is attributable to an increase in government funding; however, charitable and overseas funding have been important contributors, too. This is further illustrated in the figure below, where we can see that the private sector accounts for around 35% of HEIs R&D income, the public sector accounting for the remaining 65%.

Figure 68

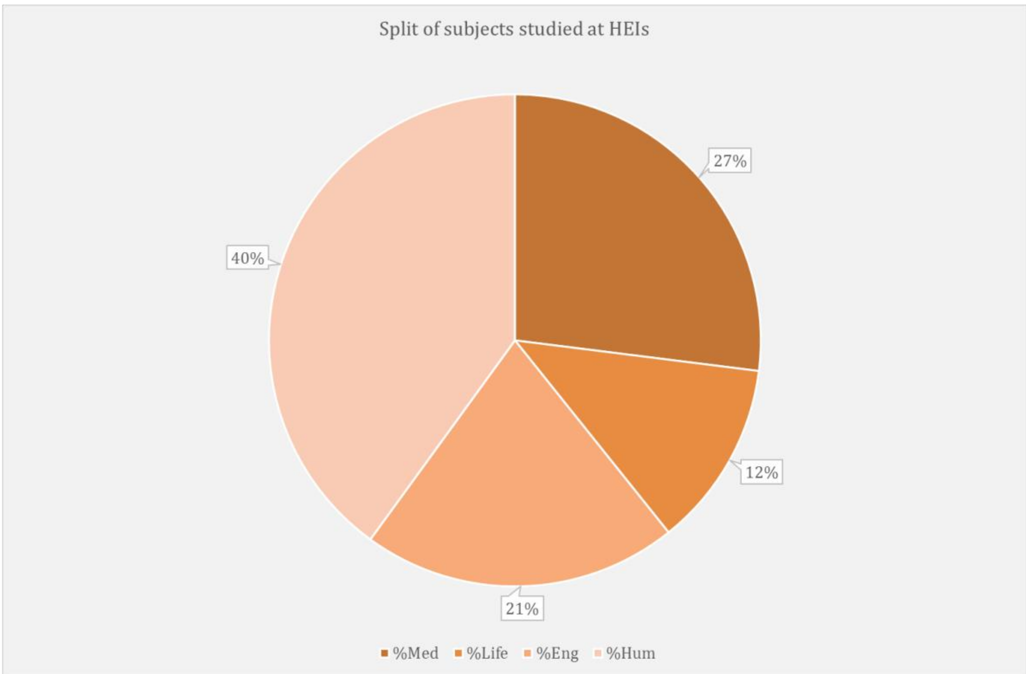


A potential factor which determines how much funding for research a HEI receives is its subject focus. Therefore, we have grouped the subjects taught at universities into four broad categories, so as to see whether the subject focus of each HEI influences private investment decisions. The four broad groups are:

- ***Medical and Human Sciences*** (clinical medicine, clinical dentistry, anatomy & physiology, nursing & paramedical studies, health & community studies, psychology & behavioural sciences, pharmacy & pharmacology)
- ***Life Sciences*** (veterinary science, biosciences, agriculture & forestry, earth, marine & environmental sciences)
- ***Engineering and Physical Sciences*** (chemistry, physics, general engineering, chemical engineering, mineral metallurgy & materials engineering, civil engineering, electrical, electronic & computer engineering, mechanical, aero & production engineering, mathematics, information technology & systems sciences & computer software engineering)
- ***Humanities*** (architecture, built environment & planning, catering & hospitality management, business & management studies, geography, social studies, media studies, humanities & language based studies, design & creative arts, education, modern languages, archaeology, sports science & leisure studies, continuing education)

The figure below shows the percentage of academic staff FTE active in each of these groups.

Figure 69



As can be seen above, 40% of academic staff (on average) works in the Humanities. The remaining 60% work in the Medical and Human Sciences, Life Sciences, and Engineering and Physical Sciences.

11.3. The relationship between private and public income

The figure below shows that HEIs that tend to have high level of public income also have a high level of private income (each data point is a HEI and refers to the latest data from 2012/13). Since many of the HEIs have public and private incomes below £10m, the subsequent figure 'zooms in' on them. It shows that there is positive correlation between them, although there is not a 'one-for-one' relationship.

Figure 70

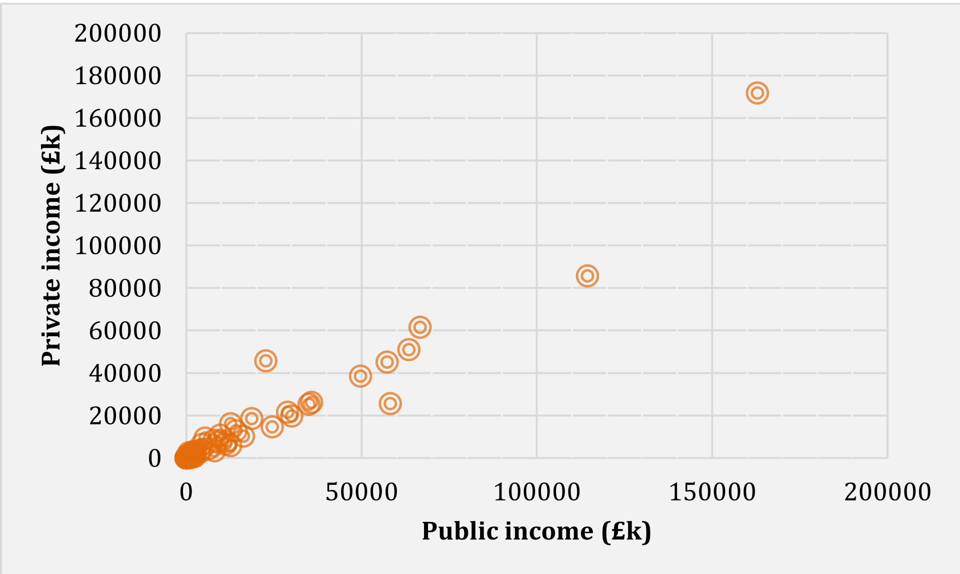
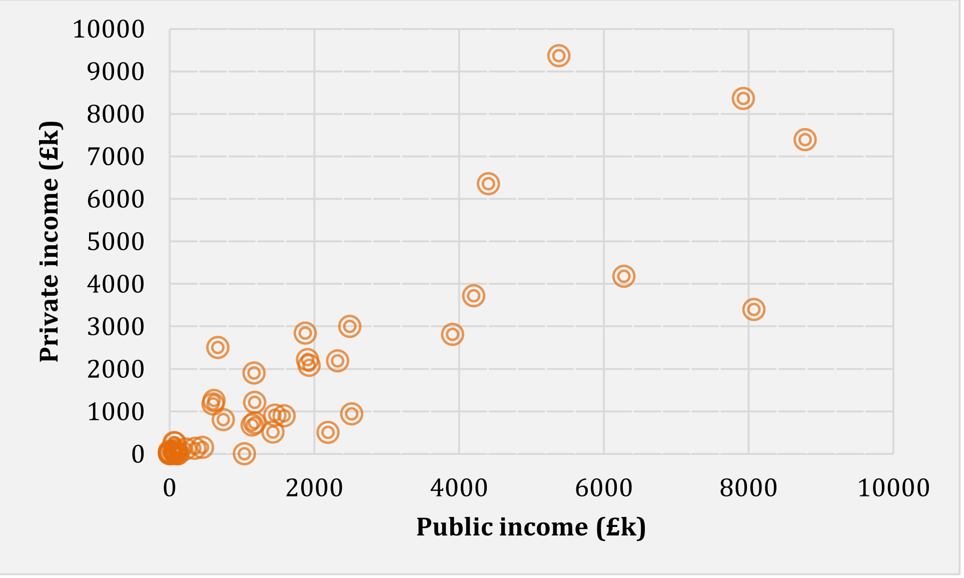


Figure 71



A number of factors will contribute to this positive correlation. One factor is institution size: a reasonable expectation is that larger institutions will tend to have higher levels of both private and public income. To help control for a possible 'size' effect, the figures below show the same data on a 'per FTE' basis. The figures continue to show a positive correlation between private and public income. This suggests that factors over and above size contribute to this correlation. They could include: quality of the HEI; and the mix of subjects they specialise in (e.g. institutions undertaking research in a more expensive mix of subjects will tend to require greater resources (this may not be partially captured by research size). We will investigate these possibilities in the next section.

Figure 72

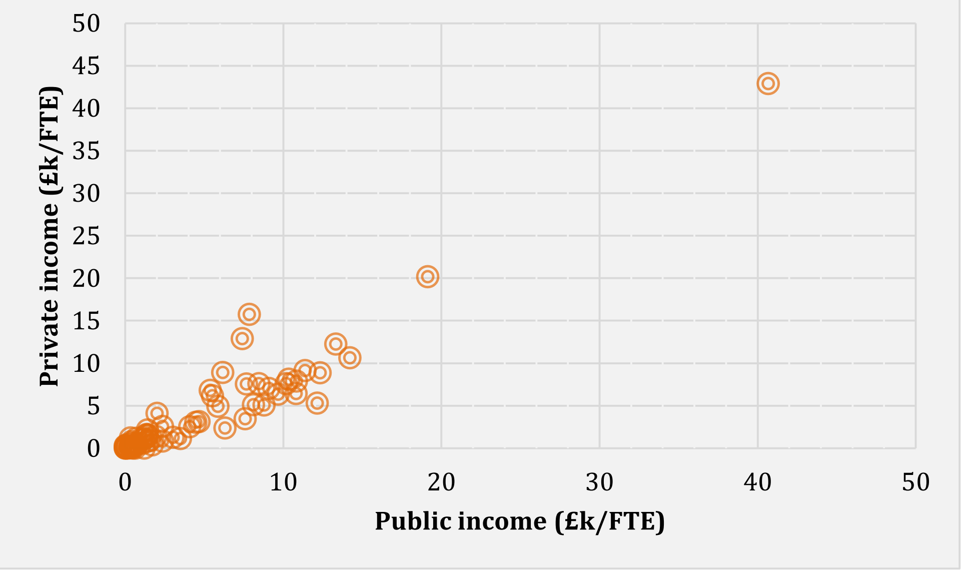
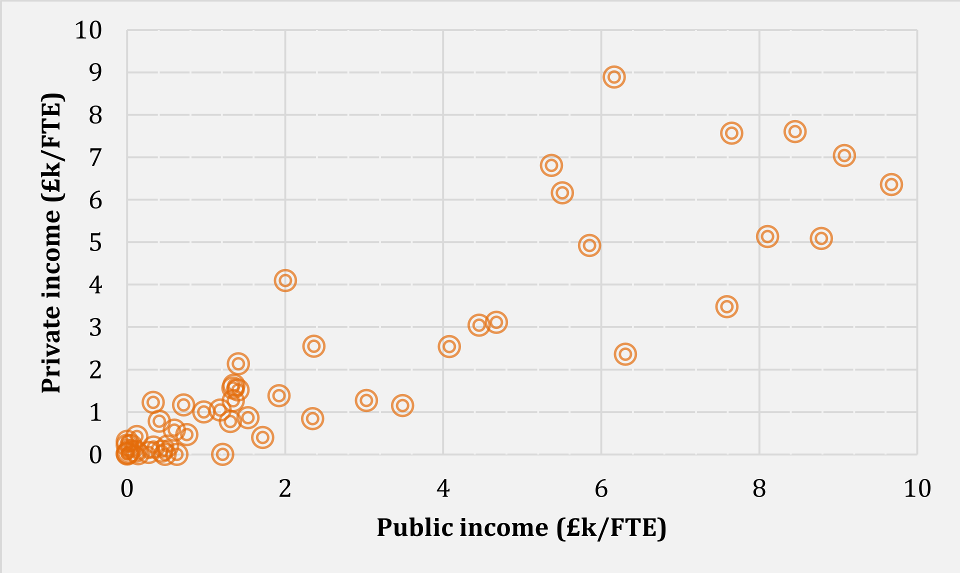


Figure 73



1. Econometric analysis

This section sets out the results of our econometric analysis using the HESA data described above, combined with other publically available data. The time period for our analysis spans from 2003/04 to 2012/13 inclusive. The data is measured at an annual frequency.

Our general specification is as set out below

$$\ln(\mathit{private\ funding})_{it} = a + b.\ln(\mathit{public\ funding})_{it} + c.\mathit{controls} + e_{it} \quad (1)$$

Assuming that the equation is properly specified, the parameter *b* measures the elasticity of private funding with respect to public funding, i.e. the % change in private income brought about by a 1% change in public income, other things being equal.

Without any controls, and using a pooled OLS (POLS) regression, the elasticity is estimated to be 0.99, i.e. the data suggests a 1% increase in public funding gives rise to a 0.99% increase in private funding of R&D (see Model 1). However, for the reasons set out above, this model fails to take account of the other factors that drive private funding, and so is likely to be biased.

To address these deficiencies, we make various changes to the analysis and control for various different factors:

- ***Size***: The rationale for including size as a control variable is based on the assumption that the bigger the HEI, the more funding it will receive (compared to a smaller HEI). We have tried different controls for size, such as total staff FTE, total academic staff FTE, total research staff, total staff, total income and total expenditure. Our preferred measure is total staff FTE, because it reflects all staff, including support staff which may facilitate greater capacity and is a consistent measure (i.e. it accounts for both full-time and part-time staff).
- ***Subject area***: Another institution specific factor is the subject area in which the HEI specialises/ has a good reputation in. Subject areas could bias our results if they are correlated with the public R&D funding a HEI receives. This could be the case if, for instance HEIs with strong science departments receive more R&D funding. To control for this, we have included size variables of the different departments at each HEI – Medical and Human Sciences, Life Sciences, Engineering and Physical Sciences and Humanities.
- ***Quality***: Further to HEI-size and department size, we consider that other institution-specific factors will affect the amount of private R&D funding it receives. These factors could bias our results when they are correlated with the amount of public R&D funding a HEI receives. Two examples of such

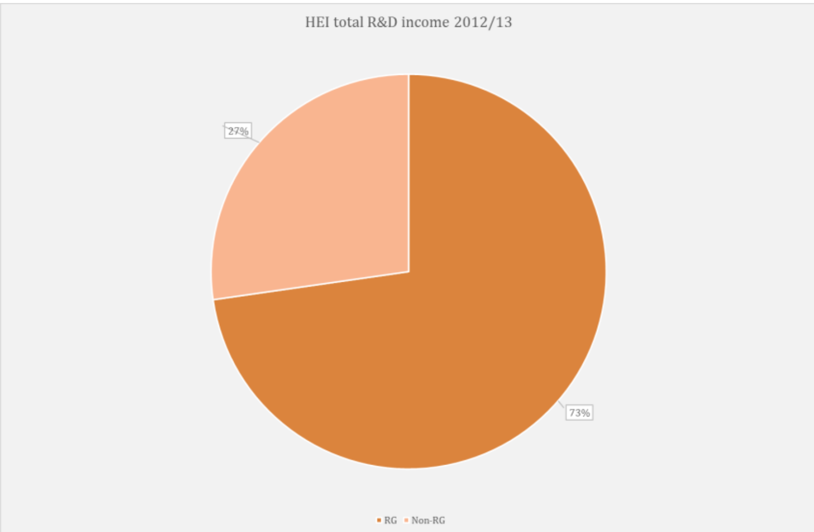
factors are: the research quality of the HEI and, relatedly, their reputation for conducting high quality research. To help control for these factors, we have included some or all of the following additions and adjustments to our modelling:

- *Ratio of total staff FTE to total students FTE*: The rationale for including this ratio is to account for HEI-specific 'quality factors'. The underlying assumption is that the more staff per student there is, the higher the quality of that HEI. This measure would help control for quality if (a) it is a good proxy for teaching quality; and (b) teaching quality is a good proxy for research quality.
- *TRAC Peer Groups*[39]*:* A HEI is in a TRAC Peer Group based on its research income as a percentage of its total income and of research areas/ quality. For instance, Peer Group 1 is the Russell Group, in which all HEIs have medical schools excluding LSE plus some specialist medical schools. TRAC Peer Group dummy variables are a good proxy for research quality if (a) all the HEIs in a Peer Group have a similar research quality; and (b) research income as a percentage of its total income is a good proxy for research quality.
- *RAE scores:* The RAE score has not been included in our model, as although it is a good indication of a HEI's research quality, the RAE score determines how much public R&D funding a HEI receives. Hence, RAE scores are correlated with public R&D funding and would bias the elasticity estimates.

- ***Region***: We have also explored whether regional differences affect public/private R&D funding, however there did not appear to be funding differences based purely on region alone.
- ***Macroeconomic conditions***: As further controls we have also included macroeconomic variables such as GDP and Gross Fixed Capital Formation, as these capture effects that affect all HEIs in the same way, at the same time, and over time (hence eliminating the need to add a time-trend to our specifications).

Overall, we have captured mostly time-invariant HEI-specific factors such as quality and department sizes. As further control for all the time invariant quality differences we have split the sample into two groups: (i) high research intensity institutions (Peer Group 1: Russell Group - RG), and (ii) others (Peer Groups 2-7: Non-RG). The rationale for doing this is, that when looking at how total R&D income is spread across the Peer Groups in 2012/13, it is discernible that RG HEIs receive 73% of R&D-specific funding, whereas the Non-RG HEIs receive the remaining 27%.

Figure 74



[39] *The peer groups are the peer groups used for TRAC (transparent approach to costing) benchmarking, c.f. http://www.hefce.ac.uk/media/hefce/content/whatwedo/leadershipgovernanceandmanagement/financialsustainabilityandtrac/tracguidance/Annex%204.1b.PDF*

This 70:30 split holds throughout the years, and hence it is important to look at these two splits of the sample, as there are 24 HEIs in the RG group, whereas there are 133 in the Non-RG group. This would indicate that the results of the aggregate sample (including RG and Non-RG together) is biased in favour of the Non-RG group, as there are more Non-RG observations than RG ones. However, when considering the research question, namely how public funding of R&D leverages private R&D funding, more weight should be placed on the RG group sample, as most of R&D specific funding is attributed to this group, and hence it is more representative/ appropriate for analysing our question.

Further to controlling for these HEI-specific factors by splitting the sample into RG and Non-RG HEIs, panel data approaches naturally deal with individual-specific factors (which have not been captured by our control variables). Panel data approaches are more informative and the estimates are more efficient. They allow to control for individual unobserved heterogeneity, such as the research quality/ reputation of a HEI, which is one of our concerns in this analysis. The general panel data specification is

$$y_{it} = \alpha + \beta_1 x_{it} + u_{it}$$

Where u_{it} is decomposed into an individual-specific time-constant unobserved heterogeneity v_i and an idiosyncratic error ε_{it}:

$$u_{it} = v_i + \varepsilon_{it}$$

Using a fixed-effects (FE) specification by definition accounts for these HEI-specific effects such as quality, brand-value, etc., which would be captured in v_i.

So, we have run pooled OLS regressions (POLS), FE regressions and RG- and Non-RG-specific POLS/FE regressions. We have analysed the effect of total public funding on total private funding (aggregated analysis), and then we have performed some more disaggregated analyses: (a) the effect of total public funding on the component parts of total private funding (UK businesses, UK charities, and Overseas); and (b) the effect of the component parts of public funding (RC funding, and other government funding) on total private funding. Below we set out the results from our aggregated and disaggregated analysis. Nonetheless the last bit of analysis should be interpreted with caution, as the explanatory variables RC and other government funding are highly correlated (0.96) and possibly biasing the results.

For all analyses we follow the same rationale of running a POLS with all the control variables mentioned above first, then comparing these results to a RG- and Non-RG-specific POLS with all the control variables, and finally, to account for uncontrolled for HEI-specific effects we have also run a RG- and Non-RG-specific FE with all the control variables. As mentioned above, roughly 70% of all R&D income flows to RG HEIs. This implies that our aggregate estimates (i.e. where the sample has not been split into RG and Non-RG) is biased towards the Non-RG group, which only receives around 30% of all R&D income. This may lead to an underestimation of the results, as Non-RG HEIs represent the majority of our sample's observations. Nonetheless, these results should not be dismissed, but rather should form part of a range of our elasticity estimates, whereby the other bound of the range is a weighted average of the RG and Non-RG results. In order to reconcile the results of the analysis of the sub-samples, we have weighted the RG estimates by a factor of 0.7 and the Non-RG ones be a factor of 0.3, to obtain a re-aggregated elasticity estimate.

Aggregated analysis

Pooled OLS

Table 29

	Model 1	Model 2	Model 3	Model 3.1 (RG)	Model 3.2 (Non-RG)
ln(public funding)$_t$	0.99*** (0.01)	0.74*** (0.02)	0.81*** (0.03)	0.64*** (0.10)	0.78*** (0.04)
ln(Medical and Human Sciences)$_t$		0.07** (0.03)	0.12*** (0.02)	0.55*** (0.05)	0.09*** (0.03)
ln(Life Sciences)$_t$		0.12*** (0.03)	0.06*** (0.02)	0.21*** (0.04)	0.09*** (0.03)
ln(Engineering and Physical Sciences)$_t$		0.14*** (0.07)	0.11*** (0.02)	0.06 (0.05)	0.13*** (0.03)
ln(Humanities)$_t$		-0.55*** (0.03)	-0.52*** (0.06)	0.07 (0.05)	-0.63*** (0.10)
ln(quality)$_t$		0.38*** (0.06)	0.03 (0.07)	0.75*** (0.08)	-0.10 (0.09)
ln(total staff FTE)$_t$		0.28** (0.23)	0.25** (0.12)	-0.85*** (0.22)	0.42*** (0.15)
ln(fixed capital)$_t$		1.17*** (0.23)	0.83*** (0.20)	0.58*** (0.18)	0.95*** (0.24)
Dummy_Peer2			-0.21*** (0.08)	omitted	omitted
Dummy_Peer3			-0.32*** (0.10)	omitted	-0.16* (0.08)
Dummy_Peer4			-0.09 (0.11)	omitted	0.03 (0.10)
Dummy_Peer5			-0.49*** (0.13)	omitted	-0.39*** (0.12)
Dummy_Peer6			-0.27 (0.17)	omitted	-0.16 (0.16)
Dummy_Peer7			-0.17 (0.20)	omitted	-0.06 (0.19)
R-squared	0.84	0.88	0.91	0.92	0.85

Statistically significant at the 10% level, 5% level** and 1% level***.*

- Here we can see that controlling for quality, the size of the departments, total staff FTE, and fixed capital, public funding has an elasticity of 0.74.
- Adding dummy variables for the Peer Groups, we can see that being in Peer Groups 2-7, as opposed to belonging to Peer Group 1, has a negative impact on private investment and is only significant for Peer Groups 2, 3, and 5. Interestingly, quality becomes insignificant, possibly as a result of correlation between staff/student numbers and research intensity. Public funding elasticity amounts to 0.81, with the size of the departments, size of the HEI and fixed capital all being significant.
- Further controlling for HEI-specific effects on quality and splitting the sample into RG and Non-RG HEIs, we see that elasticities are similar for RG (0.64) and Non-RG HEIs (0.78), being somewhat lower for RG HEIs.

As discussed above, in order to provide a range of elasticity estimates, we have weighted the RG and Non-RG results by their respective weighting factors. By doing this we obtain an elasticity coefficient amounting to 0.68. So, overall, for our aggregated POLS analysis we have a range of elasticity estimates between ***0.68*** and ***0.81***.

Exploring the panel properties

In addition to the pooled OLS estimation of the elasticities, we have also explored the FE panel estimation method, for RG and Non-RG HEIs separately. We performed the Hausman test, which indicates that a fixed effects model should be preferred to a random effects one in this situation. As can be seen from the table below, the Non-RG HEIs' elasticity of public funding is much lower than the public funding elasticity of the RG HEIs. However, the RG FE elasticity is more in line with the POLS elasticity coefficient above.

Table 30

	Model 4	**Model 4.1 (RG)**	**Model 4.2 (Non-RG)**
ln(public funding)$_{it}$	0.25*** (0.05)	0.58*** (0.09)	0.24*** (0.06)
ln(Medical and Human Sciences)$_{it}$	0.09 (0.08)	0.22** (0.09)	0.08 (0.09)
ln(Life Sciences)$_{it}$	-0.03 (0.04)	-0.02 (0.07)	-0.03 (0.05)
ln(Engineering and Physical Sciences)$_{it}$	-0.08 (0.06)	0.65*** (0.18)	-0.08 (0.07)
ln(Humanities)$_{it}$	0.06 (0.14)	-0.13 (0.12)	0.09 (0.17)
ln(quality)$_{it}$	-0.39*** (0.14)	0.22 (0.17)	-0.42** (0.16)
ln(total staff FTE)$_{it}$	0.50* (0.22)	-0.39 (0.29)	0.47* (0.25)
ln(fixed capital)$_{it}$	0.98*** (0.17)	0.63*** (0.12)	1.01*** (0.20)
Dummy_Peer2	omitted	omitted	omitted

Dummy_Peer3	omitted	omitted	omitted
Dummy_Peer4	omitted	omitted	omitted
Dummy_Peer5	omitted	omitted	omitted
Dummy_Peer6	omitted	omitted	omitted
Dummy_Peer7	omitted	omitted	omitted
R-squared	0.75	0.71	0.57

Statistically significant at the 10% level, 5% level** and 1% level***.*

- Overall, the FE elasticity coefficient is 0.25.
- The RG FE model has an elasticity of 0.58.
- The Non-RG FE model has an elasticity of 0.24.

Similarly to the above re-weighting of the POLS RG and Non-RG estimates, we have also re-aggregated the FE RG and Non-RG estimates. Doing this returns an elasticity estimate of 0.48. So, the overall range of elasticities in our panel approach is ***0.25*** to ***0.48***.

<u>Disaggregated analysis</u>

Further to this aggregated analysis, there are different types of private funding and public funding within the aggregates used above. It is possible that the effect of public funding on private funding vary by these types and, in addition, it is possible that the other drivers of private funding vary by these types.

Analysis by type of private funding type

Pooled OLS

To start exploring the different possibilities, we have re-estimated Model 3 above, but separately for the different types of private funding, i.e. UK business funding, UK charities funding and overseas funding. The results of these analyses are set out in the table below. The choice of model 3 is solely based on the fact that it is more "complete", i.e. it has more control variables. We have re-estimated model 2 above, too, however, the results were very similar to those of the re-estimation of model 3, and hence we do not present those results here.

Table 31

	Model 5 Business	**Model 6 Charities**	**Model 7 Overseas**
ln(public funding)$_t$	0.78*** (0.05)	0.74*** (0.04)	0.89*** (0.05)
ln(Medical and Human Sciences)$_t$	0.18*** (0.04)	0.25*** (0.03)	0.07* (0.04)
ln(Life Sciences)$_t$	-0.04 (0.04)	0.11*** (0.03)	0.06 (0.04)
ln(Engineering and Physical Sciences)$_t$	0.26*** (0.04)	-0.23*** (0.03)	0.28*** (0.04)
ln(Humanities)$_t$	-0.67*** (0.10)	-0.35*** (0.09)	-0.45*** (0.10)
ln(quality)$_t$	0.16	0.34***	-0.08

	(0.11)	(0.09)	(0.10)
ln(total staff FTE)t	0.21 (0.08)	0.58*** (0.15)	0.09 (0.18)
ln(fixed capital)t	0.38 (0.30)	0.17 (0.26)	2.00*** (0.29)
Dummy_Peer2	-0.14 (0.12)	-0.47*** (0.10)	0.15 (0.11)
Dummy_Peer3	-0.01 (0.15)	-0.76*** (0.13)	0.08 (0.15)
Dummy_Peer4	0.12 (0.18)	-0.71*** (0.15)	0.36** (0.17)
Dummy_Peer5	-0.23 (0.21)	-0.93*** (0.18)	-0.10 (0.20)
Dummy_Peer6	-0.04 (0.27)	-1.01*** (0.22)	0.11 (0.29)
Dummy_Peer7	-0.12 (0.39)	-0.97*** (0.25)	0.13 (0.29)
R-squared	0.81	0.90	0.84

Statistically significant at the 10% level, 5% level** and 1% level***.*

The results suggest that the association between public funding and private funding is strongest for overseas funding and weakest for charities funding, specifically:

- The estimated elasticity for business funding is 0.78 and is statistically significant at the 1% level.
- The estimated elasticity for charities funding is lower at 0.74 and is also statistically significant at the 1% level.
- The estimated elasticity for overseas funding is 0.89 and is also statistically significant at the 1% level.

Further controlling for HEI-specific effects on quality and splitting the sample into RG and Non-RG HEIs, we see that elasticities are lower for RG HEIs compared to Non-RG HEIs. Nonetheless, we see that the coefficient for 'Overseas' funding is still higher than the one for 'Business' or 'Charities' funding.

Table 32

	Model 5 .1 Business (RG)	**Model 5 .2 Business (Non-RG)**	**Model 6.1 Charities (RG)**	**Model 6.2 Charities (Non-RG)**	**Model 7.1 Overseas (RG)**	**Model 7.2 Overseas (Non-RG)**
ln(public funding)t	0.33* (0.17)	0.79*** (0.06)	0.42*** (0.15)	0.72*** (0.05)	1.20*** (0.14)	0.85*** (0.06)
ln(Medical and Human Sciences)t	0.34***	0.15***	0.61***	0.22***	0.47***	0.04

	(0.09)	(0.04)	(0.08)	(0.04)	(0.08)	(0.04)
ln(Life Sciences)$_t$	0.17** (0.07)	-0.07 (0.04)	0.25*** (0.06)	0.13*** (0.04)	0.16*** (0.06)	0.08* (0.04)
ln(Engineering and Physical Sciences)$_t$	0.07 (0.08)	0.24*** (0.05)	-0.17** (0.07)	-0.22*** (0.04)	0.33*** (0.07)	0.30*** (0.05)
ln(Humanities)$_t$	-0.32*** (0.09)	-1.03*** (0.14)	0.17** (0.08)	-0.40*** (0.12)	0.01 (0.08)	-0.46*** (0.14)
ln(quality)$_t$	-0.02 (0.14)	0.43*** (0.14)	1.30*** (0.12)	0.18 (0.12)	0.34*** (0.12)	-0.26* (0.14)
ln(total staff FTE)$_t$	0.55 (0.23)	0.61*** (0.23)	-0.70** (0.33)	0.69*** (0.19)	1.50*** (0.33)	0.13 (0.23)
ln(fixed capital)$_t$	-0.24 (0.31)	0.65* (0.36)	0.10 (0.27)	0.29 (0.31)	1.81*** (0.27)	1.99*** (0.36)
Dummy_Peer2	omitted	-0.11 (0.29)	omitted	omitted	omitted	0.16 (0.28)
Dummy_Peer3	omitted	0.10 (0.28)	omitted	-0.34*** (0.10)	omitted	0.03 (0.27)
Dummy_Peer4	omitted	0.38 (0.27)	omitted	-0.35*** (0.13)	omitted	0.23 (0.27)
Dummy_Peer5	omitted	-0.02 (0.26)	omitted	-0.56*** (0.16)	omitted	-0.24 (0.25)
Dummy_Peer6	omitted	0.27 (0.27)	omitted	-0.61*** (0.21)	omitted	0.00 (0.27)
Dummy_Peer7	omitted	omitted	omitted	-0.57** (0.24)	omitted	omitted
R-squared	0.70	0.68	0.86	0.78	0.86	0.75

Statistically significant at the 10% level, 5% level** and 1% level***.*

Reweighting the RG and Non-RG estimates to obtain an aggregate estimate returns the following results:

- The re-aggregated elasticity coefficient for UK business funding is 0.47.
- For UK charities the re-aggregated elasticity coefficient is 0.51.
- Finally, the re-aggregated 'Overseas' elasticity coefficient amounts to 1.10.

In conclusion of the disaggregated POLS analysis, our elasticity estimates ranges are the following for the different splits:

- 'Business': the business elasticity estimates range from ***0.47*** to ***0.78***.
- 'Charities': the charities elasticity estimates range from ***0.51*** to ***0.74***.
- 'Overseas': the overseas elasticity estimates range from ***0.89*** to ***1.10***.

Panel approaches

To further account for HEI-specific characteristics we have re-estimated the RG and Non-RG models above with a FE specification. As can be seen from the table below, the elasticity coefficients are very similar for RG and Non-RG businesses and charities funding, as well as Non-RG overseas funding (0.3-0.4), with the RG overseas coefficient being the only outlier (1.08):

Table 33

	Model 5 .3 Business (RG)	Model 5 .4 Business (Non-RG)	Model 6.3 Charities (RG)	Model 6.4 Charities (Non-RG)	Model 7.3 Overseas (RG)	Model 7.4 Overseas (Non-RG)
ln(public funding)$_t$	0.42** (0.19)	0.37*** (0.09)	0.37*** (0.08)	0.31*** (0.07)	1.18*** (0.14)	0.36*** (0.09)
ln(Medical and Human Sciences)$_t$	0.32 (0.20)	-0.14 (0.13)	0.28*** (0.08)	-0.17 (0.11)	0.23* (0.14)	0.29** (0.13)
ln(Life Sciences)$_t$	0.26* (0.15)	-0.01 (0.07)	-0.05 (0.06)	-0.02 (0.06)	-0.01 (0.10)	-0.08 (0.08)
ln(Engineering and Physical Sciences)$_t$	1.19*** (0.40)	-0.17 (0.14)	-0.23 (0.17)	-0.25*** (0.09)	1.05*** (0.28)	0.27** (0.13)
ln(Humanities)$_t$	-0.06 (0.28)	-0.15 (0.24)	0.08 (0.12)	-0.07 (0.20)	-0.27* (0.20)	0.18 (0.24)
ln(quality)$_t$	-0.00 (0.39)	-0.04 (0.25)	0.29* (0.16)	0.20 (0.20)	0.06 (0.28)	-0.75*** (0.25)
ln(total staff FTE)$_t$	1.43** (0.66)	0.55 (0.36)	0.02 (0.27)	0.62** (0.30)	-0.52 (0.46)	0.09 (0.37)
ln(fixed capital)$_t$	0.10 (0.27)	0.49* (0.30)	0.20* (0.11)	0.76*** (0.25)	1.42*** (0.19)	1.71*** (0.29)
Dummy_Peer2	omitted	omitted	omitted	omitted	omitted	omitted
Dummy_Peer3	omitted	omitted	omitted	omitted	omitted	omitted
Dummy_Peer4	omitted	omitted	omitted	omitted	omitted	omitted
Dummy_Peer5	omitted	omitted	omitted	omitted	omitted	omitted
Dummy_Peer6	omitted	omitted	omitted	omitted	omitted	omitted
Dummy_Peer7	omitted	omitted	omitted	omitted	omitted	omitted
R-squared	0.40	0.44	0.76	0.50	0.74	0.52

Statistically significant at the 10% level, 5% level** and 1% level***.*

Similarly to the re-aggregation of the RG and Non-RG POLs estimates, below we re-aggregate the RG and Non-RG FE estimates into an aggregate elasticity estimate:

- The re-aggregated elasticity coefficient for UK business funding is 0.41.
- For UK charities the re-aggregated elasticity coefficient is 0.35.

- Finally, the re-aggregated 'Overseas' elasticity coefficient amounts to 0.93.

In conclusion of the disaggregated FE analysis, our elasticity estimates ranges are the following for the different splits:

- 'Business': the business elasticity estimates range from ***0.36*** to ***0.41***.
- 'Charities': the charities elasticity estimates range from ***0.31*** to ***0.35***.
- 'Overseas': the overseas elasticity estimates range from ***0.42*** to ***0.93***.

So, our overall elasticity estimate ranges for the disaggregated analysis of the different types of private funding are:

- For UK business funding our elasticity estimates range from ***0.36*** to ***0.78***.
- For UK charities our elasticity estimates range from ***0.31*** to ***0.74***.
- For overseas investment our elasticity estimates range from ***0.42*** to ***1.10***.

Analysis by type of public funding

We also analysed whether the elasticity of private funding with respect to public funding varied according to the type of public funding received, i.e. (i) Research Councils funding and (ii) UK central government bodies, local authorities, health and hospital authorities, and QR related research funding. In short, we have divided public funding into two distinct funding streams: RCs and other government funding. Rather than performing the same analysis as above, we have estimated the relationship between total private and total public funding, as well as the relationship of the percentage of public funding that relates to RCs to total private funding.

Pooled OLS

The table below shows the results of the analysis with respect to total private funding and public funding, and the percentage thereof that relates to RCs. The results of the analysis suggest that there is a significant statistical difference between total public and only RC-related funding of research. This difference holds when the sample is split into RG and Non-RG, too, with RG elasticity estimates being lower than Non-RG ones:

Table 34

	Model 8	**Model 8.1 (RG)**	**Model 8.2 (Non-RG)**
ln(public funding)$_{it}$	0.78*** (0.03)	0.64*** (0.09)	0.75*** (0.03)
(RC percentage of public funding)$_{it}$	0.90*** (0.20)	0.35 (0.27)	0.87*** (0.23)
ln(Medical and Human Sciences)$_{it}$	0.15*** (0.03)	0.54*** (0.05)	0.10*** (0.03)
ln(Life Sciences)$_{it}$	0.05** (0.03)	0.19*** (0.04)	0.07*** (0.03)
ln(Engineering and Physical Sciences)$_{it}$	0.10*** (0.03)	0.04 (0.05)	0.12*** (0.03)
ln(Humanities)$_{it}$	-0.49***	0.06	-0.61***

	(0.07)	(0.05)	(0.10)
ln(quality)it	0.04 (0.07)	0.73*** (0.08)	-0.09 (0.09)
ln(total staff FTE)it	0.23* (0.12)	-0.80*** (0.22)	0.38** (0.15)
ln(fixed capital)it	0.82*** (0.20)	0.56*** (0.18)	0.93*** (0.24)
Dummy_Peer2	-0.24*** (0.08)	omitted	omitted
Dummy_Peer3	-0.29*** (0.10)	omitted	-0.09 (0.08)
Dummy_Peer4	-0.04 (0.14)	omitted	0.12 (0.11)
Dummy_Peer5	-0.45*** (0.14)	omitted	-0.31** (0.13)
Dummy_Peer6	-0.26 (0.18)	omitted	-0.10 (0.16)
Dummy_Peer7	-0.15 (0.20)	omitted	-0.00 (0.19)
R-squared	0.92	0.92	0.85

Statistically significant at the 10% level, 5% level** and 1% level***.*

Panel

Similarly to the aggregated and private disaggregated analysis, we have further controlled for HEI-specific effect by using a FE specification using the whole sample, and splitting the sample up into RG and Non-RG, too. Here, the RC proportion of public funding is statistically insignificant, and indicates that total public funding and only RC-related public funding are not statistically different from each other. However, public funding still has a positive effect on total private funding, and although in this specification RC and public funding are not different from each other, they still have a positive effect on private funding:

Table 35

	Model 9	Model 9.1 (RG)	Model 9.2 (Non-RG)
ln(public funding)it	0.25*** (0.05)	0.53*** (0.09)	0.24*** (0.06)
(RC percentage of public funding)it	-0.02 (0.23)	0.39 (0.31)	-0.07 (0.27)
ln(Medical and Human Sciences)it	0.09	0.21**	0.08

	(0.08)	(0.09)	(0.09)
ln(Life Sciences)$_{it}$	-0.03 (0.04)	-0.02 (0.07)	-0.03 (0.05)
ln(Engineering and Physical Sciences)$_{it}$	-0.08 (0.06)	0.64*** (0.18)	-0.08 (0.07)
ln(Humanities)$_{it}$	0.06 (0.14)	-0.15 (0.12)	0.09 (0.17)
ln(quality)$_{it}$	-0.39*** (0.14)	0.20 (0.17)	-0.41** (0.16)
ln(total staff FTE)$_{it}$	0.50** (0.22)	-0.33 (0.29)	0.48* (0.25)
ln(fixed capital)$_{it}$	0.98*** (0.17)	0.67*** (0.12)	1.01*** (0.20)
Dummy_Peer2	omitted	omitted	omitted
Dummy_Peer3	omitted	omitted	omitted
Dummy_Peer4	omitted	omitted	omitted
Dummy_Peer5	omitted	omitted	omitted
Dummy_Peer6	omitted	omitted	omitted
Dummy_Peer7	omitted	omitted	omitted
R-squared	0.75	0.70	0.56

Statistically significant at the 10% level, 5% level** and 1% level***.*

So, in the disaggregated analysis by type of public funding our ***overall*** results are inconclusive, as under POLS there is a statistical difference between the RC-proportion of total public funding and total public funding, whereas under an FE specification there is no such statistical difference between them.

Further, the correlation between RC-only funding and all other public funding is 0.96, indicating that it would be very had to disentangle the specific effects relating to each one of those funding streams.

Addendum A

Model 1

Source	SS	df	MS
Model	6700.01444	1	6700.01444
Residual	1264.11134	1493	.846692123
Total	7964.12578	1494	5.33074015

Number of obs	=	1495
F(1, 1493)	=	7913.16
Prob > F	=	0.0000
R-squared	=	0.8413
Adj R-squared	=	0.8412
Root MSE	=	.92016

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.9937713	.0111715	88.96	0.000	.9718578	1.015685
_cons	-.9935823	.0985975	-10.08	0.000	-1.186987	-.800178

Model 2

Source	SS	df	MS
Model	3729.49388	8	466.186736
Residual	465.353737	1069	.435316873
Total	4194.84762	1077	3.89493744

Number of obs	=	1078
F(8, 1069)	=	1070.91
Prob > F	=	0.0000
R-squared	=	0.8891
Adj R-squared	=	0.8882
Root MSE	=	.65979

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7372164	.0249096	29.60	0.000	.6883391	.7860937
lmhs	.0678418	.0275974	2.46	0.014	.0136906	.121993
lls	.121824	.0263871	4.62	0.000	.0700475	.1736004
lengphy	.1431236	.0272679	5.25	0.000	.0896189	.1966283
lhum	-.5561367	.0756697	-7.35	0.000	-.7046147	-.4076587
lqua	.3816522	.0629596	6.06	0.000	.2581137	.5051907
ltotfte	.2853933	.1279918	2.23	0.026	.0342498	.5365369
lfc	1.175391	.2315983	5.08	0.000	.720952	1.62983
_cons	-12.05335	2.748176	-4.39	0.000	-17.44579	-6.660921

Model 3

Source	SS	df	MS
Model	3767.44763	14	269.103402
Residual	346.866744	1052	.32972124
Total	4114.31437	1066	3.85958196

Number of obs =	1067
F(14, 1052) =	816.15
Prob > F =	0.0000
R-squared =	0.9157
Adj R-squared =	0.9146
Root MSE =	.57421

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.8155554	.0327378	24.91	0.000	.7513166	.8797942
lmhs	.1292652	.0266718	4.85	0.000	.0769292	.1816011
lls	.0677319	.0258298	2.62	0.009	.017048	.1184157
lengphy	.1153056	.0260524	4.43	0.000	.064185	.1664261
lhum	-.521447	.0699935	-7.45	0.000	-.6587897	-.3841042
lqua	.0306581	.073759	0.42	0.678	-.1140734	.1753895
ltotfte	.2592202	.1232162	2.10	0.036	.0174428	.5009977
lfc	.8345481	.2049867	4.07	0.000	.4323187	1.236777
_Ipeer_2	-.2127022	.0810724	-2.62	0.009	-.3717843	-.0536202
_Ipeer_3	-.3255297	.1047481	-3.11	0.002	-.5310686	-.1199908
_Ipeer_4	-.0901988	.117723	-0.77	0.444	-.3211973	.1407997
_Ipeer_5	-.4922252	.1399436	-3.52	0.000	-.7668256	-.2176247
_Ipeer_6	-.2731751	.1797164	-1.52	0.129	-.6258184	.0794683
_Ipeer_7	-.170002	.2034435	-0.84	0.404	-.5692033	.2291993
_cons	-9.316082	2.422242	-3.85	0.000	-14.06906	-4.563107

Model 3.1

Source	SS	df	MS
Model	86.7510649	8	10.8438831
Residual	7.39730115	199	.037172368
Total	94.1483661	207	.454823025

Number of obs =	208
F(8, 199) =	291.72
Prob > F =	0.0000
R-squared =	0.9214
Adj R-squared =	0.9183
Root MSE =	.1928

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.6420764	.0955698	6.72	0.000	.4536168	.830536
lmhs	.5458615	.0517875	10.54	0.000	.4437388	.6479842
lls	.2131909	.0399588	5.34	0.000	.134394	.2919879
lengphy	.0625373	.0478727	1.31	0.193	-.0318656	.1569402
lhum	.0669681	.0505736	1.32	0.187	-.0327608	.1666971
lqua	.7505829	.0814085	9.22	0.000	.5900488	.911117
ltotfte	-.8512524	.2174272	-3.92	0.000	-1.280009	-.4224954
lfc	.582748	.1781688	3.27	0.001	.2314068	.9340892
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-1.117237	2.04595	-0.55	0.586	-5.151761	2.917288

Model 3.2

Source	SS	df	MS
Model	1855.25598	13	142.711998
Residual	324.430592	845	.383941529
Total	2179.68657	858	2.54042724

Number of obs	=	859
F(13, 845)	=	371.70
Prob > F	=	0.0000
R-squared	=	0.8512
Adj R-squared	=	0.8489
Root MSE	=	.61963

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7789207	.0363747	21.41	0.000	.7075253	.8503161
lmhs	.0878295	.0303568	2.89	0.004	.0282459	.147413
lls	.0859199	.0293676	2.93	0.004	.028278	.1435618
lengphy	.1298561	.0293328	4.43	0.000	.0722823	.1874299
lhum	-.6336199	.0978805	-6.47	0.000	-.8257373	-.4415025
lqua	-.1046825	.0955108	-1.10	0.273	-.2921489	.0827838
ltotfte	.4169525	.1549115	2.69	0.007	.1128961	.7210089
lfc	.9482212	.2453896	3.86	0.000	.4665765	1.429866
_Ipeer_2	0	(omitted)				
_Ipeer_3	-.1605363	.0835491	-1.92	0.055	-.3245245	.0034519
_Ipeer_4	.0355308	.1055251	0.34	0.736	-.1715913	.2426528
_Ipeer_5	-.3898417	.1255539	-3.10	0.002	-.6362758	-.1434076
_Ipeer_6	-.1578744	.1651778	-0.96	0.339	-.4820813	.1663324
_Ipeer_7	-.0653783	.192252	-0.34	0.734	-.4427257	.3119691
_cons	-11.26219	2.898194	-3.89	0.000	-16.95069	-5.573687

Hausman test

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
lpub	.1977993	.5452403	-.3474409	.0285738
lmhs	.102918	.055087	.047831	.0563253
lls	-.0211124	.0754982	-.0966106	.0218884
lengphy	-.0623372	.1318523	-.1941895	.0470007
lhum	.0749691	-.7621297	.8370988	.0932763
lqua	-.448614	.0293564	-.4779704	.0985025
ltotfte	.5193513	.9979018	-.4785505	.1193178
lfc	1.025612	1.028643	-.0030319	.0301433

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(8) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 142.01
Prob>chi2 = 0.0000
(V_b-V_B is not positive definite)

Model 4

```
Fixed-effects (within) regression               Number of obs      =      1067
Group variable: id                              Number of groups   =       113

R-sq:  within  = 0.1751                         Obs per group: min =         1
       between = 0.8085                                        avg =       9.4
       overall = 0.7487                                        max =        10

                                                F(8,946)           =     25.09
corr(u_i, Xb)  = 0.7669                         Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.2548408	.0520387	4.90	0.000	.1527162	.3569653
lmhs	.0890021	.077836	1.14	0.253	-.0637491	.2417534
lls	-.0292181	.044743	-0.65	0.514	-.117025	.0585889
lengphy	-.0779431	.0653013	-1.19	0.233	-.2060953	.0502092
lhum	.0609258	.1416831	0.43	0.667	-.2171237	.3389753
lqua	-.3948042	.1430575	-2.76	0.006	-.6755509	-.1140575
ltotfte	.4956912	.2163303	2.29	0.022	.0711485	.9202339
lfc	.9835507	.167345	5.88	0.000	.6551403	1.311961
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-10.97275	1.922384	-5.71	0.000	-14.74538	-7.200115
sigma_u	1.4881453					
sigma_e	.40181573					
rho	.93204811	(fraction of variance due to u_i)				

F test that all u_i=0:   F(112, 946) =   11.62   Prob > F = 0.0000

Model 4.1

```
Fixed-effects (within) regression               Number of obs      =       208
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.7543                         Obs per group: min =         9
       between = 0.7058                                        avg =       9.9
       overall = 0.7095                                        max =        10

                                                F(8,179)           =     68.67
corr(u_i, Xb)  = -0.0105                        Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.577017	.0862287	6.69	0.000	.4068614	.7471726
lmhs	.2176668	.0869485	2.50	0.013	.0460909	.3892428
lls	-.0221244	.0660241	-0.34	0.738	-.1524102	.1081613
lengphy	.6477117	.1783577	3.63	0.000	.2957574	.9996659
lhum	-.1287859	.1233133	-1.04	0.298	-.3721207	.1145488
lqua	.2251144	.1747201	1.29	0.199	-.1196617	.5698906
ltotfte	-.3926681	.2907931	-1.35	0.179	-.9664918	.1811556
lfc	.6364135	.1195546	5.32	0.000	.4004958	.8723312
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-4.608805	1.639963	-2.81	0.006	-7.844952	-1.372657
sigma_u	.35639506					
sigma_e	.10849867					
rho	.91518112	(fraction of variance due to u_i)				

F test that all u_i=0: F(20, 179) = 22.47 Prob > F = 0.0000

Model 4.2

```
Fixed-effects (within) regression               Number of obs      =       859
Group variable: id                              Number of groups   =        92

R-sq:  within  = 0.1506                         Obs per group: min =         1
       between = 0.6563                                        avg =       9.3
       overall = 0.5673                                        max =        10

                                                F(8,759)           =     16.82
corr(u_i, Xb)  = 0.5979                         Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.241504	.0588268	4.11	0.000	.1260213	.3569866
lmhs	.0812544	.0894927	0.91	0.364	-.0944281	.2569369
lls	-.0287113	.0505824	-0.57	0.570	-.1280094	.0705868
lengphy	-.0782846	.0732212	-1.07	0.285	-.2220247	.0654554
lhum	.0880185	.1690746	0.52	0.603	-.2438908	.4199279
lqua	-.4157716	.1649746	-2.52	0.012	-.7396323	-.0919109
ltotfte	.4734992	.2492806	1.90	0.058	-.0158621	.9628605
lfc	1.011999	.2029097	4.99	0.000	.6136682	1.41033
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-11.66506	2.337182	-4.99	0.000	-16.25317	-7.076953
sigma_u	1.2816137					
sigma_e	.44454179					
rho	.89260806	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(91, 759) =    10.50             Prob > F = 0.0000
```

Model 5

Source	SS	df	MS
Model	2840.4968	14	202.892629
Residual	668.266813	1006	.664281126
Total	3508.76362	1020	3.43996433

Number of obs	=	1021
F(14, 1006)	=	305.43
Prob > F	=	0.0000
R-squared	=	0.8095
Adj R-squared	=	0.8069
Root MSE	=	.81503

lbus	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7834304	.0527678	14.85	0.000	.6798828	.886978
lmhs	.1801825	.0393581	4.58	0.000	.1029491	.2574158
lls	-.0414869	.0382061	-1.09	0.278	-.1164597	.0334859
lengphy	.2580032	.0407058	6.34	0.000	.1781252	.3378813
lhum	-.6658363	.1005684	-6.62	0.000	-.8631843	-.4684884
lqua	.1653483	.1061256	1.56	0.120	-.0429047	.3736012
ltotfte	.2112898	.1815742	1.16	0.245	-.1450178	.5675974
lfc	.3771726	.298065	1.27	0.206	-.2077279	.962073
_Ipeer_2	-.1454989	.1176624	-1.24	0.217	-.3763908	.0853931
_Ipeer_3	-.0140852	.1551341	-0.09	0.928	-.3185088	.2903383
_Ipeer_4	.125485	.1768043	0.71	0.478	-.2214624	.4724325
_Ipeer_5	-.2264309	.214667	-1.05	0.292	-.6476774	.1948155
_Ipeer_6	.0426889	.2691392	0.16	0.874	-.4854496	.5708274
_Ipeer_7	-.1238994	.3073648	-0.40	0.687	-.727049	.4792503
_cons	-4.454846	3.516042	-1.27	0.205	-11.35446	2.444771

Model 5.1

Source	SS	df	MS
Model	55.0861008	8	6.8857626
Residual	23.1791368	199	.116478075
Total	78.2652377	207	.378092936

Number of obs	=	208
F(8, 199)	=	59.12
Prob > F	=	0.0000
R-squared	=	0.7038
Adj R-squared	=	0.6919
Root MSE	=	.34129

lbus	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.3307502	.1691737	1.96	0.052	-.002853	.6643533
lmhs	.3401845	.091672	3.71	0.000	.1594112	.5209578
lls	.1712735	.0707333	2.42	0.016	.0317904	.3107565
lengphy	.0755535	.0847422	0.89	0.374	-.0915545	.2426615
lhum	-.3185273	.0895233	-3.56	0.000	-.4950633	-.1419914
lqua	-.0248815	.144106	-0.17	0.863	-.3090522	.2592892
ltotfte	.5498621	.3848805	1.43	0.155	-.2091054	1.30883
lfc	-.2362568	.3153869	-0.75	0.455	-.8581861	.3856726
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	1.251281	3.621654	0.35	0.730	-5.890463	8.393025

Model 5.2

Source	SS	df	MS
Model	1330.91889	13	102.378376
Residual	624.554579	799	.781670312
Total	1955.47347	812	2.40821856

Number of obs	= 813
F(13, 799)	= 130.97
Prob > F	= 0.0000
R-squared	= 0.6806
Adj R-squared	= 0.6754
Root MSE	= .88412

lbus	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.787323	.0593338	13.27	0.000	.6708545	.9037916
lmhs	.1469745	.0450599	3.26	0.001	.0585247	.2354244
lls	-.0711485	.0438312	-1.62	0.105	-.1571863	.0148894
lengphy	.2356507	.0463428	5.08	0.000	.1446828	.3266187
lhum	-1.027864	.1416969	-7.25	0.000	-1.306006	-.7497222
lqua	.4282908	.1386225	3.09	0.002	.1561834	.7003981
ltotfte	.6138451	.2289066	2.68	0.007	.1645158	1.063174
lfc	.6538231	.3603759	1.81	0.070	-.0535723	1.361219
_Ipeer_2	-.1138503	.2928335	-0.39	0.698	-.6886642	.4609635
_Ipeer_3	.1033662	.275824	0.37	0.708	-.4380591	.6447914
_Ipeer_4	.3848335	.2732572	1.41	0.159	-.1515533	.9212202
_Ipeer_5	-.0184486	.2581343	-0.07	0.943	-.5251501	.488253
_Ipeer_6	.2669389	.275156	0.97	0.332	-.2731751	.8070529
_Ipeer_7	0	(omitted)				
_cons	-7.616162	4.265085	-1.79	0.075	-15.98826	.7559334

Model 5.3

```
Fixed-effects (within) regression               Number of obs      =       208
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.1659                         Obs per group: min =         9
       between = 0.4503                                        avg =       9.9
       overall = 0.3990                                        max =        10

                                                F(8,179)           =      4.45
corr(u_i, Xb)  = -0.4287                        Prob > F           =    0.0001

------------------------------------------------------------------------------
        lbus |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lpub |   .4202198   .1948554     2.16   0.032     .0357106    .8047289
        lmhs |   .3211638   .1964819     1.63   0.104    -.0665551    .7088826
         lls |   .2561194    .149198     1.72   0.088    -.0382939    .5505327
     lengphy |   1.187586   .4030439     2.95   0.004     .3922577    1.982915
        lhum |  -.0643244   .2786572    -0.23   0.818    -.6142002    .4855514
        lqua |  -.0045427   .3948238    -0.01   0.991    -.7836507    .7745652
     ltotfte |  -1.428387   .6571198    -2.17   0.031    -2.725085   -.1316883
         lfc |   .1034783   .2701635     0.38   0.702    -.4296368    .6365934
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |   3.601648   3.705906     0.97   0.332    -3.711237    10.91453
-------------+----------------------------------------------------------------
     sigma_u |  .47305261
     sigma_e |   .2451799
         rho |   .7882533   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(20, 179) =    10.33             Prob > F = 0.0000
```

Model 5.4

```
Fixed-effects (within) regression               Number of obs      =       813
Group variable: id                              Number of groups   =        91

R-sq:  within  = 0.0513                         Obs per group: min =         1
       between = 0.4344                                        avg =       8.9
       overall = 0.4372                                        max =        10

                                                F(8,714)           =      4.82
corr(u_i, Xb)  = 0.4586                         Prob > F           =    0.0000
```

lbus	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.367038	.0944312	3.89	0.000	.181642	.552434
lmhs	-.1430897	.1335757	-1.07	0.284	-.4053378	.1191584
lls	-.0100002	.075037	-0.13	0.894	-.1573197	.1373192
lengphy	-.1752118	.1450315	-1.21	0.227	-.459951	.1095273
lhum	-.1533017	.2414073	-0.64	0.526	-.6272547	.3206513
lqua	-.0427682	.2523216	-0.17	0.865	-.5381491	.4526127
ltotfte	.5524806	.362869	1.52	0.128	-.1599371	1.264898
lfc	.4914646	.2969047	1.66	0.098	-.0914462	1.074375
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-4.789136	3.52055	-1.36	0.174	-11.701	2.122731
sigma_u	1.3155471					
sigma_e	.62461421					
rho	.81604036	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(90, 714) =     10.42           Prob > F = 0.0000
```

Model 6

Source	SS	df	MS
Model	4540.5303	14	324.323593
Residual	516.728809	1032	.500706211
Total	5057.25911	1046	4.83485575

Number of obs =	1047
F(14, 1032) =	647.73
Prob > F =	0.0000
R-squared =	0.8978
Adj R-squared =	0.8964
Root MSE =	.70761

lchar	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.74948	.0419079	17.88	0.000	.6672455	.8317144
lmhs	.2514884	.0331599	7.58	0.000	.1864199	.316557
lls	.1067237	.0334417	3.19	0.001	.0411022	.1723452
lengphy	-.2324017	.032942	-7.05	0.000	-.2970426	-.1677608
lhum	-.3490113	.086533	-4.03	0.000	-.518812	-.1792106
lqua	.3376623	.0918205	3.68	0.000	.1574862	.5178385
ltotfte	.5785373	.1533361	3.77	0.000	.2776511	.8794236
lfc	.1692614	.255579	0.66	0.508	-.3322525	.6707753
_Ipeer_2	-.4736739	.1005294	-4.71	0.000	-.6709393	-.2764085
_Ipeer_3	-.7644008	.1305162	-5.86	0.000	-1.020508	-.5082932
_Ipeer_4	-.7143857	.1475226	-4.84	0.000	-1.003864	-.4249073
_Ipeer_5	-.9352261	.1757628	-5.32	0.000	-1.280119	-.5903328
_Ipeer_6	-1.010169	.2239356	-4.51	0.000	-1.44959	-.5707479
_Ipeer_7	-.9689907	.2545469	-3.81	0.000	-1.468479	-.4695021
_cons	-3.555384	3.012313	-1.18	0.238	-9.466342	2.355574

Model 6.1

Source	SS	df	MS
Model	110.303938	8	13.7879923
Residual	17.5013456	199	.08794646
Total	127.805284	207	.617416831

Number of obs =	208
F(8, 199) =	156.78
Prob > F =	0.0000
R-squared =	0.8631
Adj R-squared =	0.8576
Root MSE =	.29656

lchar	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.4228853	.1470009	2.88	0.004	.1330059	.7127646
lmhs	.6113955	.079657	7.68	0.000	.4543153	.7684756
lls	.2517453	.0614626	4.10	0.000	.1305436	.3729469
lengphy	-.1687264	.0736354	-2.29	0.023	-.3139323	-.0235205
lhum	.1743404	.0777899	2.24	0.026	.0209422	.3277386
lqua	1.29581	.1252187	10.35	0.000	1.048884	1.542736
ltotfte	-.7017349	.3344359	-2.10	0.037	-1.361228	-.0422418
lfc	.1031925	.2740506	0.38	0.707	-.4372234	.6436084
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	6.119888	3.14698	1.94	0.053	-.0858202	12.3256

Model 6.2

Source	SS	df	MS
Model	1770.13025	13	136.163866
Residual	485.951344	825	.589031932
Total	2256.0816	838	2.69222148

Number of obs	=	839
F(13, 825)	=	231.17
Prob > F	=	0.0000
R-squared	=	0.7846
Adj R-squared	=	0.7812
Root MSE	=	.76748

lchar	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7210848	.0469203	15.37	0.000	.6289877	.8131819
lmhs	.2223614	.0379836	5.85	0.000	.1478055	.2969173
lls	.1262051	.0384753	3.28	0.001	.0506842	.201726
lengphy	-.2205923	.0373552	-5.91	0.000	-.2939147	-.14727
lhum	-.3983994	.1217726	-3.27	0.001	-.6374199	-.1593788
lqua	.1755668	.1199721	1.46	0.144	-.0599197	.4110533
ltotfte	.6935893	.1935243	3.58	0.000	.3137313	1.073447
lfc	.2894386	.3082154	0.94	0.348	-.3155401	.8944173
_Ipeer_2	0	(omitted)				
_Ipeer_3	-.3367082	.1042623	-3.23	0.001	-.5413587	-.1320576
_Ipeer_4	-.3472535	.1330422	-2.61	0.009	-.6083946	-.0861124
_Ipeer_5	-.5616588	.1587405	-3.54	0.000	-.8732415	-.250076
_Ipeer_6	-.6093596	.2073535	-2.94	0.003	-1.016362	-.2023572
_Ipeer_7	-.573753	.2418818	-2.37	0.018	-1.048529	-.0989769
_cons	-6.104009	3.630473	-1.68	0.093	-13.23006	1.022042

Model 6.3

```
Fixed-effects (within) regression               Number of obs      =       208
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.6195                         Obs per group: min =         9
       between = 0.7924                                        avg =       9.9
       overall = 0.7568                                        max =        10

                                                F(8,179)           =     36.43
corr(u_i, Xb)  = 0.6750                         Prob > F           =    0.0000

------------------------------------------------------------------------------
       lchar |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lpub |   .3732106   .0815336     4.58   0.000       .21232    .5341013
        lmhs |    .277142   .0822142     3.37   0.001     .1149083    .4393757
         lls |  -.0455987   .0624291    -0.73   0.466    -.1687905     .077593
     lengphy |  -.2349478   .1686461    -1.39   0.165    -.5677381    .0978425
        lhum |   .0849566   .1165989     0.73   0.467    -.1451286    .3150418
        lqua |    .288596   .1652066     1.75   0.082    -.0374071    .6145991
     ltotfte |   .0229859   .2749595     0.08   0.933    -.5195931    .5655649
         lfc |   .2009458   .1130448     1.78   0.077    -.0221262    .4240178
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |   2.932401   1.550667     1.89   0.060    -.1275385    5.992341
-------------+----------------------------------------------------------------
     sigma_u |  .52202932
     sigma_e |  .10259093
         rho |  .96281474   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(20, 179) =    74.19             Prob > F = 0.0000
```

Model 6.4

```
Fixed-effects (within) regression               Number of obs      =       839
Group variable: id                              Number of groups   =        92

R-sq:  within  = 0.0897                         Obs per group: min =         1
       between = 0.4803                                        avg =       9.1
       overall = 0.5024                                        max =        10

                                                F(8,739)           =      9.11
corr(u_i, Xb)  = 0.5236                         Prob > F           =    0.0000
```

lchar	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.3098268	.0733925	4.22	0.000	.1657442	.4539094
lmhs	-.1671314	.1090946	-1.53	0.126	-.3813037	.0470409
lls	-.0215888	.0654962	-0.33	0.742	-.1501696	.1069919
lengphy	-.2500408	.0895082	-2.79	0.005	-.4257614	-.0743201
lhum	-.0714357	.2037441	-0.35	0.726	-.4714218	.3285504
lqua	.2038694	.2032569	1.00	0.316	-.1951604	.6028992
ltotfte	.6232965	.3055397	2.04	0.042	.0234673	1.223126
lfc	.7580753	.2474954	3.06	0.002	.2721975	1.243953
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-7.143487	2.829214	-2.52	0.012	-12.69774	-1.589232
sigma_u	1.4048391					
sigma_e	.5319407					
rho	.87460373	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(91, 739) =    11.10             Prob > F = 0.0000
```

Model 7

Source	SS	df	MS
Model	3383.38264	14	241.670188
Residual	660.172772	1015	.650416525
Total	4043.55541	1029	3.92959709

Number of obs	= 1030
F(14, 1015)	= 371.56
Prob > F	= 0.0000
R-squared	= 0.8367
Adj R-squared	= 0.8345
Root MSE	= .80648

labr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.8927394	.0495343	18.02	0.000	.795538	.9899408
lmhs	.0741549	.0381081	1.95	0.052	-.0006247	.1489345
lls	.0556903	.0386192	1.44	0.150	-.0200923	.131473
lengphy	.2787054	.0405116	6.88	0.000	.1992094	.3582015
lhum	-.4511563	.1000872	-4.51	0.000	-.6475578	-.2547549
lqua	-.0790655	.1048145	-0.75	0.451	-.2847434	.1266123
ltotfte	.0872828	.1788993	0.49	0.626	-.263772	.4383376
lfc	2.003146	.2924997	6.85	0.000	1.429173	2.577119
_Ipeer_2	.1463098	.1146974	1.28	0.202	-.0787614	.371381
_Ipeer_3	.0822343	.1492328	0.55	0.582	-.2106057	.3750744
_Ipeer_4	.3606013	.1686771	2.14	0.033	.0296056	.6915971
_Ipeer_5	-.1015253	.2007313	-0.51	0.613	-.4954211	.2923705
_Ipeer_6	.1443868	.2612499	0.55	0.581	-.3682648	.6570385
_Ipeer_7	.1141255	.291262	0.39	0.695	-.4574192	.6856701
_cons	-25.11888	3.451088	-7.28	0.000	-31.89097	-18.3468

Model 7.1

Source	SS	df	MS
Model	101.485644	8	12.6857055
Residual	16.9255117	199	.085052822
Total	118.411155	207	.572034567

Number of obs	= 208
F(8, 199)	= 149.15
Prob > F	= 0.0000
R-squared	= 0.8571
Adj R-squared	= 0.8513
Root MSE	= .29164

labr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	1.203895	.1445623	8.33	0.000	.9188244	1.488966
lmhs	.4673484	.0783356	5.97	0.000	.312874	.6218228
lls	.1646255	.060443	2.72	0.007	.0454344	.2838165
lengphy	.3298087	.0724139	4.55	0.000	.1870116	.4726058
lhum	.0113876	.0764994	0.15	0.882	-.1394659	.1622412
lqua	.3428374	.1231414	2.78	0.006	.1000078	.5856669
ltotfte	-1.499858	.3288881	-4.56	0.000	-2.148411	-.8513046
lfc	1.810143	.2695045	6.72	0.000	1.278692	2.341594
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-19.06437	3.094776	-6.16	0.000	-25.16713	-12.9616

Model 7.2

Source	SS	df	MS
Model	1894.80414	13	145.754164
Residual	632.992024	808	.78340597
Total	2527.79616	821	3.07892346

Number of obs	=	822
F(13, 808)	=	186.05
Prob > F	=	0.0000
R-squared	=	0.7496
Adj R-squared	=	0.7456
Root MSE	=	.8851

labr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.8528263	.0560761	15.21	0.000	.7427542	.9628983
lmhs	.0432211	.0442934	0.98	0.329	-.0437227	.1301648
lls	.082654	.0449712	1.84	0.066	-.0056203	.1709282
lengphy	.2973243	.0466398	6.37	0.000	.2057748	.3888738
lhum	-.4633813	.1430622	-3.24	0.001	-.7441986	-.182564
lqua	-.2627932	.1384224	-1.90	0.058	-.5345031	.0089166
ltotfte	.1286226	.2294407	0.56	0.575	-.3217475	.5789926
lfc	1.993694	.3574276	5.58	0.000	1.292098	2.69529
_Ipeer_2	.1576926	.2803607	0.56	0.574	-.3926287	.7080138
_Ipeer_3	.0256789	.2682693	0.10	0.924	-.5009081	.5522659
_Ipeer_4	.231695	.2676066	0.87	0.387	-.2935911	.756981
_Ipeer_5	-.2454653	.2539162	-0.97	0.334	-.7438785	.2529479
_Ipeer_6	.0039084	.2684046	0.01	0.988	-.5229442	.5307609
_Ipeer_7	0	(omitted)				
_cons	-25.32662	4.229381	-5.99	0.000	-33.62849	-17.02475

Model 7.3

```
Fixed-effects (within) regression               Number of obs      =       208
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.8252                         Obs per group: min =         9
       between = 0.7427                                        avg =       9.9
       overall = 0.7384                                        max =        10

                                                F(8,179)           =    105.64
corr(u_i, Xb)  = -0.6760                        Prob > F           =    0.0000
```

labr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	1.183944	.137346	8.62	0.000	.9129182	1.454969
lmhs	.2325576	.1384924	1.68	0.095	-.0407303	.5058455
lls	-.0139701	.1051639	-0.13	0.894	-.2214905	.1935504
lengphy	1.052188	.2840899	3.70	0.000	.4915924	1.612785
lhum	-.2681495	.1964146	-1.37	0.174	-.6557354	.1194365
lqua	.0635172	.2782959	0.23	0.820	-.4856456	.61268
ltotfte	-.5184488	.4631782	-1.12	0.264	-1.432441	.3955432
lfc	1.418655	.1904277	7.45	0.000	1.042883	1.794427
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-23.23828	2.612149	-8.90	0.000	-28.39285	-18.08371
sigma_u	.48990024					
sigma_e	.17281775					
rho	.88933126	(fraction of variance due to u_i)				

F test that all u_i=0: F(20, 179) = 19.39 Prob > F = 0.0000

Model 7.4

```
Fixed-effects (within) regression               Number of obs      =       822
Group variable: id                              Number of groups   =        91

R-sq:  within  = 0.1614                         Obs per group: min =         1
       between = 0.5950                                        avg =       9.0
       overall = 0.5223                                        max =        10

                                                F(8,723)           =     17.39
corr(u_i, Xb)  = 0.3904                         Prob > F           =    0.0000
```

labr	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.3641689	.0927235	3.93	0.000	.1821295	.5462084
lmhs	.2944098	.1264693	2.33	0.020	.0461189	.5427007
lls	-.0814746	.0774815	-1.05	0.293	-.2335903	.0706411
lengphy	.2673085	.1286812	2.08	0.038	.014675	.519942
lhum	.179485	.238774	0.75	0.452	-.2892882	.6482583
lqua	-.7544558	.2458586	-3.07	0.002	-1.237138	-.2717738
ltotfte	.0917754	.3670741	0.25	0.803	-.6288829	.8124338
lfc	1.712202	.2874592	5.96	0.000	1.147847	2.276556
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-23.06478	3.384327	-6.82	0.000	-29.70906	-16.4205
sigma_u	1.3521881					
sigma_e	.61249217					
rho	.82975423	(fraction of variance due to u_i)				

F test that all u_i=0:   F(90, 723) =   11.21   Prob > F = 0.0000

Model 8

Source	SS	df	MS
Model	3773.97641	15	251.598427
Residual	340.337963	1051	.32382299
Total	4114.31437	1066	3.85958196

Number of obs	=	1067
F(15, 1051)	=	776.96
Prob > F	=	0.0000
R-squared	=	0.9173
Adj R-squared	=	0.9161
Root MSE	=	.56905

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7872249	.0330515	23.82	0.000	.7223706	.8520792
bispct	.9051462	.2015842	4.49	0.000	.5095929	1.3007
lmhs	.1468435	.0267205	5.50	0.000	.094412	.1992751
lls	.0521873	.0258308	2.02	0.044	.0015015	.1028731
lengphy	.1043158	.025934	4.02	0.000	.0534274	.1552042
lhum	-.4948928	.0696163	-7.11	0.000	-.6314954	-.3582901
lqua	.0384012	.0731166	0.53	0.600	-.1050699	.1818724
ltotfte	.2262223	.1223301	1.85	0.065	-.0138166	.4662613
lfc	.8177796	.2031793	4.02	0.000	.4190963	1.216463
_Ipeer_2	-.2404728	.0805817	-2.98	0.003	-.3985922	-.0823535
_Ipeer_3	-.2893757	.1041187	-2.78	0.006	-.4936799	-.0850714
_Ipeer_4	-.0431756	.1171343	-0.37	0.713	-.2730194	.1866682
_Ipeer_5	-.4491917	.1390171	-3.23	0.001	-.7219742	-.1764091
_Ipeer_6	-.260581	.1781238	-1.46	0.144	-.6100996	.0889377
_Ipeer_7	-.1468077	.2016818	-0.73	0.467	-.5425526	.2489372
_cons	-8.958746	2.401797	-3.73	0.000	-13.67161	-4.245882

Model 8.1

Source	SS	df	MS
Model	86.8143782	9	9.64604203
Residual	7.33398784	198	.037040343
Total	94.1483661	207	.454823025

Number of obs	=	208
F(9, 198)	=	260.42
Prob > F	=	0.0000
R-squared	=	0.9221
Adj R-squared	=	0.9186
Root MSE	=	.19246

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.6398199	.0954156	6.71	0.000	.4516587	.8279811
bispct	.353569	.2704357	1.31	0.193	-.1797351	.886873
lmhs	.539418	.0519299	10.39	0.000	.4370114	.6418246
lls	.1925517	.0428981	4.49	0.000	.107956	.2771474
lengphy	.0394806	.0509378	0.78	0.439	-.0609697	.139931
lhum	.0592293	.0508295	1.17	0.245	-.0410074	.159466
lqua	.7306752	.0826781	8.84	0.000	.5676325	.8937179
ltotfte	-.7962416	.2210816	-3.60	0.000	-1.232219	-.3602648
lfc	.5651351	.1783616	3.17	0.002	.2134029	.9168674
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-1.133917	2.042353	-0.56	0.579	-5.161473	2.893639

Model 8.2

Source	SS	df	MS
Model	1860.74138	14	132.910098
Residual	318.945195	844	.37789715
Total	2179.68657	858	2.54042724

Number of obs	=	859
F(14, 844)	=	351.71
Prob > F	=	0.0000
R-squared	=	0.8537
Adj R-squared	=	0.8512
Root MSE	=	.61473

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.7522926	.0367578	20.47	0.000	.6801451	.8244401
bispct	.8659732	.2272936	3.81	0.000	.4198461	1.3121
lmhs	.1043367	.0304269	3.43	0.001	.0446153	.164058
lls	.0726	.0293445	2.47	0.014	.0150033	.1301967
lengphy	.1207966	.029198	4.14	0.000	.0634873	.1781058
lhum	-.6085736	.0973292	-6.25	0.000	-.7996093	-.4175379
lqua	-.0861725	.0948805	-0.91	0.364	-.272402	.1000569
ltotfte	.3828427	.1539478	2.49	0.013	.0806772	.6850081
lfc	.9310946	.2434919	3.82	0.000	.4531739	1.409015
_Ipeer_2	0	(omitted)				
_Ipeer_3	-.0939191	.084713	-1.11	0.268	-.260192	.0723538
_Ipeer_4	.1156633	.106783	1.08	0.279	-.093928	.3252546
_Ipeer_5	-.3100743	.126309	-2.45	0.014	-.5579909	-.0621578
_Ipeer_6	-.1028371	.1645079	-0.63	0.532	-.4257296	.2200555
_Ipeer_7	-.0035665	.1914214	-0.02	0.985	-.3792843	.3721514
_cons	-10.90782	2.876794	-3.79	0.000	-16.55433	-5.261306

Model 9

```
Fixed-effects (within) regression               Number of obs      =      1067
Group variable: id                              Number of groups   =       113

R-sq:  within  = 0.1751                         Obs per group: min =         1
       between = 0.8069                                        avg =       9.4
       overall = 0.7469                                        max =        10

                                                F(9,945)           =     22.28
corr(u_i, Xb)  = 0.7655                         Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.2548457	.0520659	4.89	0.000	.1526675	.3570239
bispct	-.0240947	.233241	-0.10	0.918	-.4818248	.4336355
lmhs	.0894531	.077999	1.15	0.252	-.0636182	.2425243
lls	-.029426	.0448116	-0.66	0.512	-.1173677	.0585158
lengphy	-.0781765	.0653746	-1.20	0.232	-.2064726	.0501197
lhum	.0606776	.1417776	0.43	0.669	-.2175578	.3389129
lqua	-.3943486	.1432003	-2.75	0.006	-.6753759	-.1133213
ltotfte	.4965012	.2165855	2.29	0.022	.0714572	.9215453
lfc	.9840153	.167493	5.87	0.000	.6553141	1.312717
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-10.97629	1.923696	-5.71	0.000	-14.7515	-7.201078
sigma_u	1.4902478					
sigma_e	.402026					
rho	.9321606	(fraction of variance due to u_i)				

F test that all u_i=0:   F(112, 945) =   11.28   Prob > F = 0.0000

Model 9.1

```
Fixed-effects (within) regression               Number of obs      =       208
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.7565                         Obs per group: min =         9
       between = 0.6964                                        avg =       9.9
       overall = 0.7007                                        max =        10

                                                F(9,178)           =     61.44
corr(u_i, Xb)  = -0.0210                        Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.5318624	.0930783	5.71	0.000	.3481835	.7155412
bispct	.3906761	.3063909	1.28	0.204	-.2139499	.9953021
lmhs	.2112667	.0869419	2.43	0.016	.0396972	.3828362
lls	-.0167795	.0660422	-0.25	0.800	-.1471059	.1135468
lengphy	.6400193	.1781489	3.59	0.000	.2884637	.9915749
lhum	-.1488233	.1240973	-1.20	0.232	-.3937145	.0960678
lqua	.2043876	.1751713	1.17	0.245	-.1412921	.5500673
ltotfte	-.328261	.294648	-1.11	0.267	-.9097138	.2531918
lfc	.6725121	.122658	5.48	0.000	.4304611	.914563
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-5.046038	1.67263	-3.02	0.003	-8.346773	-1.745302
sigma_u	.36209247					
sigma_e	.10830949					
rho	.91787462	(fraction of variance due to u_i)				

F test that all u_i=0: F(20, 178) = 22.36 Prob > F = 0.0000

Model 9.2

```
Fixed-effects (within) regression               Number of obs      =       859
Group variable: id                              Number of groups   =        92

R-sq:  within  = 0.1506                         Obs per group: min =         1
       between = 0.6471                                        avg =       9.3
       overall = 0.5581                                        max =        10

                                                F(9,758)           =     14.94
corr(u_i, Xb)  = 0.5903                         Prob > F           =    0.0000
```

lother	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lpub	.241174	.0588752	4.10	0.000	.1255962	.3567517
bispct	-.072542	.2658618	-0.27	0.785	-.5944548	.4493709
lmhs	.0826322	.0896895	0.92	0.357	-.0934372	.2587016
lls	-.0292557	.0506526	-0.58	0.564	-.1286918	.0701804
lengphy	-.0790684	.0733221	-1.08	0.281	-.223007	.0648701
lhum	.0861753	.1693126	0.51	0.611	-.246202	.4185526
lqua	-.4136337	.1652611	-2.50	0.013	-.7380576	-.0892098
ltotfte	.4764941	.2496741	1.91	0.057	-.0136407	.9666289
lfc	1.014043	.2031717	4.99	0.000	.6151971	1.412889
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-11.67722	2.339032	-4.99	0.000	-16.26897	-7.085467
sigma_u	1.2884575					
sigma_e	.44481308					
rho	.8935088	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(91, 758) =     10.16            Prob > F = 0.0000
```

Addendum B

i. *Description of variables*

Variable code	Variable	Description
INSTID	**Institution identifier**	*Institution identifier (INSTID) is the unique identifier allocated to institutions by HESA.*
YEAR	**Year**	*This variable identifies the year of the observation. i.e. 2004 refers to the institutions' financial year 1 August 2003 to 31 July 2004.*
UKPUB	**UK public income**	*This variable comprises all UK public income of a HEI that relates to research activities. It is sourced from HESA financial data relating to "Research Grants and Contracts" and "Funding body grants for HE provision (SFC grants for all provision) Recurrent (Research)".*
OTHER	**Other income**	*This variable comprises all other income of a HEI that relates to research activities (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*

BUS	**Business income**	*This variable comprises all UK business income of a HEI that relates to research activities.*
CHAR	**Charities income**	*This variable comprises all UK charities income of a HEI that relates to research activities.*
ABR	**Abroad income**	*This variable comprises all income from abroad of a HEI that relates to research activities.*
INC	**Income**	*Total net income a HEI receives (i.e. total income less the share of income in joint ventures), as reported in the FSR.*
EXP	**Expenditure**	*Total expenditure of a HEI, as reported in the FSR.*
STAFFC	**Staff costs**	*This covers the costs of all staff for whom the institution is liable to pay Class 1 National Insurance contributions and/or who have a contract of employment with the institution, and includes any redundancy or restructuring payments (that are not treated as exceptional items) made to these staff.*
REG	**Region**	*This variable identifies a HEI's location and is constant over time. There are 12 different regions, according to HESA.*
PEER	**Peer group**	*This variable captures each HEI's peer group, and is a proxy for quality.*
ACSTFTE	**Academic staff FTE**	*Academic staff are defined as staff at least one of whose contracts of employment was for an academic function and whose contract activity can be categorised as 'Managers, directors and senior officials', 'Professional occupations' or 'Associate professional and technical occupations' as defined by the 2010 Standard Occupational Classification (SOC) major groups 1, 2 or 3. This may therefore include vice-chancellors and other senior academic managers, medical practitioners, dentists, veterinarians and other health care professionals whose contract of employment includes an academic function.* *The academic employment function may be teaching, research, teaching and research or neither teaching nor research (where an academic professional has taken up a senior administrative responsibility but there is no change to the academic function in their contract of employment).*
TOTSTFTE	**Total staff FTE**	*Staff full-time equivalent (FTE) is defined by the contract(s) of employment and is proportioned to each activity's cost centre. FTE indicates the proportion of a full-time year being undertaken over the course of the reporting period 1 August to 31 July. The FTE is therefore counted using a population of staff who were active during the reporting period, not just on a given snapshot date, and uses the HESA staff contract session population.*
MHSFTE	**Medical and human science staff FTE**	*Number of academic staff FTE working in the Medical and Human Sciences*
LSFTE	**Life science staff FTE**	*Number of academic staff FTE working in the Life Sciences*
EPFTE	**Engineering and physical science staff FTE**	*Number of academic staff FTE working in Engineering and Physical Sciences*
HUMFTE	**Humanities staff FTE**	*Number of academic staff FTE working in Humanities*
STUDFTE	**Total students FTE**	*Number of total students FTE*

RSTAFF	**Research staff**	*Number of staff working in "teaching and research" or "research only"*
TSTAFF	**Total staff**	*Number of totalstaff*
QUA	**Quality**	*This variable captures the "quality" of a HEI by dividing the number of academic staff FTE by the number of total students FTE*
W	**Aggregate wage-rate**	*This variable captures the aggregate wage-rate for a whole year, and is the same for all HEIs*
FC	**Fixed capital**	*ONS*
GDP	**Gross domestic product**	*ONS*

Addendum C

Regional variables:

Variable	Region code	Region
1	EAST	*East of England*
2	NEAST	*North East*
3	SEAS	*South East*
4	EMID	*East Midlands*
5	WMID	*West Midlands*
6	NWES	*North West*
7	SWES	*South West*
8	LOND	*London*
9	YORH	*Yorkshire and the Humber*
10	WALE	*Wales*
11	SCOT	*Scotland*
12	NIRE	*Northern Ireland*

Addendum D

Peer Groups and HEI codes:

Peer group	HEI codes	HEI
1	0110	*University of Birmingham*
1	0112	*University of Bristol*
1	0114	*University of Cambridge*
1	0188	*Institute of Cancer Research*
1	0132	*Imperial College London*
1	0134	*King's College London*

1	0124	*University of Leeds*
1	0125	*University of Leicester*
1	0126	*University of Liverpool*
1	0138	*London School of Hygiene & Tropical Medicine*
1	0204	*University of Manchester*
1	0154	*University of Newcastle upon Tyne*
1	0155	*University of Nottingham*
1	0156	*University of Oxford*
1	0139	*Queen Mary, University of London*
1	0145	*St George's Hospital Medical School*
1	0159	*University of Sheffield*
1	0160	*University of Southampton*
1	0149	*University College London*
1	0163	*University of Warwick*
1	0167	*University of Edinburgh*
1	0168	*University of Glasgow*
1	0184	*Queen's University Belfast*
1	0179	*Cardiff University*
2	0109	*University of Bath*
2	0127	*Birkbeck College*
2	0002	*Cranfield University*
2	0116	*University of Durham*
2	0117	*University of East Anglia*
2	0133	*Institute of Education*
2	0118	*University of Essex*
2	0119	*University of Exeter*
2	0131	*Goldsmiths College, University of London*
2	0121	*Keele University*
2	0122	*University of Kent*
2	0123	*Lancaster University*
2	0152	*Loughborough University*
2	0147	*School of Pharmacy*
2	0157	*University of Reading*
2	0141	*Royal Holloway, University of London*
2	0161	*University of Surrey*
2	0162	*University of Sussex*
2	0164	*University of York*

2	0170	*University of Aberdeen*
2	0172	*University of Dundee*
2	0171	*Heriot-Watt University*
2	0173	*University of St Andrews*
2	0169	*University of Strathclyde*
2	0185	*University of Ulster*
2	0178	*Bangor University*
2	0180	*Swansea University*
3	0108	*Aston University*
3	0111	*University of Bradford*
3	0051	*University of Brighton*
3	0113	*Brunel University*
3	0115	*City University, London*
3	0068	*De Montfort University*
3	0120	*University of Hull*
3	0065	*Liverpool John Moores University*
3	0135	*London Business School*
3	0137	*London School of Economics and Political Science*
3	0146	*School of Oriental and African Studies*
3	0073	*University of Plymouth*
3	0143	*Royal Veterinary College*
3	0158	*University of Salford*
3	0095	*University of Abertay Dundee*
3	0100	*Queen Margaret University Edinburgh*
3	0175	*Scottish Agricultural College*
3	0174	*University of Stirling*
3	0177	*Aberystwyth University*
3	0176	*University of Wales, Lampeter*
4	0052	*Birmingham City University*
4	0053	*University of Central Lancashire*
4	0059	*University of Greenwich*
4	0060	*University of Hertfordshire*
4	0063	*Kingston University*
4	0064	*Leeds Metropolitan University*
4	0151	*University of London*
4	0202	*London Metropolitan University*
4	0066	*Manchester Metropolitan University*

4	0067	*Middlesex University*
4	0069	*University of Northumbria at Newcastle*
4	0071	*Nottingham Trent University*
4	0001	*Open University*
4	0072	*Oxford Brookes University*
4	0074	*University of Portsmouth*
4	0075	*Sheffield Hallam University*
4	0081	*University of the West of England, Bristol*
4	0083	*University of Westminster*
4	0085	*University of Wolverhampton*
4	0107	*Edinburgh Napier University*
4	0106	*Glasgow Caledonian University*
4	0104	*Robert Gordon University*
4	0090	*University of Glamorgan*
5	0047	*Anglia Ruskin University*
5	0026	*University of Bedfordshire*
5	0049	*University of Bolton*
5	0050	*Bournemouth University*
5	0009	*Buckinghamshire New University*
5	0012	*Canterbury Christ Church University*
5	0011	*University of Chester*
5	0056	*Coventry University*
5	0038	*University of Cumbria*
5	0057	*University of Derby*
5	0058	*University of East London*
5	0016	*Edge Hill University*
5	0061	*University of Huddersfield*
5	0062	*University of Lincoln*
5	0023	*Liverpool Hope University*
5	0076	*London South Bank University*
5	0027	*University of Northampton*
5	0031	*Roehampton University*
5	0037	*Southampton Solent University*
5	0077	*Staffordshire University*
5	0078	*University of Sunderland*
5	0079	*University of Teesside*
5	0080	*The University of West London*

5	0105	*University of the West of Scotland*
6	0048	*Bath Spa University*
6	0200	*University College Birmingham*
6	0007	*Bishop Grosseteste University College, Lincoln*
6	0082	*University of Chichester*
6	0054	*University of Gloucestershire*
6	0018	*Harper Adams University College*
6	0040	*Leeds Trinity University College*
6	0028	*Newman University College*
6	0014	*University College Plymouth St Mark & St John*
6	0195	*Royal Agricultural College*
6	0039	*St Mary's University College*
6	0021	*University of Winchester*
6	0046	*University of Worcester*
6	0189	*Writtle College*
6	0013	*York St John University*
6	0196	*UHI Millennium Institute*
6	0089	*University of Wales Institute, Cardiff*
6	0086	*University of Wales, Newport*
6	0091	*Swansea Metropolitan University*
7	0197	*The Arts University College at Bournemouth*
7	0010	*Central School of Speech and Drama*
7	0201	*Courtauld Institute of Art*
7	0206	*University for the Creative Arts*
7	0199	*Conservatoire for Dance and Drama*
7	0017	*University College Falmouth*
7	0208	*Guildhall School of Music & Drama*
7	0205	*Heythrop College*
7	0207	*Leeds College of Music*
7	0209	*Liverpool Institute for Performing Arts*
7	0024	*University of the Arts London*
7	0190	*Norwich University College of the Arts*
7	0030	*Ravensbourne*
7	0032	*Rose Bruford College*
7	0033	*Royal Academy of Music*
7	0003	*Royal College of Art*
7	0034	*Royal College of Music*

7	0035	*Royal Northern College of Music*
7	0041	*Trinity Laban Conservatoire of Music and Dance*
7	0096	*Edinburgh College of Art*
7	0097	*Glasgow School of Art*
7	0101	*Royal Scottish Academy of Music and Drama*
7	0087	*Glyndwr University*
7	0092	*Trinity University College*
7	0186	*University of Wales*

12. Annex F – Extension of HESA analysis

This annex sets out the extension analysis of the Higher Education Statistics Agency (HESA) data.

12.1. Overview of the HESA data

This analysis is based on the income from research grants and contracts that HEIs report, split by individual subject area. It does not incorporate QR-related research funding. This income is split by the categories shown in the table below.

Table 36. Categories of research income

Research grants and contracts: *This includes all income in respect of externally sponsored research carried out by the institution or its subsidiary undertaking for which directly related expenditure has been incurred.*	
BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh	*This includes all research grants and contracts income from Research Councils sponsored by the Department for Business, Innovation and Skills (BIS), The Royal Society, British Academy and The Royal Society of Edinburgh, returned to HESA under the following categories:* *Biotechnology and Biological Sciences Research Council (BBSRC)* *Medical Research Council (MRC)* *Natural Environment Research Council (NERC)* *Engineering and Physical Sciences Research Council (EPSRC)* *Economic and Social Research Council (ESRC)* *Arts and Humanities Research Council (AHRC)* *Science and Technology Facilities Council (STFC)* *Other (i.e. sponsored research grants and contracts income not included above).*
UK-based charities	*This includes all research grants and contracts income from all charitable foundations, charitable trusts, etc. based in the UK which are registered with the Charities Commission or those recognised as charities by the Office of the Scottish Charity Regulator (OSCR) in Scotland. Income from UK-based charities is split between those with an open competitive process for the allocation of funds and other charities.*
UK-based charities (open competitive process)	*This includes research grants or contracts income from UK-based charities that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus). Income awarded by the Education Endowment Foundation is included under this heading where funding originated from grants made by non-government sources.*
UK-based charities (other)	*This includes research grants or contracts income from UK-based charities that does not meet the definition of open competition.*
UK central government bodies, local authorities, health and hospital authorities	*This includes all research grants and contract income from UK central government bodies, UK local authorities and UK health and hospital authorities, except Research Councils and UK public corporations. This includes government departments and other organisations (including registered charities) financed from central government funds. Research grants and contracts from non-departmental public bodies (NDPBs) such as the British Council are also included in this source of income. Income awarded by the Education Endowment Foundation is included under this heading where funding originated from grants made by UK government sources.*

UK industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory organisations with a substantial degree of financial independence) operating in the UK.*
EU government bodies	*This includes all research grants and contracts income from all government bodies operating in the EU, which includes the European Commission, but excludes bodies in the UK.*
EU-based charities (open competitive process)	*This includes research grants or contracts income from EU bodies with exclusively charitable purposes (consistent with the definition set out in the Charities Act 2006 and which exists for the public benefit in a manner which is consistent with the Public Benefit Guidance published by the Charity Commission for England and Wales), that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus).*
EU industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory corporations, with a substantial degree of financial independence) operating in the EU outside of the UK.*
EU other	*This includes all research grants and contracts income from EU-based non-competitive charities and any other EU income not otherwise specified.*
Non-EU-based charities (open competitive process)	*This includes research grants or contracts income from non-EU bodies with exclusively charitable purposes (consistent with the definition set out in the Charities Act 2006 and which exists for the public benefit in a manner which is consistent with the Public Benefit Guidance published by the Charity Commission for England and Wales), that was available to more than one institution through direct competition, awarded to the institution that demonstrated the highest quality research proposal according to external peer review. It also includes grants where it can be shown that the charity took external expert advice on its choice of institution, and either the charity had made it known that it was open to grant applications from other institutions, even though an open invitation to bid for the particular grant was not issued; or the charity restricted the funding opportunity on a reasoned basis in that particular requirements of the project could only be met by a limited number of institutions (i.e. where a project required highly specialist expertise or facilities, or a specific regional focus).*
Non-EU industry, commerce and public corporations	*This includes all research grants and contracts income from industrial and commercial companies and public corporations (defined as publicly owned trading bodies, usually statutory corporations, with a substantial degree of financial independence) operating outside the EU.*
Non-EU other	*This includes all research grants and contracts income from all non-EU-based non-competitive charities and any other non-EU income not otherwise specified.*
Other sources	*This includes all research grants and contracts income not covered above. This includes income from other higher education institutions (HEIs) where the HEI is the original contractor.*

For the purpose of this analysis we have grouped the categories that relate to '*research income*' into two broad categories:

- ***UK public funding***: which comprises (i) BIS Research Councils, the Royal Society, British Academy and The Royal Society of Edinburgh (henceforth referred to as RCs funding), and (ii) UK central

government bodies, local authorities, health and hospital authorities(henceforth referred to as other government funding).
- ***Private funding***: which comprises (i) UK-based charities, (ii) UK-based charities (open competitive process), (iii) UK-based charities (other), (iv) UK industry, commerce and public corporations, (v) EU government bodies, (vi) EU-based charities (open competitive process), (vii) EU industry, commerce and public corporations, (viii) EU other, (ix) Non-EU-based charities (open competitive process), (x) Non-EU industry, commerce and public corporations, (xi) Non-EU other, and (xii) Other sources.

These splits broadly align with the ONS splits and definitions, and make comparisons easier.

Furthermore, HESA reports this R&D income for around 45 different subjects (varying from year to year). We have aggregated those 45 different subjects into ten subject groups, in line with HESA's aggregation of those subjects in their Staff Statistics[40]. The ten subject groups are as follows:

- ***Medicine, dentistry & health***: which comprises (i) clinical medicine, (ii) clinical dentistry, (iii) nursing & allied health professions, (iv) psychology & behavioural sciences, (v) health & community studies, (vi) anatomy & physiology, and (vii) pharmacy & pharmacology.
- ***Agriculture, forestry & veterinary science***: which comprises (i) agriculture, forestry & food science, and (ii) veterinary science.
- ***Biological, mathematical & physical sciences***: which comprises (i) earth, marine & environmental sciences, (ii) biosciences, (iii) chemistry, (iv) physics, and (v) mathematics.
- ***Engineering & technology***: which comprises (i) general engineering, (ii) chemical engineering, (iii) mineral, metallurgy & materials engineering, (iv) civil engineering, (v) electrical, electronic & computer engineering, (vi) mechanical, aero & production engineering, and (vii) IT, systems science & computer software engineering.
- ***Architecture & planning***: which comprises (i) architecture, built environment & planning.
- ***Administrative & business studies***: which comprises (i) business & management studies, and (ii) catering & hospitality management.
- ***Social studies***: which comprises (i) geography, (ii) anthropology & development studies, (iii) politics & international affairs, (iv) economics & econometrics, (v) law, (vi) social work & social policy, (vii) sociology, and (viii) media studies.
- ***Humanities & language based studies & archaeology***: which comprises (i) area studies, (ii) modern languages, (iii) English language & literature, (iv) history, (v) classics, (vi) philosophy, (vii) theology & religious studies, and (viii) archaeology.
- ***Design, creative & performing arts***: which comprises (i) art & design, and (ii) music, dance, drama & performing arts.
- ***Education***: which comprises (i) sports science & leisure studies, (ii) education, and (iii) continuing education.

12.2. Key facts and figures relating to HESA data

This section sets out the key facts and figures relating to HEIs' R&D income. Here, we examine how income in 2012/13 is split between different subject areas.

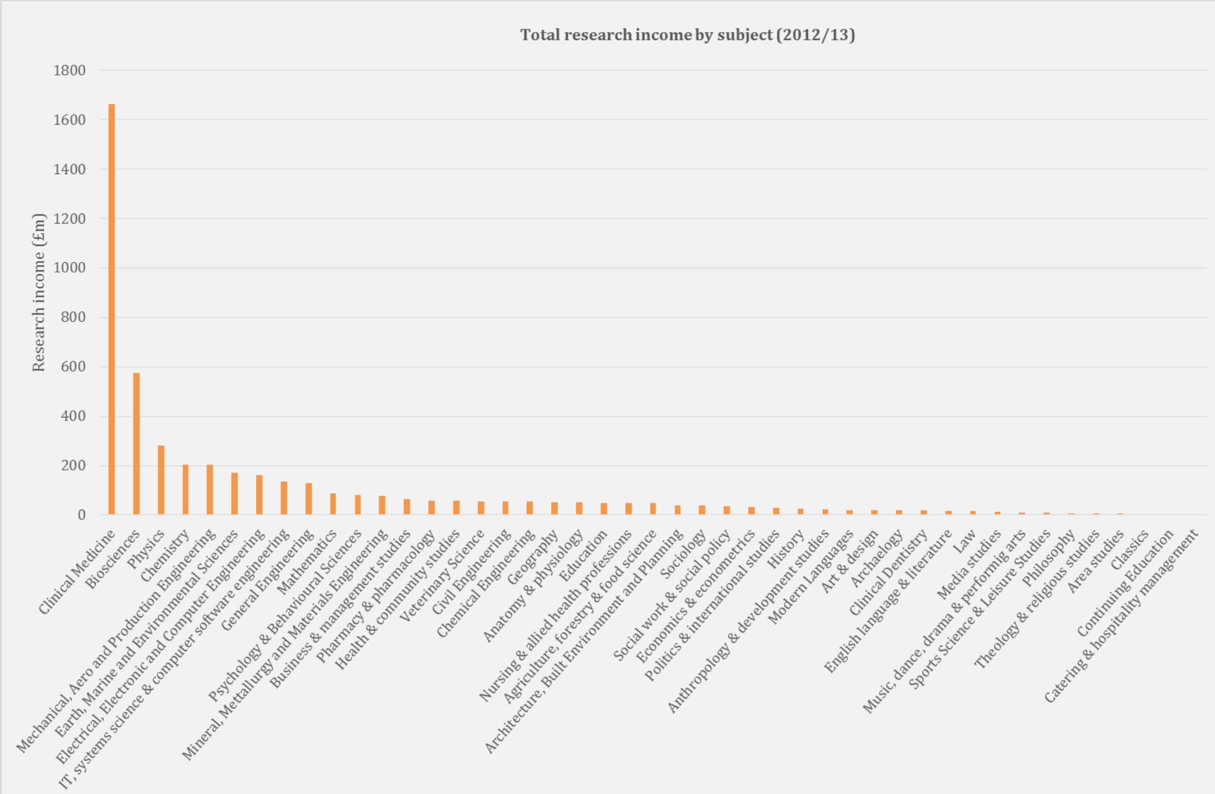
Income in 2012/13

In 2012/13, 161 UK HEIs reported income from research grants and contracts of £4.7 billion (£29 million per HEI on average).

The subjects that received most research grants and contracts income were clinical medicine, biosciences, physics, chemistry, and mechanical, aero and production engineering.

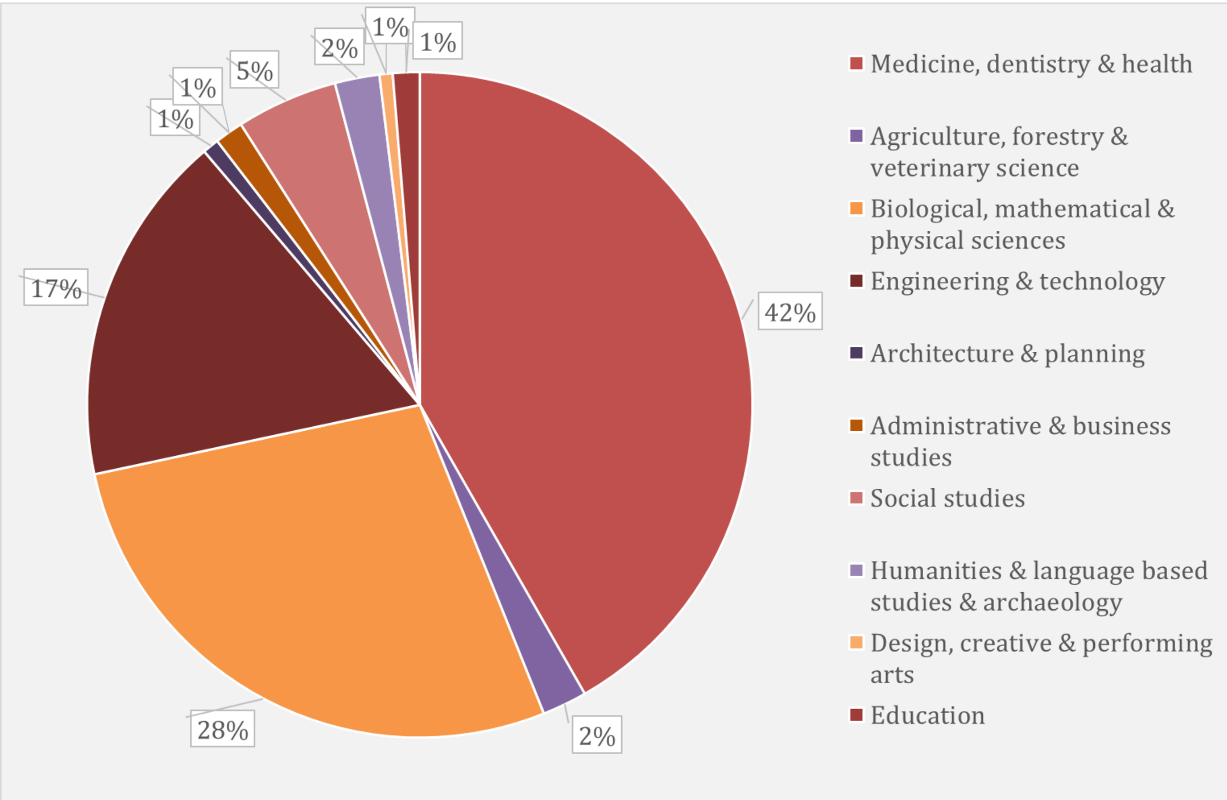
[40] *HESA (2014), Staff Statistics 2012/13, Table 16.*

Figure 75. Total income from research grants and contracts by subject (2012/13)



The chart below shows how this is split between the different subject groups. The subject group that received most income for research grants and contracts was medicine, dentistry & health (42%), followed by biological, mathematical & physical sciences (28%) and engineering & technology (17%).

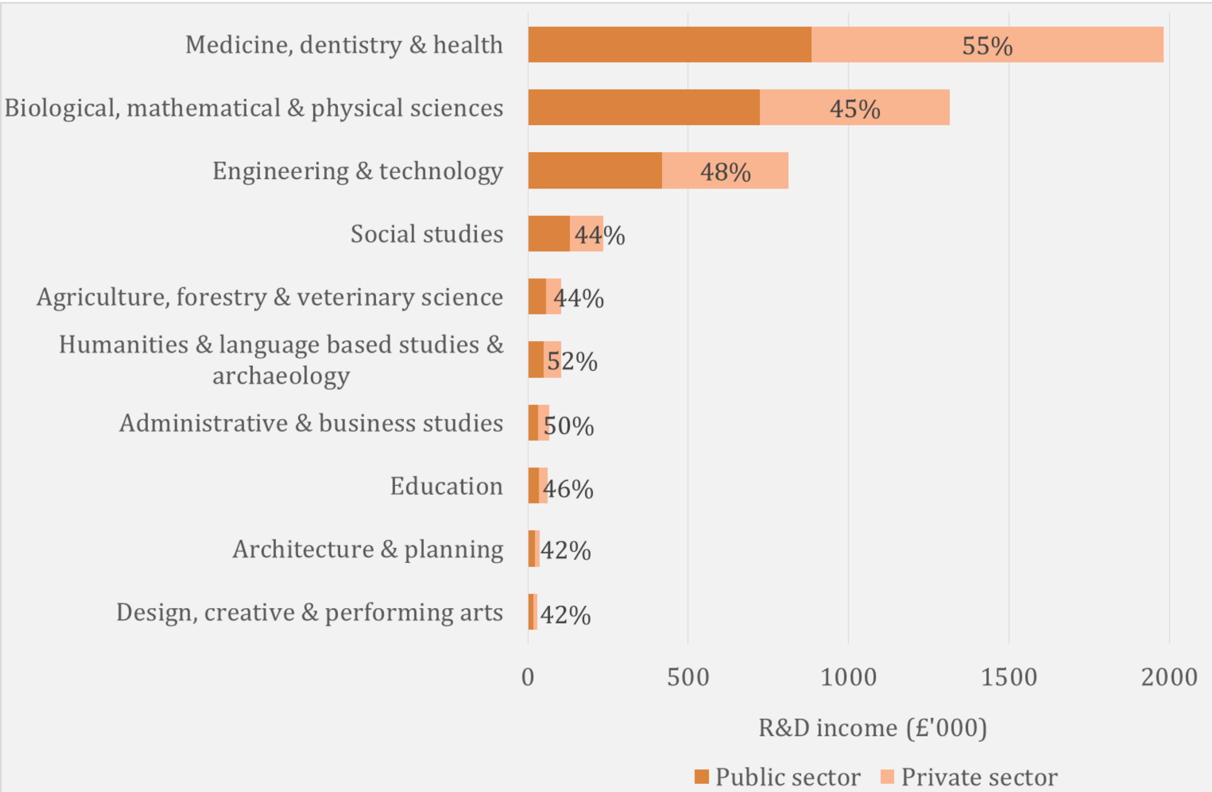
Figure 76. Income from research grants and contracts by subject group (2012/13)



The following chart shows how the research income received by each one of these subjects groups is split between private and public funders. Medicine, dentistry & health received 45% of its R&D income from the UK public sector, whereas biological, mathematical & physical sciences, and engineering & technology received 55% and 52%, respectively. This almost 50:50 split public-private funding holds for most subject groups. Only medicine, dentistry & health, and humanities & language based studies & archaeology received over 50% of funding from the private sector (55% and 52% respectively).

This average 50:50 split between income from the UK public sector and elsewhere masks significant variation in the percentage split in different HEIs, as not all HEIs offer all subjects, and neither do they all attract the same levels of private and public funding.

Figure 77. Private sector percentage by subject group (2012/13)



12.3. The relationship between private and public income

The following figures show that HEIs that tend to have a high level of public income for a subject group also have a high level of private income for that subject group (each data point is a HEI and refers to the latest data from 2012/13).

Figure 78. Medicine, dentistry & health

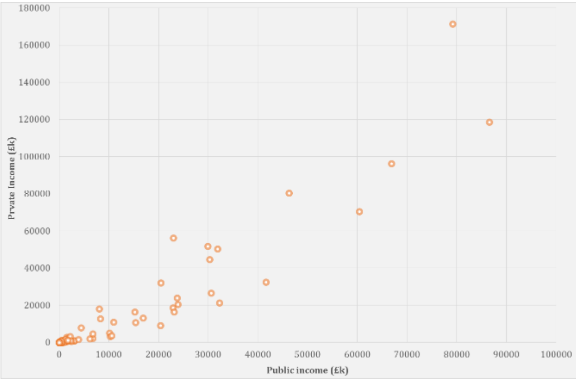


Figure 79. Administrative & business studies

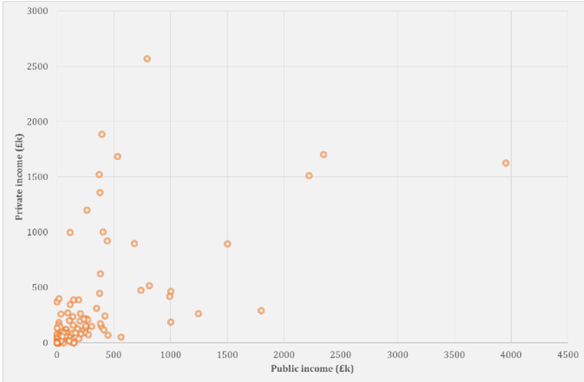


Figure 80. Agriculture, forestry & veterinary science

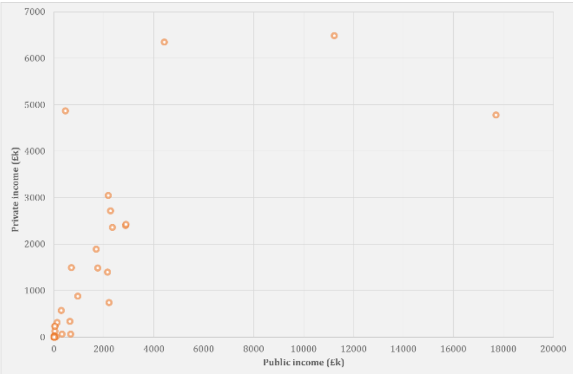


Figure 81. Social studies

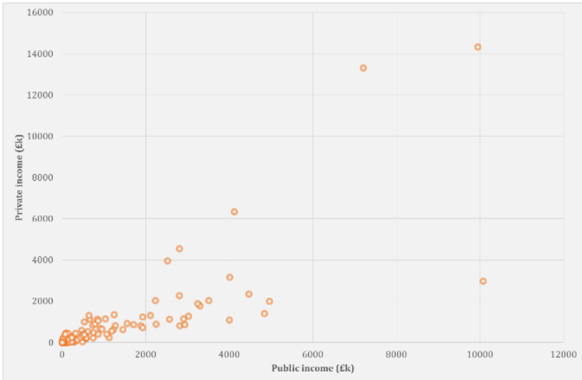


Figure 82. Biological, mathematical & physical sciences

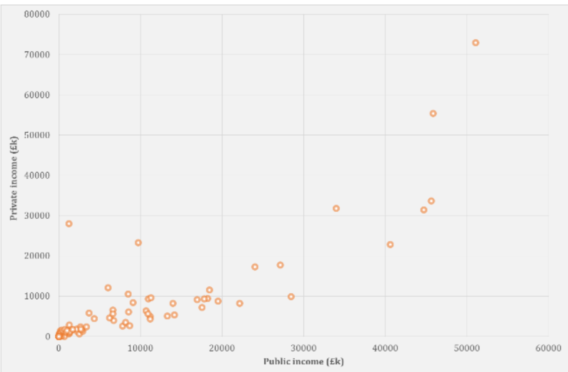


Figure 83. Humanities & language based studies & archaeology

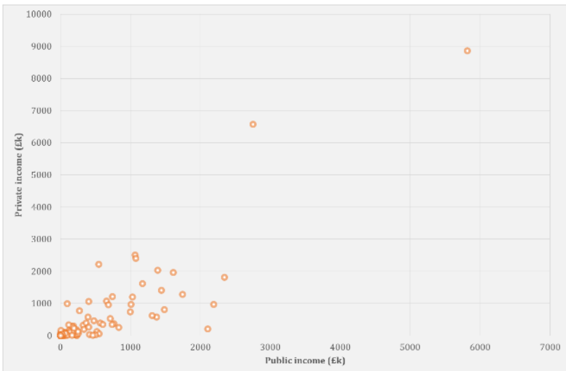


Figure 84. Engineering & technology

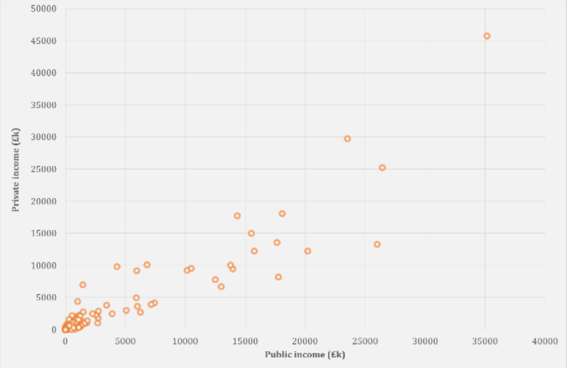


Figure 85. Design, creative & performing arts

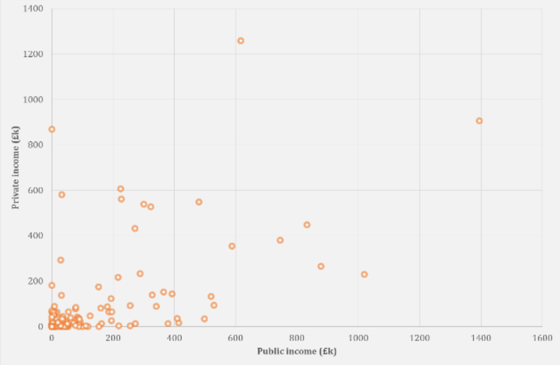


Figure 86. Architecture & planning

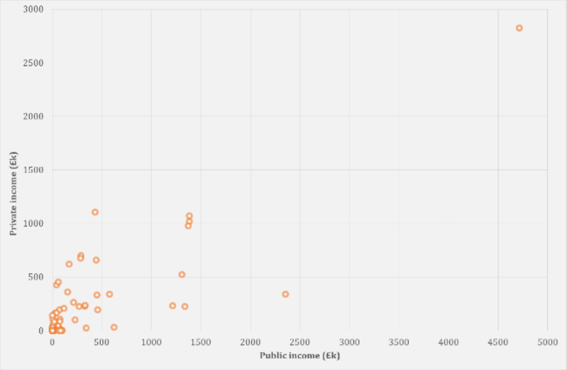
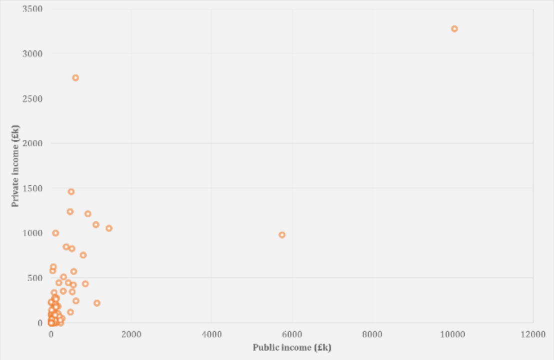


Figure 87. Education



A number of factors will contribute to this positive correlation. One factor is institution size, as it is expected that larger institutions will have both higher levels of private and public income. In order to control for a possible 'size' effect, the figures overleaf show the same data on a 'per FTE' basis. As can be seen, there is still a positive correlation between private and public R&D funding.

Figure 88. Medicine, dentistry & health

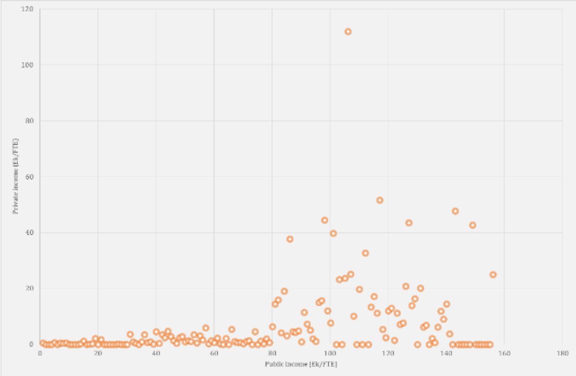


Figure 89. Administrative & business studies

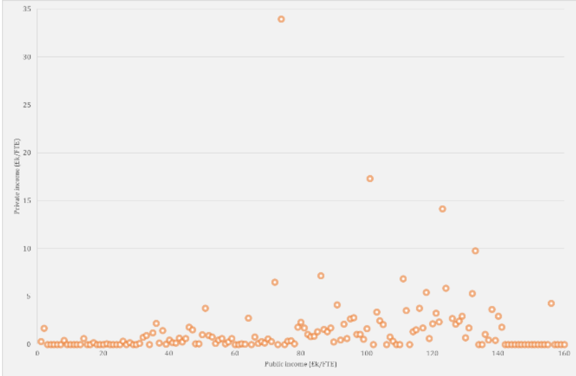


Figure 90 Agriculture, forestry & veterinary science

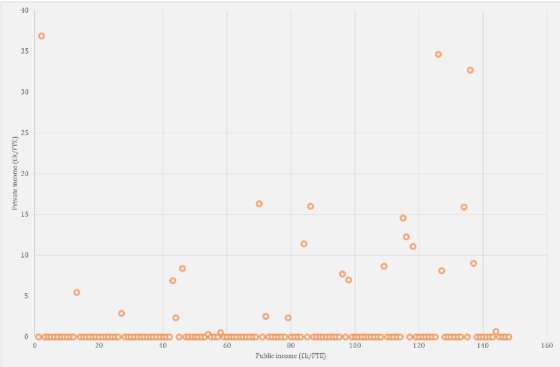


Figure 91 Social studies

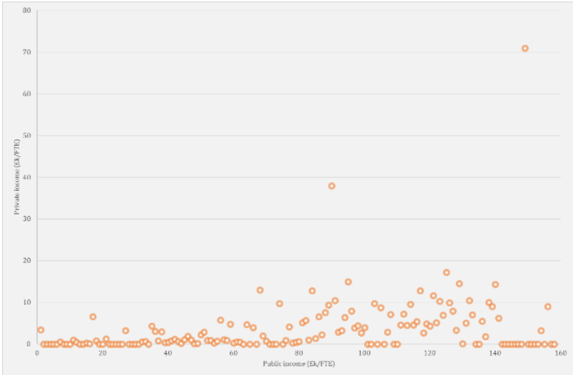


Figure 92. Biological, mathematical & physical sciences

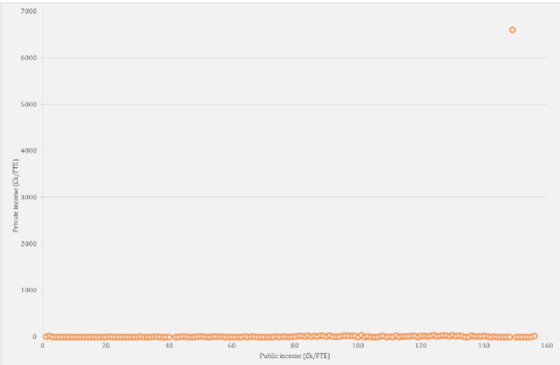


Figure 93. Humanities & language based studies & archaeology

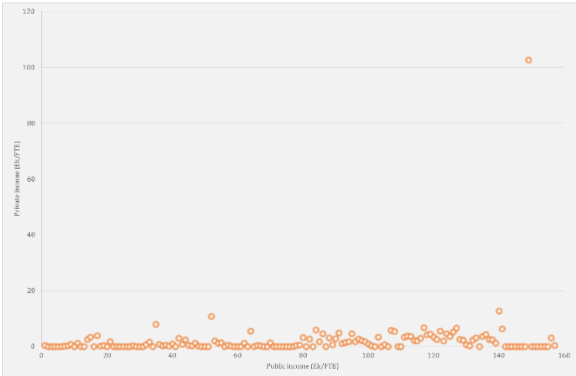


Figure 94. Engineering & technology

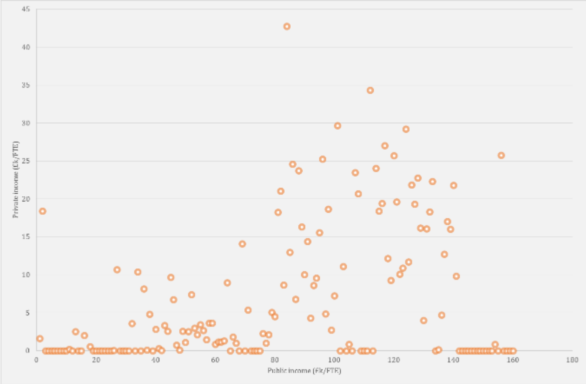


Figure 95. Design, creative & performing arts

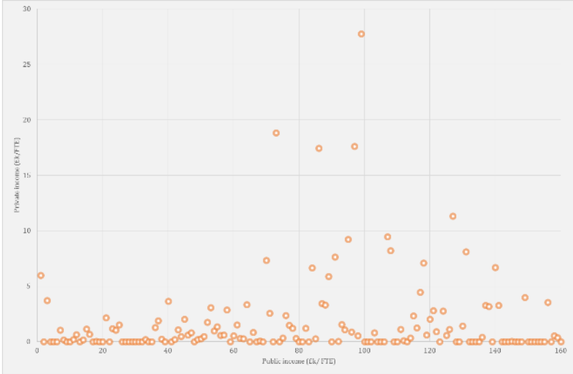


Figure 96. Architecture & planning

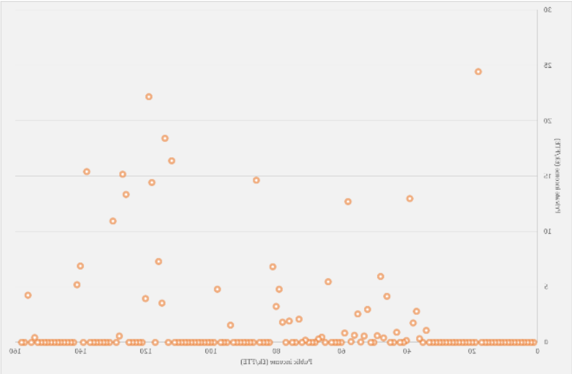
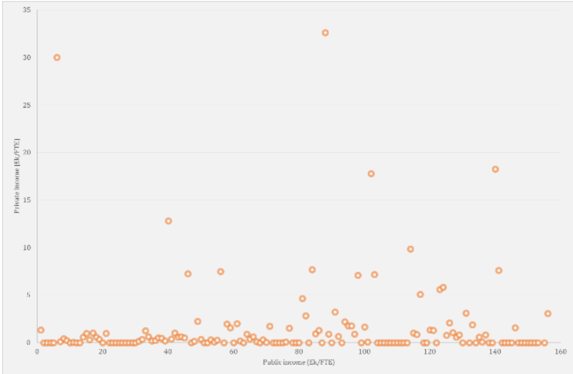


Figure 97. Education



Correlation analysis

We analysed the correlation between public and private income for R&D both at a disaggregated and at an aggregated level, using the latest available data (2012/13). The disaggregated analysis looks at the correlation of public and private funding of all 45 subjects for 2012/13 for all HEIs. The aggregated analysis groups these 45 subjects into ten subjects groups and looks at the correlation of private and public funding for all HEIs in 2012/13. Results are presented in the subsequent paragraphs.

Disaggregated analysis:

The following table outlines the correlation between the public and private income for R&D for each individual subject reported in HESA for 2012/13. Subjects in the area of medicine, dentistry & health; engineering & technology; and biological, mathematical & physical sciences demonstrate highest correlations.

Table 37. Correlation coefficients by academic subject

Subject	Correlation	Total R&D income (£m)	Institutions
Clinical Medicine	0.95	1663.4	42
Mechanical, Aero and Production Engineering	0.94	202.7	52
Physics	0.94	279.9	46
Anthropology & development studies	0.92	23.3	24

General Engineering	0.91	127.8	39
Psychology & Behavioural Sciences	0.90	81.3	93
Sports Science & Leisure Studies	0.89	10.3	48
Politics & international studies	0.88	28.7	62
Electrical, Electronic and Computer Engineering	0.88	160.3	59
Nursing & allied health professions	0.88	48.7	72
Chemistry	0.87	202.8	52
Anatomy & physiology	0.87	50.2	24
Pharmacy & pharmacology	0.86	59.5	38
Clinical Dentistry	0.86	19.1	18
Architecture, Built Environment and Planning	0.85	37.8	57
Chemical Engineering	0.83	54.0	19
Agriculture, forestry & food science	0.82	48.3	24
Biosciences	0.80	575.0	94
Earth, Marine and Environmental Sciences	0.79	170.0	63
Mineral, Metallurgy and Materials Engineering	0.79	78.6	18
Area studies	0.78	4.9	15
IT, systems science & computer software engineering	0.78	134.5	99
Theology & religious studies	0.78	6.5	32
Health & community studies	0.77	58.3	60
Veterinary Science	0.76	55.0	9
Modern Languages	0.76	19.4	62
Education	0.74	49.2	89
Social work & social policy	0.74	33.8	67
Sociology	0.74	37.3	59
Law	0.74	16.1	69
Geography	0.74	51.3	59
Mathematics	0.74	88.0	61
English language & literature	0.71	16.9	79
History	0.70	26.2	78
Philosophy	0.69	6.9	37
Archaeology	0.68	19.3	28
Art & design	0.66	19.3	73
Business & management studies	0.62	64.8	115
Civil Engineering	0.61	54.8	37
Continuing Education	0.60	2.2	18
Economics & econometrics	0.54	31.8	53

Media studies	0.50	11.5	57
Catering & hospitality management	0.45	1.0	12
Classics	0.44	2.8	21
Music, dance, drama & performing arts	0.44	11.1	77

Aggregated analysis:

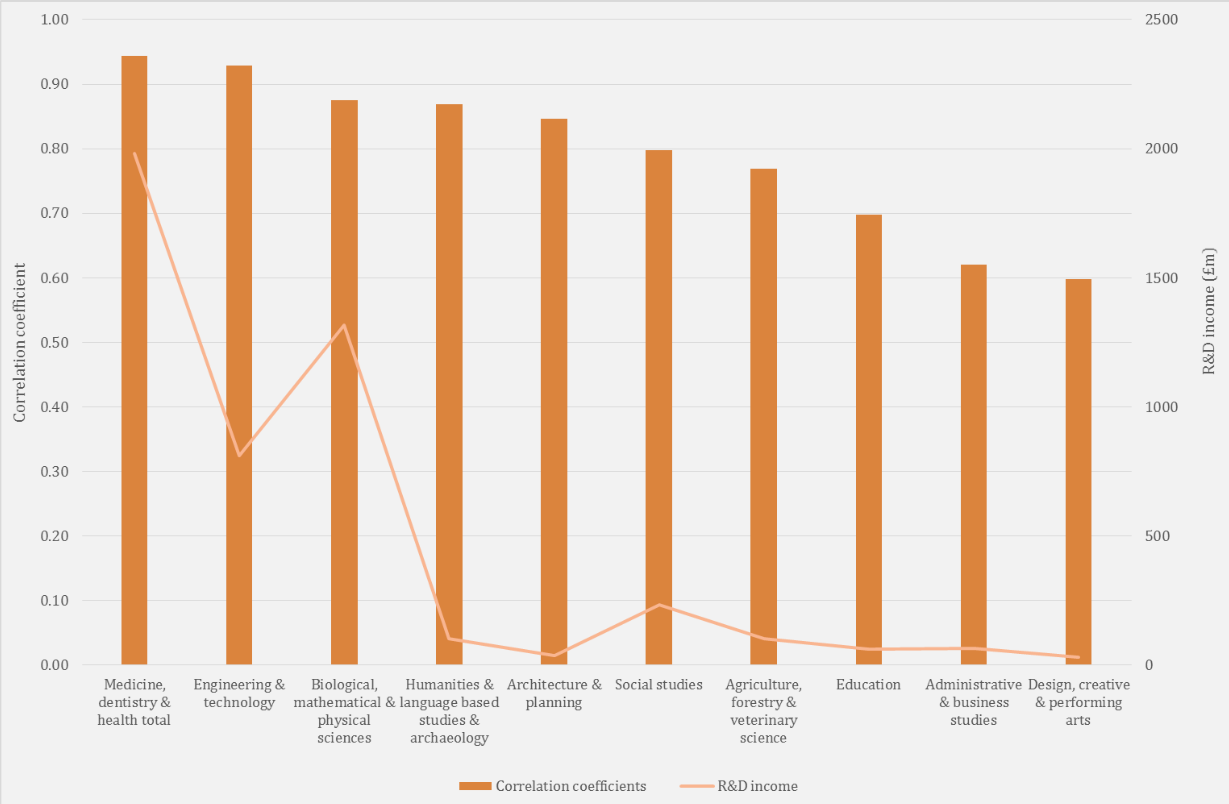
The following table shows that the correlation between public and private income for R&D is highest for medicine, dentistry & health and lowest for design, creative & performing arts. Altogether, all subject areas demonstrate a high correlation between both sources of income.

Table 38. Correlation coefficients by academic subject group

Subject	Correlation	Total R&D income (£bn)	Institutions
Medicine, dentistry & health	0.94	1.98	118
Engineering & technology	0.93	0.81	108
Biological, mathematical & physical sciences	0.87	1.32	105
Humanities & language based studies & archaeology	0.87	0.10	105
Architecture & planning	0.85	0.04	57
Social studies	0.80	0.23	113
Agriculture, forestry & veterinary science	0.77	0.10	31
Education	0.70	0.06	103
Administrative & business studies	0.62	0.07	115
Design, creative & performing arts	0.60	0.03	112

The following figure shows the total research income of each subject group (£bn) for 2012/13, as well as the correlation of public-private research funding.

Figure 98. Correlation of public-private research income, by subject group (2012/13)



Econometric analysis

This section sets out the results of our econometric analysis using the HESA data described above, combined with other publically available data. The time period for our analysis spans from 2003/04 to 2012/13 inclusive. The data is measured at an annual frequency.

Our general specification is as set out below:

$$\ln(\textit{private funding subject}_j)_{it} = a + b.\ln(\textit{public funding subject}_j)_{it} + c.\text{controls}_{it} + e_{it} \quad (1)$$

Assuming that the equation is properly specified, the parameter b measures the elasticity of private funding with respect to public funding, i.e. the % change in private income brought about by a 1% change in public income, other things being equal.

We control for various different factors, such as:

- ***Size***: The rationale for including size as a control variable is based on the assumption that the bigger the HEI, the more funding it will receive (compared to a smaller HEI). We have tried different controls for size, such as total staff FTE, total academic staff FTE, total research staff, total staff, total income and total expenditure. Our preferred measure is total staff FTE, because it reflects all staff, including support staff which may facilitate greater capacity and is a consistent measure (i.e. it accounts for both full-time and part-time staff).
- ***Quality***: Further to HEI-size and department size, we consider that other institution-specific factors will affect the amount of private R&D funding it receives. These factors could bias our results when they are correlated with the amount of public R&D funding a HEI receives. Two examples of such factors are: the research quality of the HEI and, relatedly, their reputation for conducting high quality research. To help control for these factors, we have included some or all of the following additions and adjustments to our modelling:
    - *Ratio of total staff FTE to total students FTE*: The rationale for including this ratio is to account for HEI-specific 'quality factors'. The underlying assumption is that the more

staff per student there is, the higher the quality of that HEI. This measure would help control for quality if (a) it is a good proxy for teaching quality; and (b) teaching quality is a good proxy for research quality.

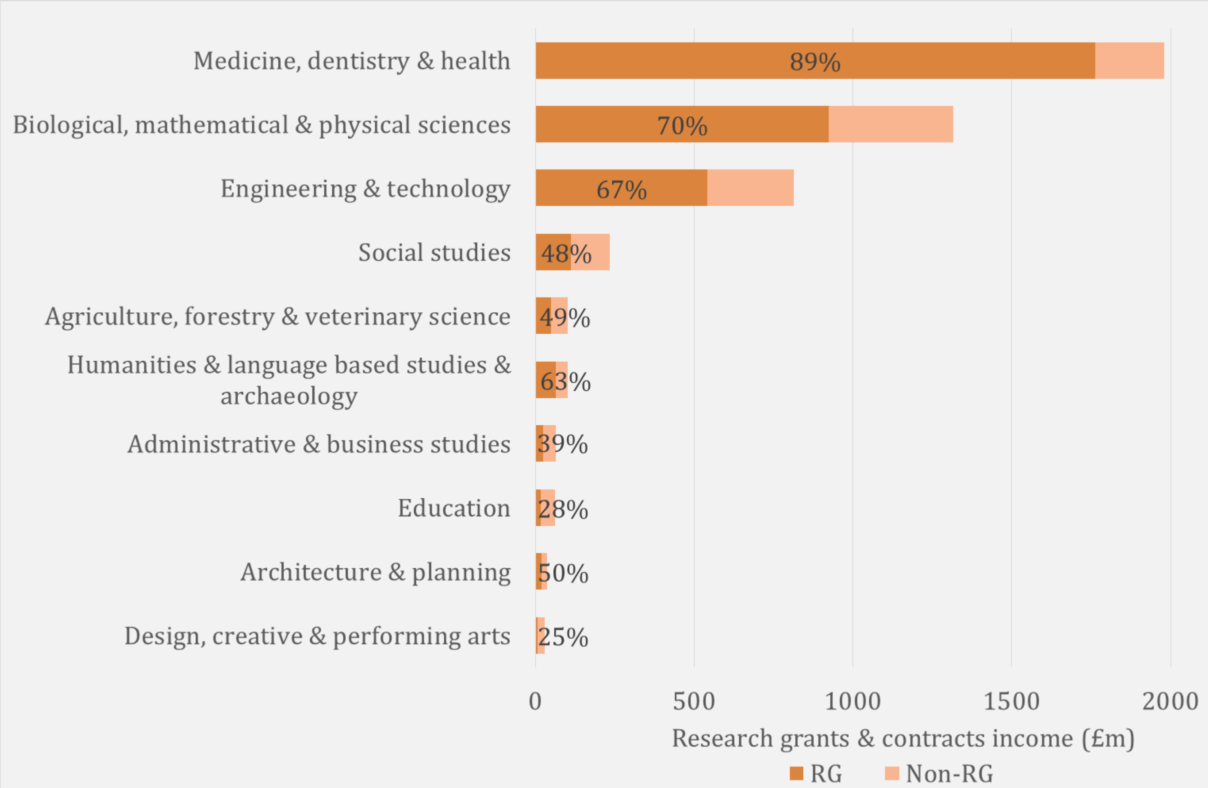
- *TRAC Peer Groups*[41]*:* A HEI is in a TRAC Peer Group based on its research income as a percentage of its total income and of research areas/ quality. For instance, Peer Group 1 is the Russell Group, in which all HEIs have medical schools excluding LSE plus some specialist medical schools. TRAC Peer Group dummy variables are a good proxy for research quality if (a) all the HEIs in a Peer Group have a similar research quality; and (b) research income as a percentage of its total income is a good proxy for research quality.
- *RAE scores:* The RAE score has not been included in our model, as although it is a good indication of a HEI's research quality, the RAE score determines how much public R&D funding a HEI receives. Hence, RAE scores are correlated with public R&D funding and would bias the elasticity estimates.

- ***Macroeconomic conditions***: As further controls we have also included macroeconomic variables such as GDP and Gross Fixed Capital Formation, as these capture effects that affect all HEIs in the same way, at the same time, and over time (hence eliminating the need to add a time-trend to our specifications).

We have captured mostly time-invariant HEI-specific factors such as quality. As further control for all the time invariant quality differences we have split the sample into two groups: (i) high research intensity institutions (Peer Group 1: Russell Group - RG), and (ii) others (Peer Groups 2-7: Non-RG). The rationale for doing this is, that when looking at how R&D income is spread across the Peer Groups in 2012/13, it is discernible that RG HEIs receive most of R&D-specific funding. Nonetheless, depending on subject group, Non-RG HEIs receive most of R&D-specific funding, for instance in the subject groups of design, creative & performing arts and education. These splits are varied, and are due to different HEIs specialising in different subjects. This is reflected in the following chart.

[41] *The peer groups are the peer groups used for TRAC (transparent approach to costing) benchmarking, c.f. http://www.hefce.ac.uk/media/hefce/content/whatwedo/leadershipgovernanceandmanagement/financialsustainabilityandtrac/tracguidance/Annex%204.1b.PDF*

Figure 99. RG and Non-RG percentage of R&D income, by subject group (2012/13)



As the subject groups that attract most of R&D-specific income have a roughly 70:30 split it is important to look at these two splits of the sample, as there are 24 HEIs in the RG group, whereas there are 133 in the Non-RG group. This would indicate that the results of the aggregate sample (including RG and Non-RG together) is biased in favour of the Non-RG group, as there are more Non-RG observations than RG ones. However, when considering the research question, namely how public funding of R&D leverages private R&D funding, more weight should be placed on the RG group sample, as most of R&D specific funding is attributed to this group, and hence it is more representative/ appropriate for analysing our question.

Further to controlling for these HEI-specific factors, panel data approaches naturally deal with individual-specific factors (which have not been captured by our control variables). The general panel data specification we use is:

$$y_{it} = \alpha + \beta_1 x_{it} + u_{it}$$

Where u_{it} is decomposed into an individual-specific time-constant unobserved heterogeneity v_i and an idiosyncratic error ε_{it}:

$$u_{it} = v_i + \varepsilon_{it}$$

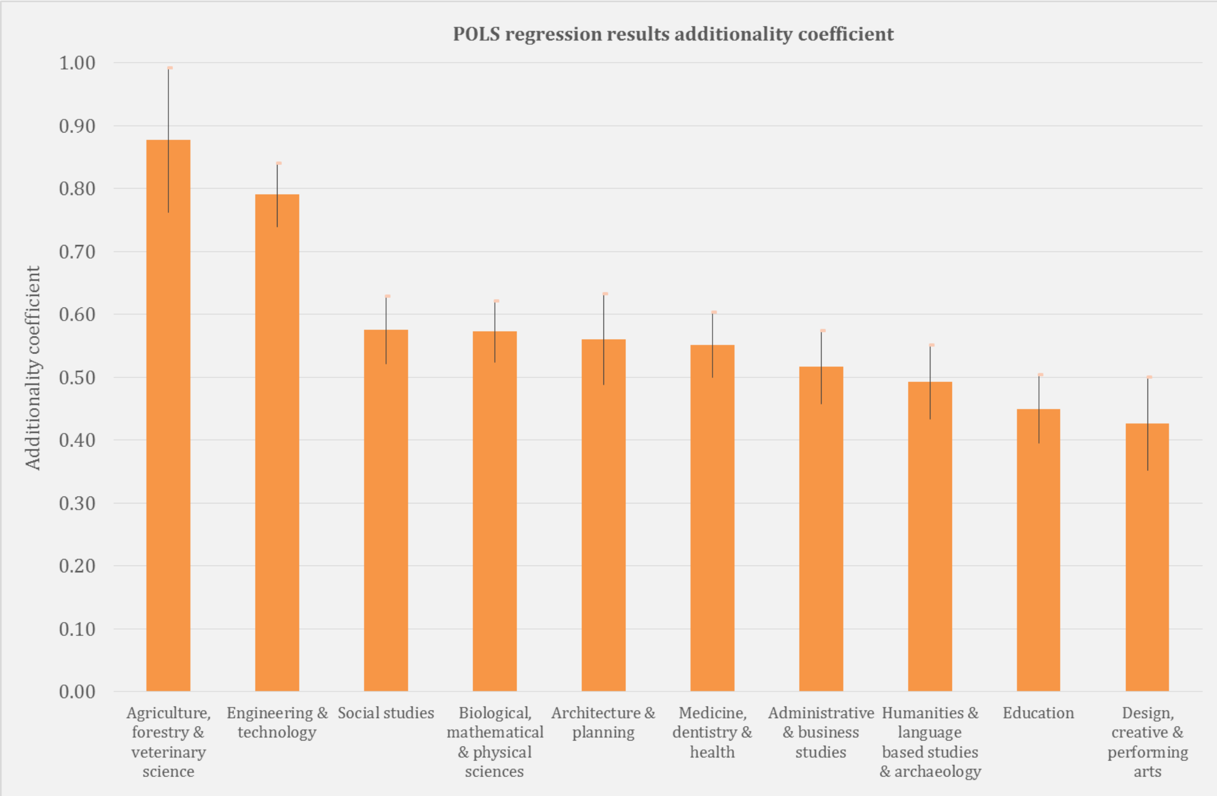
Using a fixed-effects (FE) specification by definition accounts for these HEI-specific effects such as quality, brand-value, etc., which would be captured in v_i.

We have run pooled OLS regressions (POLS), FE regressions and RG-specific POLS/FE regressions. We have analysed the effect of total public funding for a given subject group on total private funding for that group. In total, we have analysed the relationship of public and private funding for ten subject groups. Below we set out the results from our analysis.

Pooled OLS

We have undertaken ten regressions (one for each subject group) with the control variables mentioned above. The following chart summarises our results and demonstrates that under this specification, agriculture, forestry & veterinary science achieves the highest additionality coefficient (0.88), followed closely by engineering & technology (0.79), and the social studies (0.58).

Figure 100. POLS regression results with confidence intervals



The following table summarises the results for the regression relating to medicine, dentistry & health[42]. We can see that a 1% increase in public funding for R&D in medicine, dentistry & health would lead to a 0.55% increase in private funding for R&D in medicine, dentistry & health. This is equivalent to a £1 increase in public funding giving rise to a £0.80 increase in private funding for this subject group. All other explanatory variables are significant, too, and their signs are in the expected directions.

Table 39. POLS regression results medicine, dentistry & health

	Model 1
ln(S1_public funding)$_{it}$	0.55*** (0.03)
ln(quality)$_{it}$	0.20*** (0.06)
ln(total staff FTE)$_{it}$	0.12** (0.06)
ln(fixed capital)$_{it}$	0.98*** (0.34)
Dummy_Peer2	-1.55*** (0.12)
Dummy_Peer3	-1.71*** (0.15)

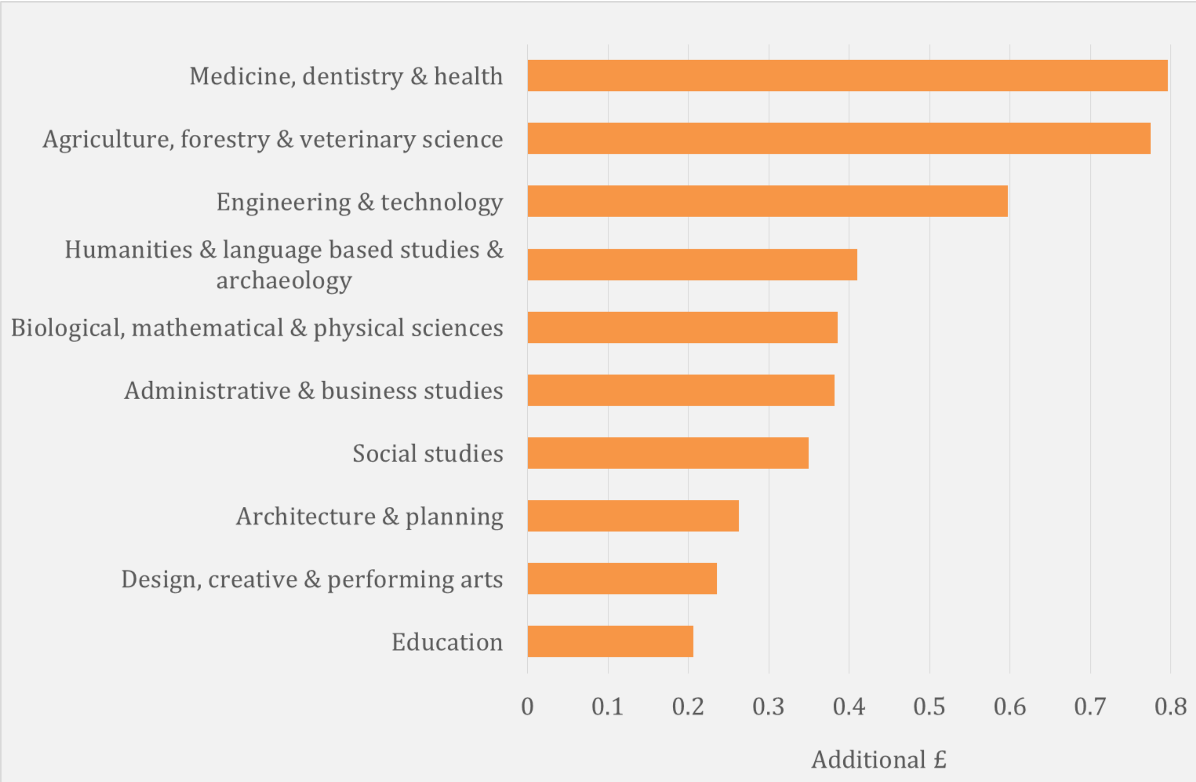
[42] *We only summarise the results for this subject group for presentational purposes. For the regression results of all groups, please refer to Addendum A.*

Dummy_Peer4	-2.39*** (0.16)
Dummy_Peer5	-2.77*** (0.18)
Dummy_Peer6	-2.77*** (0.25)
Dummy_Peer7	-3.72*** (0.36)
R-squared	0.84

Although all regression results are significant at the 1% significance level, the confidence intervals of the different, subject-specific additionality coefficients overlap for certain subjects (cf. Figure 100). That is, we cannot say with certainty that these coefficients are statistically different from each other.

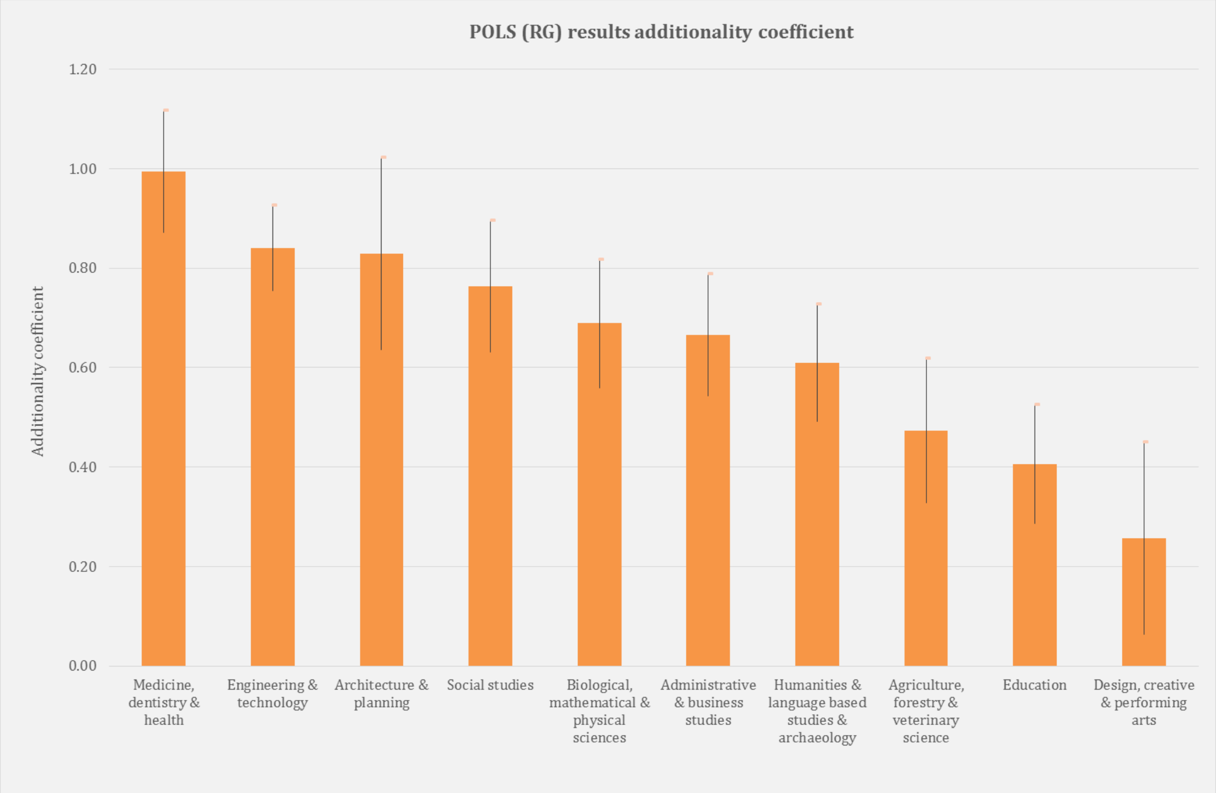
Further, translating these results into a £-measure, the ranking changes. Medicine, dentistry & health leverages most £s (£0.80), closely followed by agriculture, forestry & veterinary science (£0.77), and engineering & technology (£0.60). Results for all subject groups have been summarised in the following figure. The weighted average of these ten additionality estimates results in £0.44 additional private funding for every £1 of UK public funding. This is slightly above the main HESA analysis (additional £0.36). This could be because the main HESA analysis estimate of £0.36 already captures both the POLS and FE estimates of additionality, but also because the main HESA analysis is estimating a different effect and includes QR-funding in the UK public sector.

Figure 101. Additional £s (POLS)



As a further sensitivity check, we have performed the same regressions for RG HEIs only. A summary of the results is presented in the following figure. Here, the subject groups with the highest additionality coefficients are medical, dentistry & health (0.99), engineering & technology (0.84) and architecture & planning (0.67).

Figure 102. POLS (RG) regression results with confidence intervals



These additionality coefficients imply the following additional £s for each subject group:

- ***Medicine, dentistry & health***: For every £1 of UK public funding, the private sector invests £1.58.
- ***Engineering & technology***: For every £1 of UK public funding, the private sector invests £0.57.
- ***Humanities & language based studies & archaeology***: For every £1 of UK public funding, the private sector invests £0.55.
- ***Social studies***: For every £1 of UK public funding, the private sector invests £0.53.
- ***Biological, mathematical & physical sciences***: For every £1 of UK public funding, the private sector invests £0.46.
- ***Architecture & planning:*** For every £1 of UK public funding, the private sector invests £0.42.
- ***Administrative & business studies***: For every £1 of UK public funding, the private sector invests £0.35.
- ***Agriculture, forestry & veterinary science***: For every £1 of UK public funding, the private sector invests £0.30.
- ***Education***: For every £1 of UK public funding, the private sector invests £0.24.
- ***Design, creative & performing arts***: For every £1 of UK public funding, the private sector invests £0.11.

The following table summarises the results for medicine, dentistry & health under this specification.

Table 40. POLS (RG) regression results medicine, dentistry & health

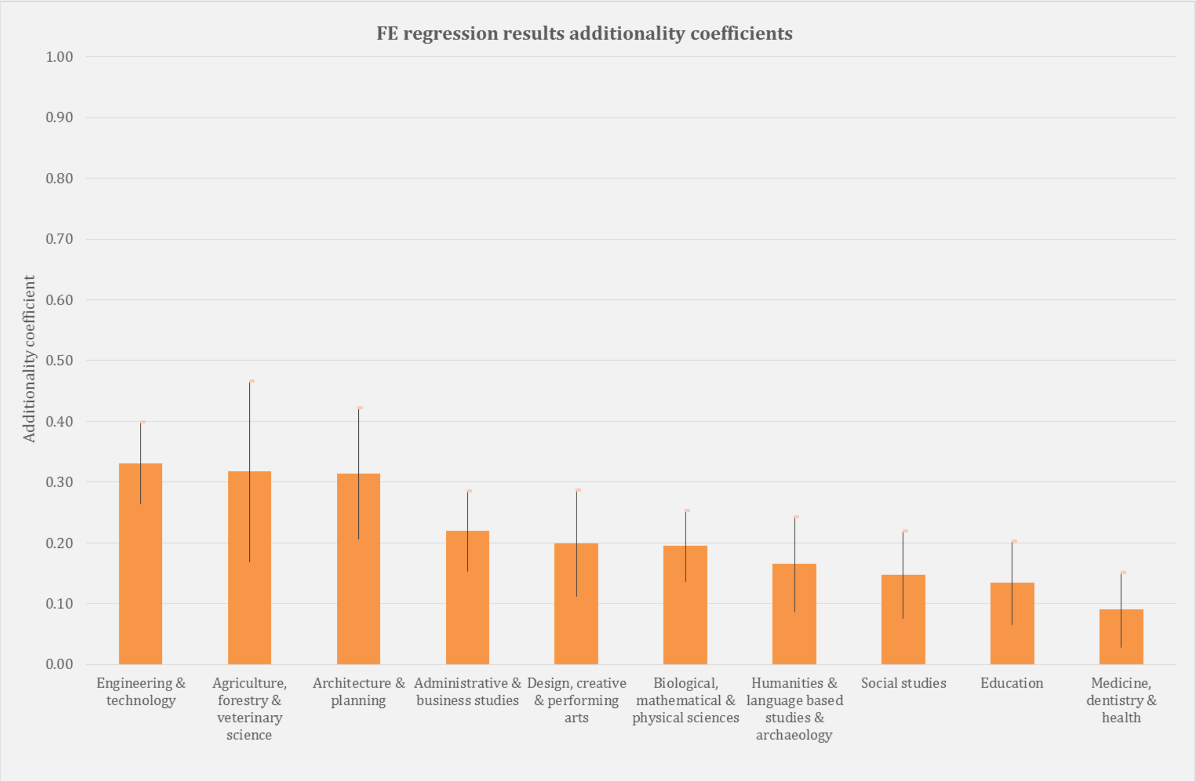
	Model 11
ln(S1_ public funding)$_{it}$	0.99*** (0.06)
ln(quality)$_{it}$	0.26*** (0.07)
ln(total staff FTE)$_{it}$	0.05 (0.08)
ln(fixed capital)$_{it}$	-1.45*** (0.34)
Dummy_Peer2	omitted

Dummy_Peer3	omitted
Dummy_Peer4	omitted
Dummy_Peer5	omitted
Dummy_Peer6	omitted
Dummy_Peer7	omitted
R-squared	0.70

Fixed effects

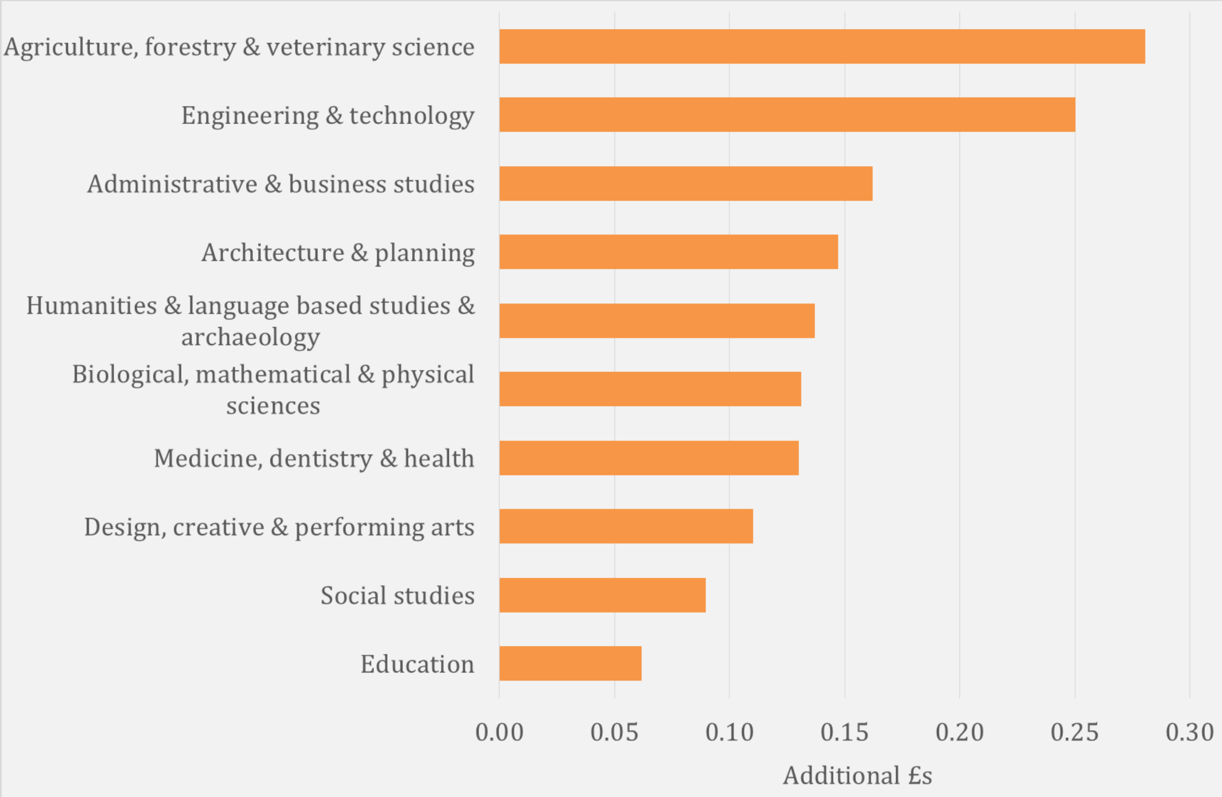
In order to explore the panel properties of the data, we have run a fixed-effects model. The chart below summarises the results of the fixed-effects regressions. The additionality estimates are much lower than in the OLS specification – the highest coefficient (engineering & technology) being 0.33. This is because the fixed effect takes account of HEI specific factors that drive private investment, but are not captured through the observed variable, hence explaining much of the variation between HEIs. These results are in line with the main HESA analysis.

Figure 103. FE regression results with confidence intervals



If you translate these results into a £-measure, agriculture, forestry & veterinary science achieves the highest leverage – with an additional £0.28 from the private sector, for every £1 from the UK public sector. Engineering and technology leverages an additional £0.25 from the private sector. The results have been summarised in the following figure.

Figure 104. Additional £s (FE)



Here, the weighted average of the £-estimates below the main HESA analysis at £0.15. This could be because the main HESA estimate already aggregates POLS and FE results in the final estimate, where the FE estimate is also below the POLS one.

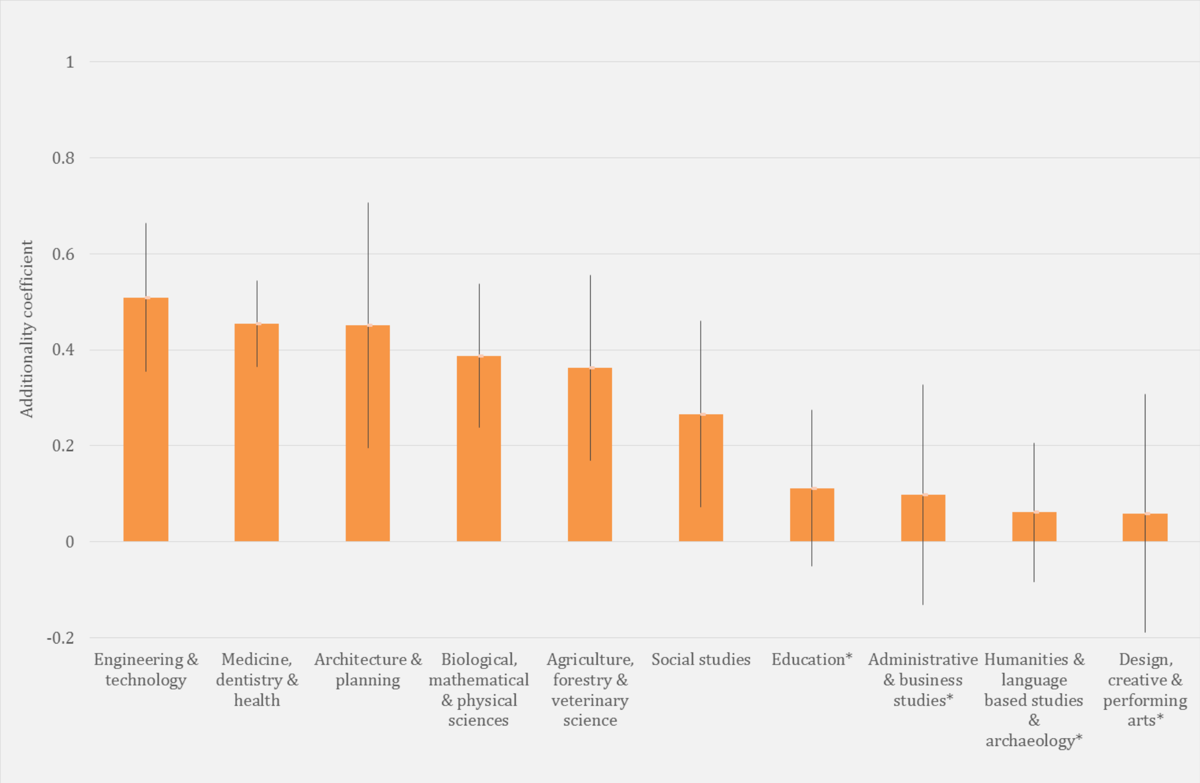
The following table summarises the regression results for medicine, dentistry & health under this specification.

Table 41. FE regression results medicine, dentistry & health

	Model 21
ln(S1_ public funding)$_{it}$	0.09*** (0.03)
ln(quality)$_{it}$	omitted
ln(total staff FTE)$_{it}$	omitted
ln(fixed capital)$_{it}$	1.98*** (0.22)
Dummy_Peer2	omitted
Dummy_Peer3	omitted
Dummy_Peer4	omitted
Dummy_Peer5	omitted
Dummy_Peer6	omitted
Dummy_Peer7	omitted
R-squared	0.43

As a further sensitivity check, and in line with the main HESA analysis, we have performed the same regressions for RG HEIs only. A summary of the results is presented in the following figure. Here, the subject groups with the highest additionality coefficients are engineering & technology (0.51), medical, dentistry & health (0.45), and architecture & planning (0.45). As can be seen from the graph, most confidence intervals overlap – as such we cannot be certain that the additionality coefficients are significantly statistically different from one another.

Figure 105. FE (RG) regression results with confidence intervals



** Insignificant results.*

Translating these additionality coefficients into £s measures, we obtain slightly higher measures than in the previous FE analysis. The subject group with the highest £ effect is medicine, dentistry & health, followed by engineering & technology:

- ***Medicine, dentistry & health***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.72.
- ***Engineering & technology***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.35.
- ***Biological, mathematical & physical sciences***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.26.
- ***Architecture & planning***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.23.
- ***Agriculture, forestry & veterinary science***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.23.
- ***Social studies***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.18.
- ***Education***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.07.
- ***Administrative & business studies***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.05.
- ***Humanities & language based studies & archaeology***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.06.

- ***Design, creative & performing arts***: For every £1 invested by the UK public sector in this subject group, the private sector contributes £0.02.

The following table summarises the regression results for medicine, dentistry & health under this specification.

Table 42. FE (RG) regression results medicine, dentistry & health

	Model 31
ln(public funding)$_{it}$	0.45*** (0.04)
ln(quality)$_{it}$	omitted
ln(total staff FTE)$_{it}$	omitted
ln(fixed capital)$_{it}$	0.18 (0.21)
Dummy_Peer2	omitted
Dummy_Peer3	omitted
Dummy_Peer4	omitted
Dummy_Peer5	omitted
Dummy_Peer6	omitted
Dummy_Peer7	omitted
R-squared	0.63

Addendum A

Model 1

Source	SS	df	MS
Model	5186.82352	10	518.682352
Residual	1009.87935	1051	.960874737
Total	6196.70286	1061	5.84043625

Number of obs	=	1062
F(10, 1051)	=	539.80
Prob > F	=	0.0000
R-squared	=	0.8370
Adj R-squared	=	0.8355
Root MSE	=	.98024

ls1pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls1pub	.5514703	.0263619	20.92	0.000	.4997423	.6031983
lqua	.2052747	.0590516	3.48	0.001	.0894023	.3211471
lstaff	.1231331	.0582558	2.11	0.035	.0088223	.237444
lfc	.9848598	.3450699	2.85	0.004	.3077554	1.661964
_Ipeer_2	-1.556426	.1229132	-12.66	0.000	-1.797609	-1.315243
_Ipeer_3	-1.709335	.1467899	-11.64	0.000	-1.99737	-1.421301
_Ipeer_4	-2.38623	.1561095	-15.29	0.000	-2.692552	-2.079908
_Ipeer_5	-2.770555	.1768882	-15.66	0.000	-3.117649	-2.42346
_Ipeer_6	-2.777566	.2545121	-10.91	0.000	-3.276975	-2.278156
_Ipeer_7	-3.716118	.3629308	-10.24	0.000	-4.428269	-3.003966
_cons	-7.678148	4.111053	-1.87	0.062	-15.74495	.3886576

Model 2

Source	SS	df	MS
Model	763.2309	9	84.8034334
Residual	214.936219	202	1.06404069
Total	978.167119	211	4.63586312

Number of obs	=	212
F(9, 202)	=	79.70
Prob > F	=	0.0000
R-squared	=	0.7803
Adj R-squared	=	0.7705
Root MSE	=	1.0315

ls2pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls2pub	.8773365	.0583358	15.04	0.000	.7623112	.9923617
lqua	.0187465	.109515	0.17	0.864	-.1971926	.2346856
lstaff	-.0403892	.1744708	-0.23	0.817	-.3844069	.3036285
lfc	.0168088	.8033209	0.02	0.983	-1.567161	1.600779
_Ipeer_2	.281118	.3013617	0.93	0.352	-.3131002	.8753362
_Ipeer_3	.13761	.3624655	0.38	0.705	-.5770913	.8523114
_Ipeer_4	-.2840494	.3817794	-0.74	0.458	-1.036833	.4687345
_Ipeer_5	-.7751666	.4841781	-1.60	0.111	-1.729858	.1795249
_Ipeer_6	.4701396	.6193099	0.76	0.449	-.7510016	1.691281
_Ipeer_7	0	(omitted)				
_cons	.8431772	9.468668	0.09	0.929	-17.82693	19.51328

Model 3

Source	SS	df	MS
Model	3593.6424	10	359.36424
Residual	674.826465	932	.724062731
Total	4268.46887	942	4.5312833

Number of obs	=	943
F(10, 932)	=	496.32
Prob > F	=	0.0000
R-squared	=	0.8419
Adj R-squared	=	0.8402
Root MSE	=	.85092

ls3pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls3pub	.5731072	.0248103	23.10	0.000	.5244166	.6217978
lqua	.3848164	.0524032	7.34	0.000	.2819745	.4876583
lstaff	-.026115	.0645362	-0.40	0.686	-.1527681	.1005381
lfc	.8947266	.3134449	2.85	0.004	.2795869	1.509866
_Ipeer_2	-.2598803	.1027052	-2.53	0.012	-.4614405	-.05832
_Ipeer_3	-.7089163	.1354073	-5.24	0.000	-.9746549	-.4431777
_Ipeer_4	-.5445947	.1397964	-3.90	0.000	-.818947	-.2702424
_Ipeer_5	-1.152473	.1832614	-6.29	0.000	-1.512125	-.7928197
_Ipeer_6	-1.79141	.2565627	-6.98	0.000	-2.294918	-1.287903
_Ipeer_7	-.2891458	.6263313	-0.46	0.644	-1.518329	.9400372
_cons	-6.230646	3.765992	-1.65	0.098	-13.62145	1.160161

Model 4

Source	SS	df	MS
Model	2192.93513	10	219.293513
Residual	739.271393	965	.766084345
Total	2932.20652	975	3.0073913

Number of obs	=	976
F(10, 965)	=	286.25
Prob > F	=	0.0000
R-squared	=	0.7479
Adj R-squared	=	0.7453
Root MSE	=	.87526

ls4pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls4pub	.7903967	.0258741	30.55	0.000	.7396207	.8411727
lqua	.0698975	.0820022	0.85	0.394	-.0910257	.2308207
lstaff	.1896556	.0810353	2.34	0.019	.0306298	.3486813
lfc	1.634122	.3183243	5.13	0.000	1.009434	2.258809
_Ipeer_2	-.0335453	.1147762	-0.29	0.770	-.258785	.1916944
_Ipeer_3	-.1020148	.1351138	-0.76	0.450	-.3671656	.1631359
_Ipeer_4	.2079452	.1377317	1.51	0.131	-.062343	.4782333
_Ipeer_5	.1929578	.1670708	1.15	0.248	-.1349061	.5208218
_Ipeer_6	.549282	.3094956	1.77	0.076	-.05808	1.156644
_Ipeer_7	-.250538	.2795305	-0.90	0.370	-.7990959	.2980198
_cons	-19.45563	3.856695	-5.04	0.000	-27.02411	-11.88716

Model 5

Source	SS	df	MS
Model	462.437556	10	46.2437556
Residual	469.803922	395	1.18937702
Total	932.241478	405	2.30183081

Number of obs	=	406
F(10, 395)	=	38.88
Prob > F	=	0.0000
R-squared	=	0.4960
Adj R-squared	=	0.4833
Root MSE	=	1.0906

ls5pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls5pub	.5604003	.036647	15.29	0.000	.4883527	.632448
lqua	-.1174137	.1718569	-0.68	0.495	-.4552823	.220455
lstaff	-.0125922	.1837262	-0.07	0.945	-.3737957	.3486113
lfc	2.32924	.6149657	3.79	0.000	1.120225	3.538256
_Ipeer_2	-.4782451	.2297992	-2.08	0.038	-.9300276	-.0264627
_Ipeer_3	-.5076924	.24323	-2.09	0.038	-.9858797	-.0295051
_Ipeer_4	-.5143506	.1925833	-2.67	0.008	-.892967	-.1357343
_Ipeer_5	-1.023786	.3003255	-3.41	0.001	-1.614222	-.4333493
_Ipeer_6	-.1542125	.4437093	-0.35	0.728	-1.02654	.7181147
_Ipeer_7	-1.376712	.5665844	-2.43	0.016	-2.49061	-.2628142
_cons	-25.65864	7.566405	-3.39	0.001	-40.5341	-10.78317

Model 6

Source	SS	df	MS
Model	874.090897	10	87.4090897
Residual	1353.48275	888	1.52419229
Total	2227.57365	898	2.48059426

Number of obs	=	899
F(10, 888)	=	57.35
Prob > F	=	0.0000
R-squared	=	0.3924
Adj R-squared	=	0.3856
Root MSE	=	1.2346

ls6pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls6pub	.5165595	.0297166	17.38	0.000	.4582365	.5748825
lqua	.3534686	.1165552	3.03	0.002	.1247128	.5822243
lstaff	-.1065134	.1035272	-1.03	0.304	-.3096998	.0966731
lfc	1.029723	.4659487	2.21	0.027	.1152339	1.944212
_Ipeer_2	-.2368581	.1596417	-1.48	0.138	-.5501772	.076461
_Ipeer_3	.2027394	.18389	1.10	0.271	-.1581702	.5636491
_Ipeer_4	.2374893	.1682058	1.41	0.158	-.0926379	.5676165
_Ipeer_5	-.2113185	.2166454	-0.98	0.330	-.6365153	.2138783
_Ipeer_6	-1.098019	.3911302	-2.81	0.005	-1.865666	-.3303715
_Ipeer_7	-1.473109	.5081076	-2.90	0.004	-2.470341	-.4758775
_cons	-8.518633	5.632627	-1.51	0.131	-19.57345	2.53618

Model 7

Source	SS	df	MS
Model	1975.8182	10	197.58182
Residual	1080.76355	956	1.13050581
Total	3056.58175	966	3.1641633

Number of obs	=	967
F(10, 956)	=	174.77
Prob > F	=	0.0000
R-squared	=	0.6464
Adj R-squared	=	0.6427
Root MSE	=	1.0633

ls7pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls7pub	.5750733	.0275687	20.86	0.000	.5209711	.6291755
lqua	.0600947	.0763755	0.79	0.432	-.0897882	.2099776
lstaff	.1360799	.0768275	1.77	0.077	-.0146901	.2868499
lfc	1.656188	.3858609	4.29	0.000	.8989553	2.41342
_Ipeer_2	-.2517586	.1338751	-1.88	0.060	-.5144816	.0109644
_Ipeer_3	-.3233779	.1558953	-2.07	0.038	-.6293144	-.0174414
_Ipeer_4	-.8525453	.1486131	-5.74	0.000	-1.144191	-.5608998
_Ipeer_5	-1.230788	.1835593	-6.71	0.000	-1.591014	-.8705624
_Ipeer_6	-1.589901	.3186108	-4.99	0.000	-2.215158	-.9646434
_Ipeer_7	-1.187972	.3588566	-3.31	0.001	-1.892209	-.4837339
_cons	-17.96844	4.653235	-3.86	0.000	-27.10018	-8.836709

Model 8

Source	SS	df	MS
Model	1540.55324	10	154.055324
Residual	1110.03536	798	1.39102175
Total	2650.5886	808	3.28043143

Number of obs	=	809
F(10, 798)	=	110.75
Prob > F	=	0.0000
R-squared	=	0.5812
Adj R-squared	=	0.5760
Root MSE	=	1.1794

ls8pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls8pub	.4926691	.030084	16.38	0.000	.4336159	.5517223
lqua	.4015085	.0862849	4.65	0.000	.2321363	.5708807
lstaff	-.2353507	.0856638	-2.75	0.006	-.4035037	-.0671976
lfc	1.242649	.461453	2.69	0.007	.3368434	2.148454
_Ipeer_2	-1.013005	.1516677	-6.68	0.000	-1.31072	-.7152906
_Ipeer_3	-1.124005	.1995455	-5.63	0.000	-1.515701	-.7323089
_Ipeer_4	-1.157043	.1764152	-6.56	0.000	-1.503336	-.8107502
_Ipeer_5	-1.377604	.2329599	-5.91	0.000	-1.834891	-.9203174
_Ipeer_6	-2.12566	.3148536	-6.75	0.000	-2.7437	-1.507621
_Ipeer_7	-2.790615	.6070613	-4.60	0.000	-3.982241	-1.59899
_cons	-9.014534	5.5341	-1.63	0.104	-19.87765	1.848579

Model 9

Source	SS	df	MS
Model	400.509156	10	40.0509156
Residual	1503.8402	683	2.20181582
Total	1904.34936	693	2.74797887

Number of obs	=	694
F(10, 683)	=	18.19
Prob > F	=	0.0000
R-squared	=	0.2103
Adj R-squared	=	0.1988
Root MSE	=	1.4839

ls9pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls9pub	.4265424	.0376496	11.33	0.000	.3526195	.5004653
lqua	-.122808	.1497548	-0.82	0.412	-.416843	.171227
lstaff	.100027	.125636	0.80	0.426	-.1466522	.3467062
lfc	.2792232	.6422205	0.43	0.664	-.9817404	1.540187
_Ipeer_2	-.0219692	.2280739	-0.10	0.923	-.4697794	.425841
_Ipeer_3	.5618688	.2518517	2.23	0.026	.0673724	1.056365
_Ipeer_4	.1900131	.2223089	0.85	0.393	-.2464779	.6265041
_Ipeer_5	.3114729	.2843334	1.10	0.274	-.2467996	.8697455
_Ipeer_6	.0192183	.3751314	0.05	0.959	-.7173309	.7557675
_Ipeer_7	1.191116	.4176848	2.85	0.004	.3710154	2.011216
_cons	-2.865725	7.759913	-0.37	0.712	-18.10187	12.37042

Model 10

Source	SS	df	MS
Model	943.057143	10	94.3057143
Residual	1197.65468	787	1.52179756
Total	2140.71182	797	2.68596213

Number of obs	=	798
F(10, 787)	=	61.97
Prob > F	=	0.0000
R-squared	=	0.4405
Adj R-squared	=	0.4334
Root MSE	=	1.2336

ls10pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls10pub	.4497968	.0277244	16.22	0.000	.3953743	.5042192
lqua	-.3512005	.1365353	-2.57	0.010	-.6192169	-.083184
lstaff	.2941492	.1236074	2.38	0.018	.05151	.5367885
lfc	1.867128	.4987238	3.74	0.000	.8881417	2.846114
_Ipeer_2	-.1920397	.176603	-1.09	0.277	-.5387084	.1546289
_Ipeer_3	-.9071124	.2044583	-4.44	0.000	-1.30846	-.5057643
_Ipeer_4	-.8054857	.1814376	-4.44	0.000	-1.161645	-.4493269
_Ipeer_5	-.9668303	.2276109	-4.25	0.000	-1.413627	-.5200339
_Ipeer_6	-.8623216	.3114108	-2.77	0.006	-1.473616	-.2510274
_Ipeer_7	-.9567873	.5183293	-1.85	0.065	-1.974259	.0606842
_cons	-22.26416	6.063275	-3.67	0.000	-34.16626	-10.36205

Model 11

Source	SS	df	MS
Model	141.462289	4	35.3655724
Residual	60.0135713	215	.27913289
Total	201.475861	219	.919981099

Number of obs	=	220
F(4, 215)	=	126.70
Prob > F	=	0.0000
R-squared	=	0.7021
Adj R-squared	=	0.6966
Root MSE	=	.52833

ls1pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls1pub	.9939634	.0623141	15.95	0.000	.8711386	1.116788
lqua	.2623596	.0567118	4.63	0.000	.1505774	.3741419
lstaff	.0539027	.0838435	0.64	0.521	-.1113578	.2191632
lfc	-1.449887	.4462549	-3.25	0.001	-2.329482	-.5702921
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	17.62041	5.249908	3.36	0.001	7.272535	27.96829

Model 12

Source	SS	df	MS
Model	8.44382798	4	2.110957
Residual	12.1436493	68	.178583078
Total	20.5874773	72	.285937185

Number of obs	=	73
F(4, 68)	=	11.82
Prob > F	=	0.0000
R-squared	=	0.4101
Adj R-squared	=	0.3754
Root MSE	=	.42259

ls2pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls2pub	.4737337	.0728918	6.50	0.000	.3282803	.619187
lqua	.1076663	.3140023	0.34	0.733	-.5189155	.734248
lstaff	-.1405531	.3376729	-0.42	0.679	-.8143689	.5332628
lfc	1.039065	.556822	1.87	0.066	-.0720566	2.150186
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-7.195956	6.971673	-1.03	0.306	-21.10771	6.7158

Model 13

Source	SS	df	MS
Model	108.943139	4	27.2357846
Residual	42.3212552	197	.214828707
Total	151.264394	201	.752559173

Number of obs	=	202
F(4, 197)	=	126.78
Prob > F	=	0.0000
R-squared	=	0.7202
Adj R-squared	=	0.7145
Root MSE	=	.4635

ls3pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls3pub	.6888472	.0655795	10.50	0.000	.5595193	.8181751
lqua	.8205736	.0477258	17.19	0.000	.7264546	.9146925
lstaff	.2488512	.1065758	2.33	0.021	.0386753	.4590271
lfc	.8040792	.3715145	2.16	0.032	.0714233	1.536735
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-7.822932	4.469052	-1.75	0.082	-16.63626	.990392

Model 14

Source	SS	df	MS
Model	122.591187	4	30.6477968
Residual	32.0056197	185	.17300335
Total	154.596807	189	.817972524

Number of obs	=	190
F(4, 185)	=	177.15
Prob > F	=	0.0000
R-squared	=	0.7930
Adj R-squared	=	0.7885
Root MSE	=	.41594

ls4pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls4pub	.8407298	.0439676	19.12	0.000	.7539875	.9274721
lqua	.1655083	.1296108	1.28	0.203	-.0901968	.4212135
lstaff	.4091182	.1406085	2.91	0.004	.131716	.6865204
lfc	1.239993	.3472978	3.57	0.000	.5548199	1.925167
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-16.84505	4.317764	-3.90	0.000	-25.36344	-8.326666

Model 15

Source	SS	df	MS
Model	78.4051589	4	19.6012897
Residual	78.2707163	83	.943020678
Total	156.675875	87	1.80087213

Number of obs	= 88
F(4, 83)	= 20.79
Prob > F	= 0.0000
R-squared	= 0.5004
Adj R-squared	= 0.4764
Root MSE	= .97109

ls5pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls5pub	.8291667	.0973129	8.52	0.000	.6356152	1.022718
lqua	-.910352	.6171712	-1.48	0.144	-2.137881	.3171767
lstaff	.5035688	.6291434	0.80	0.426	-.7477721	1.75491
lfc	2.544447	1.170309	2.17	0.033	.2167491	4.872145
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-35.51027	15.05424	-2.36	0.021	-65.45255	-5.567982

Model 16

Source	SS	df	MS
Model	196.302747	4	49.0756867
Residual	162.648909	165	.985750964
Total	358.951656	169	2.12397429

Number of obs	= 170
F(4, 165)	= 49.79
Prob > F	= 0.0000
R-squared	= 0.5469
Adj R-squared	= 0.5359
Root MSE	= .99285

ls6pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls6pub	.6651636	.0623429	10.67	0.000	.542071	.7882562
lqua	-.6855983	.320832	-2.14	0.034	-1.319064	-.0521331
lstaff	2.120265	.3219152	6.59	0.000	1.484661	2.755869
lfc	1.643211	.8631963	1.90	0.059	-.0611231	3.347545
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-36.49161	10.78676	-3.38	0.001	-57.78949	-15.19373

Model 17

Source	SS	df	MS
Model	85.9538418	4	21.4884605
Residual	47.6192557	175	.272110033
Total	133.573098	179	.746218422

Number of obs	=	180
F(4, 175)	=	78.97
Prob > F	=	0.0000
R-squared	=	0.6435
Adj R-squared	=	0.6353
Root MSE	=	.52164

ls7pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls7pub	.7632883	.0671818	11.36	0.000	.6306975	.8958791
lqua	.2085258	.1942202	1.07	0.284	-.1747897	.5918412
lstaff	.4333194	.1829885	2.37	0.019	.072171	.7944678
lfc	.9580269	.4479012	2.14	0.034	.0740436	1.84201
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-13.25402	5.579442	-2.38	0.019	-24.26567	-2.242359

Model 18

Source	SS	df	MS
Model	83.6028955	4	20.9007239
Residual	105.993235	185	.572936408
Total	189.596131	189	1.00315413

Number of obs	=	190
F(4, 185)	=	36.48
Prob > F	=	0.0000
R-squared	=	0.4410
Adj R-squared	=	0.4289
Root MSE	=	.75693

ls8pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls8pub	.6100706	.0601532	10.14	0.000	.4913962	.7287449
lqua	.3640204	.2536917	1.43	0.153	-.1364804	.8645211
lstaff	.0661063	.2555387	0.26	0.796	-.4380383	.5702508
lfc	1.98914	.6252536	3.18	0.002	.7555957	3.222684
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-21.19352	7.821054	-2.71	0.007	-36.62344	-5.763598

Model 19

Source	SS	df	MS
Model	35.0285178	4	8.75712945
Residual	247.919726	112	2.21356898
Total	282.948243	116	2.43920899

Number of obs	=	117
F(4, 112)	=	3.96
Prob > F	=	0.0048
R-squared	=	0.1238
Adj R-squared	=	0.0925
Root MSE	=	1.4878

ls9pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls9pub	.2568415	.0977659	2.63	0.010	.0631308	.4505521
lqua	-.499875	.6830119	-0.73	0.466	-1.853176	.8534256
lstaff	.8654102	.6055013	1.43	0.156	-.3343129	2.065133
lfc	2.874017	1.493809	1.92	0.057	-.0857747	5.833808
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-39.82764	18.95001	-2.10	0.038	-77.37466	-2.280629

Model 20

Source	SS	df	MS
Model	44.519344	4	11.129836
Residual	117.738335	144	.817627328
Total	162.257679	148	1.09633567

Number of obs	=	149
F(4, 144)	=	13.61
Prob > F	=	0.0000
R-squared	=	0.2744
Adj R-squared	=	0.2542
Root MSE	=	.90423

ls10pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls10pub	.406037	.0606892	6.69	0.000	.2860803	.5259938
lqua	-.2591206	.4162069	-0.62	0.535	-1.081785	.5635437
lstaff	.4778301	.4039034	1.18	0.239	-.3205153	1.276176
lfc	1.037018	.8411141	1.23	0.220	-.6255073	2.699543
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-13.46759	10.63917	-1.27	0.208	-34.49671	7.561526

Model 21

```
Fixed-effects (within) regression               Number of obs      =      1062
Group variable: id                              Number of groups   =       117

R-sq:  within  = 0.0979                         Obs per group: min =         1
       between = 0.7999                                        avg =       9.1
       overall = 0.4333                                        max =        10

                                                F(2,943)           =     51.18
corr(u_i, Xb)  = 0.6106                         Prob > F           =    0.0000

------------------------------------------------------------------------------
      ls1pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      ls1pub |   .0900942   .0314625     2.86   0.004     .0283497    .1518388
        lqua |          0  (omitted)
      lstaff |          0  (omitted)
         lfc |    1.98875    .228542     8.70   0.000      1.54024    2.437259
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |  -17.78386   2.673149    -6.65   0.000    -23.02986   -12.53785
-------------+----------------------------------------------------------------
     sigma_u |    2.31178
     sigma_e |  .62847138
         rho |  .93118045   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(116, 943) =    24.58            Prob > F = 0.0000
```

Model 22

```
Fixed-effects (within) regression               Number of obs      =       212
Group variable: id                              Number of groups   =        35

R-sq:  within  = 0.1061                         Obs per group: min =         1
       between = 0.7644                                        avg =       6.1
       overall = 0.7557                                        max =        10

                                                F(2,175)           =     10.39
corr(u_i, Xb)  = 0.8161                         Prob > F           =    0.0001

------------------------------------------------------------------------------
      ls2pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      ls2pub |   .3177422   .0755113     4.21   0.000      .168712    .4667723
        lqua |          0  (omitted)
      lstaff |          0  (omitted)
         lfc |   .5370234   .5877674     0.91   0.362    -.6230017    1.697048
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |  -2.146094   6.915991    -0.31   0.757    -15.79558    11.50339
-------------+----------------------------------------------------------------
     sigma_u |  1.5534791
     sigma_e |  .68492962
         rho |  .83724522   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(34, 175) =     9.60             Prob > F = 0.0000
```

Model 23

```
Fixed-effects (within) regression               Number of obs      =       943
Group variable: id                              Number of groups   =       108

R-sq:  within  = 0.0871                         Obs per group: min =         2
       between = 0.9029                                        avg =       8.7
       overall = 0.7826                                        max =        10

                                                F(2,833)           =     39.73
corr(u_i, Xb)  = 0.8625                         Prob > F           =    0.0000

------------------------------------------------------------------------------
      ls3pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      ls3pub |   .1947075   .0298773     6.52   0.000     .1360638    .2533512
        lqua |          0  (omitted)
      lstaff |          0  (omitted)
         lfc |   1.276106   .2260963     5.64   0.000     .8323202    1.719891
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |  -9.700211   2.683388    -3.61   0.000    -14.96721   -4.433214
-------------+----------------------------------------------------------------
     sigma_u |  1.7936382
     sigma_e |  .60596547
         rho |  .89755577   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(107, 833) =    12.70            Prob > F = 0.0000
```

Model 24

```
Fixed-effects (within) regression               Number of obs      =       976
Group variable: id                              Number of groups   =       107

R-sq:  within  = 0.1706                         Obs per group: min =         1
       between = 0.8446                                        avg =       9.1
       overall = 0.7145                                        max =        10

                                                F(2,867)           =     89.14
corr(u_i, Xb)  = 0.7532                         Prob > F           =    0.0000

------------------------------------------------------------------------------
      ls4pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      ls4pub |   .3314408   .0344849     9.61   0.000     .2637571    .3991245
        lqua |          0  (omitted)
      lstaff |          0  (omitted)
         lfc |   1.895303   .2233861     8.48   0.000     1.456862    2.333744
    _Ipeer_2 |          0  (omitted)
    _Ipeer_3 |          0  (omitted)
    _Ipeer_4 |          0  (omitted)
    _Ipeer_5 |          0  (omitted)
    _Ipeer_6 |          0  (omitted)
    _Ipeer_7 |          0  (omitted)
       _cons |   -18.1801   2.648532    -6.86   0.000    -23.37838   -12.98181
-------------+----------------------------------------------------------------
     sigma_u |  1.2395415
     sigma_e |   .6074235
         rho |  .80636182   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(106, 867) =    11.62            Prob > F = 0.0000
```

Model 25

```
Fixed-effects (within) regression               Number of obs      =       406
Group variable: id                              Number of groups   =        54

R-sq:  within  = 0.1051                         Obs per group: min =         1
       between = 0.6825                                        avg =       7.5
       overall = 0.4592                                        max =        10

                                                F(2,350)           =     20.56
corr(u_i, Xb)  = 0.5458                         Prob > F           =    0.0000
```

ls5pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls5pub	.3139448	.0549206	5.72	0.000	.2059289	.4219607
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.828335	.5157424	3.55	0.000	.8139914	2.842679
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-18.65944	6.175602	-3.02	0.003	-30.8054	-6.513487
sigma_u	1.1059992					
sigma_e	.88051928					
rho	.61206133	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(53, 350) =     5.57             Prob > F = 0.0000
```

Model 26

```
Fixed-effects (within) regression               Number of obs      =       899
Group variable: id                              Number of groups   =       112

R-sq:  within  = 0.0663                         Obs per group: min =         1
       between = 0.5257                                        avg =       8.0
       overall = 0.3426                                        max =        10

                                                F(2,785)           =     27.86
corr(u_i, Xb)  = 0.5054                         Prob > F           =    0.0000
```

ls6pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls6pub	.2193845	.0339221	6.47	0.000	.1527958	.2859732
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.283904	.3594795	3.57	0.000	.5782496	1.989559
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-11.68806	4.275292	-2.73	0.006	-20.08042	-3.295701
sigma_u	1.1528075					
sigma_e	.9326259					
rho	.60441676	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(111, 785) =     7.71            Prob > F = 0.0000
```

Model 27

```
Fixed-effects (within) regression               Number of obs      =       967
Group variable: id                              Number of groups   =       111

R-sq:  within  = 0.0474                         Obs per group: min =         1
       between = 0.7885                                        avg =       8.7
       overall = 0.5144                                        max =        10

                                                F(2,854)           =     21.26
corr(u_i, Xb)  = 0.7061                         Prob > F           =    0.0000
```

ls7pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls7pub	.1476355	.0367531	4.02	0.000	.0754985	.2197725
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.508546	.2925036	5.16	0.000	.9344357	2.082656
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-13.38041	3.486789	-3.84	0.000	-20.22409	-6.536729
sigma_u	1.7018991					
sigma_e	.79138145					
rho	.82221689	(fraction of variance due to u_i)				

F test that all u_i=0:   F(110, 854) =   10.17   Prob > F = 0.0000

Model 28

```
Fixed-effects (within) regression               Number of obs      =       809
Group variable: id                              Number of groups   =       104

R-sq:  within  = 0.0596                         Obs per group: min =         1
       between = 0.6431                                        avg =       7.8
       overall = 0.4399                                        max =        10

                                                F(2,703)           =     22.29
corr(u_i, Xb)  = 0.6258                         Prob > F           =    0.0000
```

ls8pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls8pub	.16496	.0399609	4.13	0.000	.0865029	.2434171
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.639226	.3647743	4.49	0.000	.9230486	2.355404
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-15.55358	4.309166	-3.61	0.000	-24.01395	-7.0932
sigma_u	1.4428117					
sigma_e	.89690064					
rho	.72127764	(fraction of variance due to u_i)				

F test that all u i=0:   F(103, 703) =   8.94   Prob > F = 0.0000

Model 29

```
Fixed-effects (within) regression               Number of obs      =       694
Group variable: id                              Number of groups   =       105

R-sq:  within  = 0.0455                         Obs per group: min =         1
       between = 0.2270                                        avg =       6.6
       overall = 0.1638                                        max =        10

                                                F(2,587)           =     13.99
corr(u_i, Xb)  = 0.2975                         Prob > F           =    0.0000

------------------------------------------------------------------------------
       ls9pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       ls9pub |   .1992858   .0444599     4.48   0.000      .111966    .2866056
         lqua |          0  (omitted)
       lstaff |          0  (omitted)
          lfc |   1.097388   .5267852     2.08   0.038     .0627745    2.132001
     _Ipeer_2 |          0  (omitted)
     _Ipeer_3 |          0  (omitted)
     _Ipeer_4 |          0  (omitted)
     _Ipeer_5 |          0  (omitted)
     _Ipeer_6 |          0  (omitted)
     _Ipeer_7 |          0  (omitted)
        _cons |  -10.33851   6.240587    -1.66   0.098     -22.5951     1.91809
-------------+----------------------------------------------------------------
      sigma_u |  1.2252964
      sigma_e |  1.1572749
          rho |  .52852637   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(104, 587) =     5.63             Prob > F = 0.0000
```

Model 30

```
Fixed-effects (within) regression               Number of obs      =       798
Group variable: id                              Number of groups   =       109

R-sq:  within  = 0.0333                         Obs per group: min =         1
       between = 0.5505                                        avg =       7.3
       overall = 0.3530                                        max =        10

                                                F(2,687)           =     11.82
corr(u_i, Xb)  = 0.5760                         Prob > F           =    0.0000

------------------------------------------------------------------------------
      ls10pri |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      ls10pub |   .1343102   .0350215     3.84   0.000     .0655482    .2030721
         lqua |          0  (omitted)
       lstaff |          0  (omitted)
          lfc |   1.307402   .3837279     3.41   0.001     .5539814    2.060822
     _Ipeer_2 |          0  (omitted)
     _Ipeer_3 |          0  (omitted)
     _Ipeer_4 |          0  (omitted)
     _Ipeer_5 |          0  (omitted)
     _Ipeer_6 |          0  (omitted)
     _Ipeer_7 |          0  (omitted)
        _cons |  -11.72429   4.585782    -2.56   0.011    -20.72812   -2.720461
-------------+----------------------------------------------------------------
      sigma_u |  1.2620336
      sigma_e |  .91062586
          rho |  .65761753   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(108, 687) =     8.33             Prob > F = 0.0000
```

Model 31

```
Fixed-effects (within) regression               Number of obs      =       220
Group variable: id                              Number of groups   =        22

R-sq:  within  = 0.4997                         Obs per group: min =        10
       between = 0.7177                                        avg =      10.0
       overall = 0.6384                                        max =        10

                                                F(2,196)           =     97.87
corr(u_i, Xb)  = 0.5816                         Prob > F           =    0.0000
```

ls1pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls1pub	.4547375	.0455108	9.99	0.000	.3649838	.5444911
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	.1858371	.2112036	0.88	0.380	-.2306863	.6023605
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	3.43556	2.248627	1.53	0.128	-.9990508	7.87017
sigma_u	.68015954					
sigma_e	.20890042					
rho	.91379983	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(21, 196) =     64.65          Prob > F = 0.0000
```

Model 32

```
Fixed-effects (within) regression               Number of obs      =        73
Group variable: id                              Number of groups   =         9

R-sq:  within  = 0.2882                         Obs per group: min =         1
       between = 0.7229                                        avg =       8.1
       overall = 0.4058                                        max =        10

                                                F(2,62)            =     12.55
corr(u_i, Xb)  = 0.2241                         Prob > F           =    0.0000
```

ls2pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls2pub	.3627515	.0965338	3.76	0.000	.1697831	.5557198
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.039282	.4093296	2.54	0.014	.2210433	1.85752
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-7.655762	4.781893	-1.60	0.114	-17.21463	1.903105
sigma_u	.37033702					
sigma_e	.29804045					
rho	.60691635	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(8, 62) =      9.38            Prob > F = 0.0000
```

Model 33

```
Fixed-effects (within) regression               Number of obs      =       202
Group variable: id                              Number of groups   =        21

R-sq:  within  = 0.3584                         Obs per group: min =         2
       between = 0.3782                                        avg =       9.6
       overall = 0.2649                                        max =        10

                                                F(2,179)           =     50.00
corr(u_i, Xb)  = 0.1512                         Prob > F           =    0.0000
```

ls3pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls3pub	.3877318	.0756692	5.12	0.000	.2384133	.5370504
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.229939	.1962285	6.27	0.000	.84272	1.617158
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-9.206499	2.189466	-4.20	0.000	-13.52698	-4.886014
sigma_u	.78476041					
sigma_e	.2293632					
rho	.92130006	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(20, 179) =     95.83             Prob > F = 0.0000
```

Model 34

```
Fixed-effects (within) regression               Number of obs      =       190
Group variable: id                              Number of groups   =        19

R-sq:  within  = 0.5229                         Obs per group: min =        10
       between = 0.8098                                        avg =      10.0
       overall = 0.7280                                        max =        10

                                                F(2,169)           =     92.63
corr(u_i, Xb)  = 0.6057                         Prob > F           =    0.0000
```

ls4pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls4pub	.5089792	.0780292	6.52	0.000	.3549418	.6630166
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.676266	.2215485	7.57	0.000	1.238906	2.113625
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-15.98472	2.390695	-6.69	0.000	-20.70419	-11.26525
sigma_u	.53353652					
sigma_e	.23848739					
rho	.83346999	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(18, 169) =     26.92             Prob > F = 0.0000
```

Model 35

```
Fixed-effects (within) regression               Number of obs      =        88
Group variable: id                              Number of groups   =        10

R-sq:  within  = 0.2259                         Obs per group: min =         1
       between = 0.6842                                        avg =       8.8
       overall = 0.4628                                        max =        10

                                                F(2,76)            =     11.09
corr(u_i, Xb)  = 0.4482                         Prob > F           =    0.0001
```

ls5pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls5pub	.4504848	.1280586	3.52	0.001	.1954339	.7055357
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	2.937063	.9892378	2.97	0.004	.9668249	4.9073
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-32.08936	11.76038	-2.73	0.008	-55.51219	-8.666529
sigma_u	.74838222					
sigma_e	.80438998					
rho	.46397734	(fraction of variance due to u_i)				

F test that all u_i=0: F(9, 76) = 5.47 Prob > F = 0.0000

Model 36

```
Fixed-effects (within) regression               Number of obs      =       170
Group variable: id                              Number of groups   =        19

R-sq:  within  = 0.0514                         Obs per group: min =         2
       between = 0.3681                                        avg =       8.9
       overall = 0.1904                                        max =        10

                                                F(2,149)           =      4.04
corr(u_i, Xb)  = 0.3724                         Prob > F           =    0.0196
```

ls6pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls6pub	.0982495	.1156834	0.85	0.397	-.1303425	.3268415
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.926314	.7204995	2.67	0.008	.5025971	3.35003
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-18.06767	8.567187	-2.11	0.037	-34.99654	-1.138792
sigma_u	1.1671048					
sigma_e	.82530401					
rho	.66664714	(fraction of variance due to u_i)				

F test that all u_i=0: F(18, 149) = 9.48 Prob > F = 0.0000

Model 37

```
Fixed-effects (within) regression               Number of obs      =       180
Group variable: id                              Number of groups   =        18

R-sq:  within  = 0.1993                         Obs per group: min =        10
       between = 0.7933                                        avg =      10.0
       overall = 0.4835                                        max =        10

                                                F(2,160)           =     19.92
corr(u_i, Xb)  = 0.5713                         Prob > F           =    0.0000
```

ls7pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls7pub	.2660417	.0980044	2.71	0.007	.0724927	.4595907
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	1.527255	.3405079	4.49	0.000	.8547853	2.199725
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-13.07755	3.867832	-3.38	0.001	-20.71614	-5.438963
sigma_u	.63294334					
sigma_e	.38006862					
rho	.73498394	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(17, 160) =     11.99             Prob > F = 0.0000
```

Model 38

```
Fixed-effects (within) regression               Number of obs      =       190
Group variable: id                              Number of groups   =        19

R-sq:  within  = 0.2201                         Obs per group: min =        10
       between = 0.5695                                        avg =      10.0
       overall = 0.1423                                        max =        10

                                                F(2,169)           =     23.85
corr(u_i, Xb)  = 0.1762                         Prob > F           =    0.0000
```

ls8pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls8pub	.0612267	.0731679	0.84	0.404	-.083214	.2056674
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	2.451655	.3703067	6.62	0.000	1.720632	3.182678
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-23.03457	4.348647	-5.30	0.000	-31.61923	-14.4499
sigma_u	.86128012					
sigma_e	.44349135					
rho	.79042399	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(18, 169) =     21.63             Prob > F = 0.0000
```

Model 39

```
Fixed-effects (within) regression               Number of obs      =       117
Group variable: id                              Number of groups   =        18

R-sq:  within  = 0.1301                         Obs per group: min =         1
       between = 0.3709                                        avg =       6.5
       overall = 0.0631                                        max =        10

                                                F(2,97)            =      7.26
corr(u_i, Xb)  = -0.0851                        Prob > F           =    0.0012
```

ls9pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls9pub	.0593308	.1247831	0.48	0.636	-.188329	.3069907
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	4.751005	1.37889	3.45	0.001	2.01429	7.487721
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	-53.38459	16.24545	-3.29	0.001	-85.62731	-21.14186
sigma_u	1.2982326					
sigma_e	1.2869516					
rho	.50436365	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(17, 97) =     3.28             Prob > F = 0.0001
```

Model 40

```
Fixed-effects (within) regression               Number of obs      =       149
Group variable: id                              Number of groups   =        17

R-sq:  within  = 0.0180                         Obs per group: min =         1
       between = 0.6194                                        avg =       8.8
       overall = 0.2572                                        max =        10

                                                F(2,130)           =      1.19
corr(u_i, Xb)  = 0.4558                         Prob > F           =    0.3077
```

ls10pri	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ls10pub	.1117966	.0821556	1.36	0.176	-.0507385	.2743317
lqua	0	(omitted)				
lstaff	0	(omitted)				
lfc	-.0135558	.5546346	-0.02	0.981	-1.110834	1.083722
_Ipeer_2	0	(omitted)				
_Ipeer_3	0	(omitted)				
_Ipeer_4	0	(omitted)				
_Ipeer_5	0	(omitted)				
_Ipeer_6	0	(omitted)				
_Ipeer_7	0	(omitted)				
_cons	5.13755	6.837029	0.75	0.454	-8.388694	18.6638
sigma_u	1.0063698					
sigma_e	.52986576					
rho	.78295361	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(16, 130) =    18.39            Prob > F = 0.0000
```

Addendum B

Table 43. Description of variables

Variable code	Variable	Description
ID	Institution identifier	*Institution identifier is the unique identifier allocated to institutions by HESA.*
YEAR	Year	*This variable identifies the year of the observation, i.e. 2004 refers to the institutions' financial year 1 August 2003 to 31 July 2004.*
S1_PUB	Medicine, dentistry & health public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of medicine, dentistry & health. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S1_PRIV	Medicine, dentistry & health private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of medicine, dentistry & health (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S2_PUB	Agriculture, forestry & veterinary science public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of agriculture, forestry & veterinary science. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S2_PRIV	Agriculture, forestry & veterinary science private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of agriculture, forestry & veterinary science (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S3_PUB	Biological, mathematical & physical sciences public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of biological, mathematical & physical sciences. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S3_PRIV	Biological, mathematical & physical sciences private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of biological, mathematical & physical sciences (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S4_PUB	Engineering & technology public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of engineering & technology. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S4_PRIV	Engineering & technology public income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of engineering & technology (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S5_PUB	Architecture & planning public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of architecture & planning. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S5_PRIV	Architecture & planning private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of architecture & planning (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S6_PUB	Administrative & business studies public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of administrative & business studies. It is sourced from HESA financial data relating to "Research Grants and Contracts".*

S6_PRIV	Administrative & business studies private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of administrative & business studies (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S7_PUB	Social studies public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of social studies. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S7_PRIV	Social studies private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of social studies (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S8_PUB	Humanities & language based studies & archaeology public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of humanities & language based studies & archaeology. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S8_PRIV	Humanities & language based studies & archaeology private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of humanities & language based studies & archaeology (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S9_PUB	Design, creative & performing arts public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of design, creative & performing arts. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S9_PRIV	Design, creative & performing arts private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of design, creative & performing arts (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S10_PUB	Education public income	*This variable comprises all UK public income of a HEI that relates to research grants and contracts in the subject area of education. It is sourced from HESA financial data relating to "Research Grants and Contracts".*
S10_PRIV	Education private income	*This variable comprises all other income of a HEI that relates to research grants and contracts in the subject area of education (UK private and abroad private and public). It is sourced from HESA financial data relating to "Research Grants and Contracts".*
QUA	Quality	*This variable captures the "quality" of a HEI by dividing the number of academic staff FTE by the number of total students FTE*
STAFF	Total staff FTE	*Staff full-time equivalent (FTE) is defined by the contracts of employment and is proportioned to each activity's cost centre. FTE indicates the proportion of a full-time year being undertaken over the course of the reporting period 1 August to 31 July. The FTE is therefore counted using a population of staff who were active during the reporting period, not just on a given snapshot date, and uses the HESA staff contract session population.*
FC	Fixed capital	*ONS*
PEER	Peer group	*This variable captures each HEI's peer group and is a proxy for quality.*

Addendum C

10 main subject areas[43]:

1. Medicine, dentistry & health
2. Agriculture, forestry & veterinary science
3. Biological, mathematical & physical sciences
4. Engineering & technology
5. Architecture & planning
6. Administrative & business studies
7. Social studies
8. Humanities & language based studies & archaeology
9. Design, creative & performing arts
10. Education

Table 44. Mapping for 2012/13 subjects to 10 main subject areas

Subject code	2012/13 Subjects	Mapping
101	Clinical medicine	1
102	Clinical dentistry	1
103	Nursing & allied health professions	1
104	Psychology & behavioural sciences	1
105	Health & community studies	1
106	Anatomy & physiology	1
107	Pharmacy & pharmacology	1
108	Sports science & leisure studies	10
109	Veterinary science	2
110	Agriculture, forestry & food science	2
111	Earth, marine and environmental sciences	3
112	Biosciences	3
113	Chemistry	3
114	Physics	3
115	General engineering	4
116	Chemical engineering	4
117	Mineral, metallurgy & materials engineering	4
118	Civil engineering	4
119	Electrical, electronic & computer engineering	4
120	Mechanical, aero & production engineering	4
121	IT, systems science & computer software engineering	4
122	Mathematics	3
123	Architecture, built environment & planning	5

[43] *Taken from HESA (2014), Staff Statistics 2012/13, Table 16.*

124	Geography	7
125	Area studies	8
126	Archaeology	8
127	Anthropology & development studies	7
128	Politics & international studies	7
129	Economics & econometrics	7
130	Law	7
131	Social work & social policy	7
132	Sociology	7
133	Business & management studies	6
134	Catering & hospitality management	6
135	Education	10
136	Continuing education	10
137	Modern languages	8
138	English language & literature	8
139	History	8
140	Classics	8
141	Philosophy	8
142	Theology & religious studies	8
143	Art & design	9
144	Music, dance, drama & performing arts	9
145	Media studies	7

13. Annex G– MRC data analysis

This annex presents our analysis of the MRC data.

13.1. Overview of data

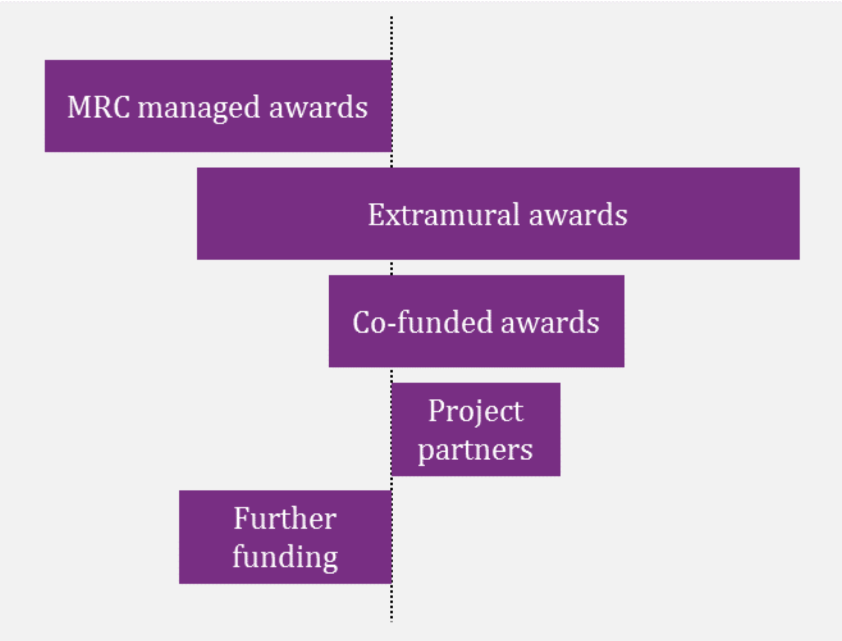
MRC has provided us with various datasets to enable us to explore further funding. Further funding occurs when additional funds are attained to explore new, but related, research as a result of an MRC-funded award. These further funds could be from a public sector organisation (such as a RC, including MRC) or a private sector organisation (such as a business or charity).

There are a number of distinctions that are important to the interpretation of the data that was supplied:

- ***Intramural awards*** are funding allocations to MRC units, such as the MRC Laboratory of Molecular Biology.
- ***Extramural awards*** are funding allocations to external organisations or individuals which have applied specifically for MRC funding.
- MRC does not ***manage*** some of the extramural awards it gives, and as such does not have the same amount of information on them compared to awards that they do manage.
- ***Co-funding*** arises where a sponsoring organisation has agreed to contribute to the costs of a project in partnership with a RC. Co-funders could be, for example, other RCs or private sector organisations.
- A ***project partner*** is an organisation that provides a specific contribution to an award but is not seeking funding from the RC for its involvement.

MRC has provided five datasets and the relationship between them is illustrated in the figure below.

Figure 106.



Note: sizes not to any scale

'MRC managed awards' contains all of the awards included in Researchfish, broadly those active on or after 1st April 2006. It includes the awards managed by MRC and covers both those that are intramural and extramural. 'Extramural awards' contains data on extramural awards, including those that are not managed by MRC. 'Co-funding awards' includes data on co-funded awards that MRC has contributed to. This includes both cases of where MRC does and does not manage the award. 'Project partners' consists of data on the contributions of project partners – which is not managed by MRC. 'Further funding' contains information on the instances of further funding.

As we understand it, co-funding, project partner, and further funding data is based on information reported by PIs and is not always complete. That is, the data that we have may not represent all cases of the type of funding under consideration.

As this analysis package is primarily concerned with further funding, we start with an overview of the data contained in 'further funding'.

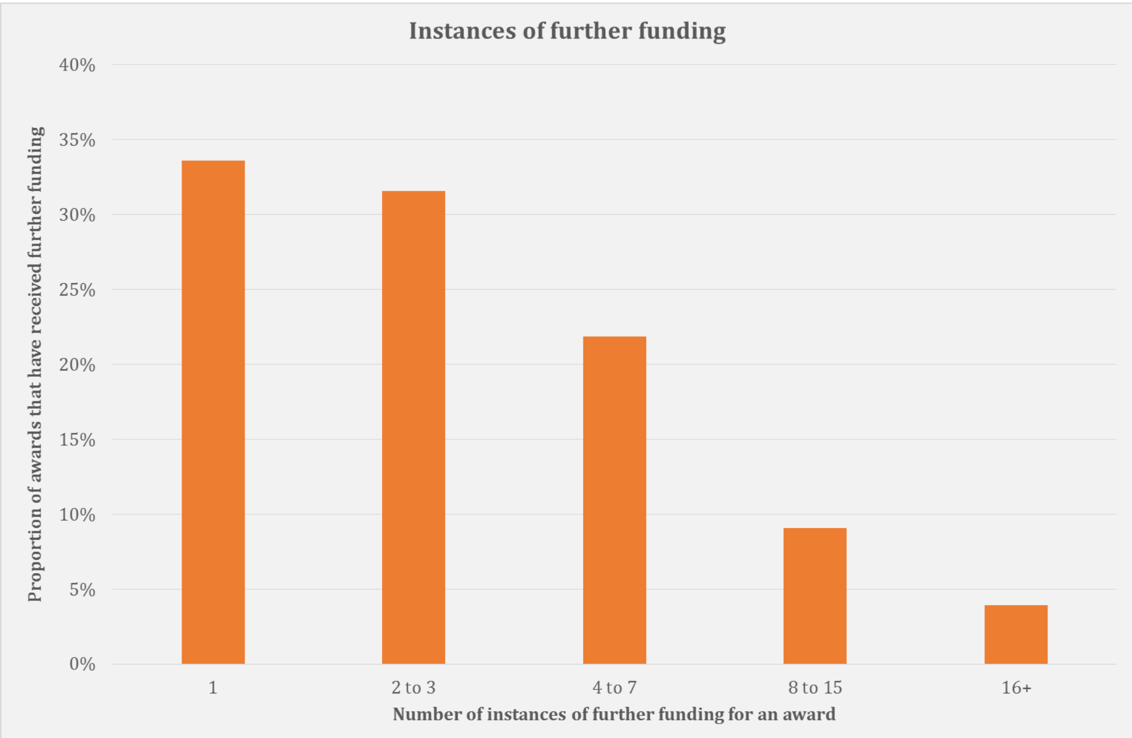
Further funding

The further funding dataset contains the following variables of interest:

- Original award title
- Research organisation
- Original award start date
- Original award end date
- Further funder organisation
- Further funder sector
- Further fund amount
- Further funding start date
- Further funding end date

The dataset contains 15,104 observations of further funding which relate to 3,100 unique original awards – an award can receive multiple instances of further funding. The chart below shows the distribution of the number of instances of further funding that awards have received.

Figure 107.



As can be seen, about a third of awards that have received further funding have only so far reported one instance of further funding. There are a number of awards that have reported very large numbers of further funding – the largest being 289 instances of further funding.

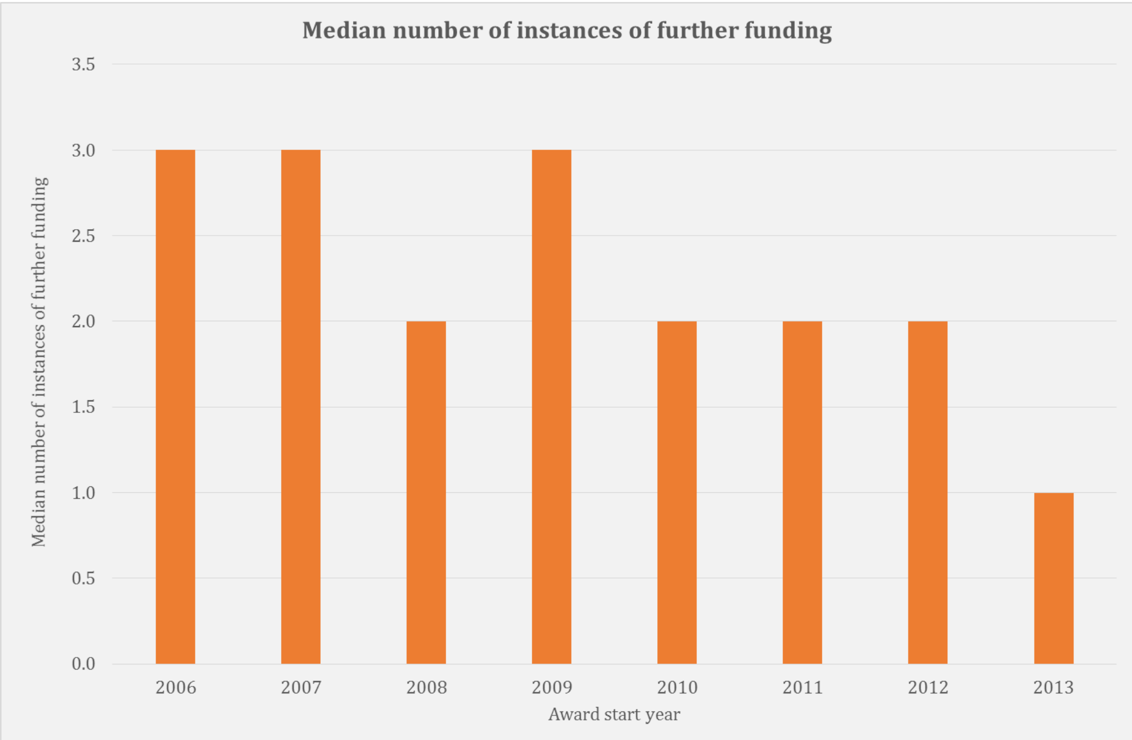
Awards that started longer ago have naturally had longer to attract further funding, and one could reasonably expect that there is a positive correlation between the start date of an award and the number of instances of further funding that have been recorded against it.

The fact that the dataset comprises broadly those awards active on or after 1st April 2006 may influence any correlations computed using the whole set. Older projects will appear in the dataset if they were active on 1st April 2006, but their counterparts that finished before will not be included. The sample of awards that started prior to 2006 may therefore not be an accurate representation of awards, and in any case our sample will underrepresent them.

Our analysis suggests that there is a correlation between the age of a project and the number of instances of further funding that it has received. Due to the discussions above, we have computed the correlation coefficient using awards with a start date of 2006-2013, and removed those that have received more than 15 instances of further funding. The resulting correlation coefficient is -0.1 (i.e. newer project that have a higher date value have less instances of further funding).

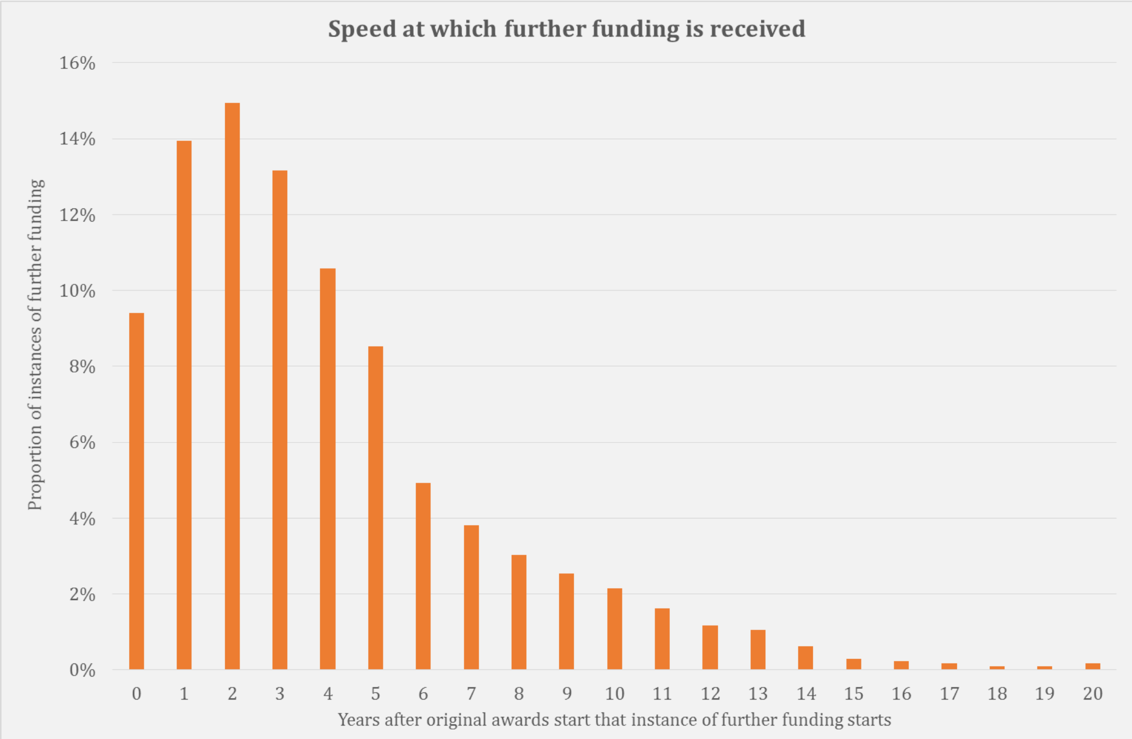
The weak negative correlation can also be seen by looking at the average instances of further funding by project start date. To reduce the effect of outliers, the chart below shows the median (rather than the mean) number of instances of further funding received by awards started in different years. As can be seen, the median tends to be lower for more recent award start years.

Figure 108.



The chart below shows how quickly the instances of further funding were received. Specifically, the chart shows the years between the start of the original award, and the start of the further funding. The chart has been constrained to between 0 and 20 years – there is a long tail of large values and some instances of further funding are reported to have started before the original award. About 50% of instances of further funding were received within three years of the original award starting.

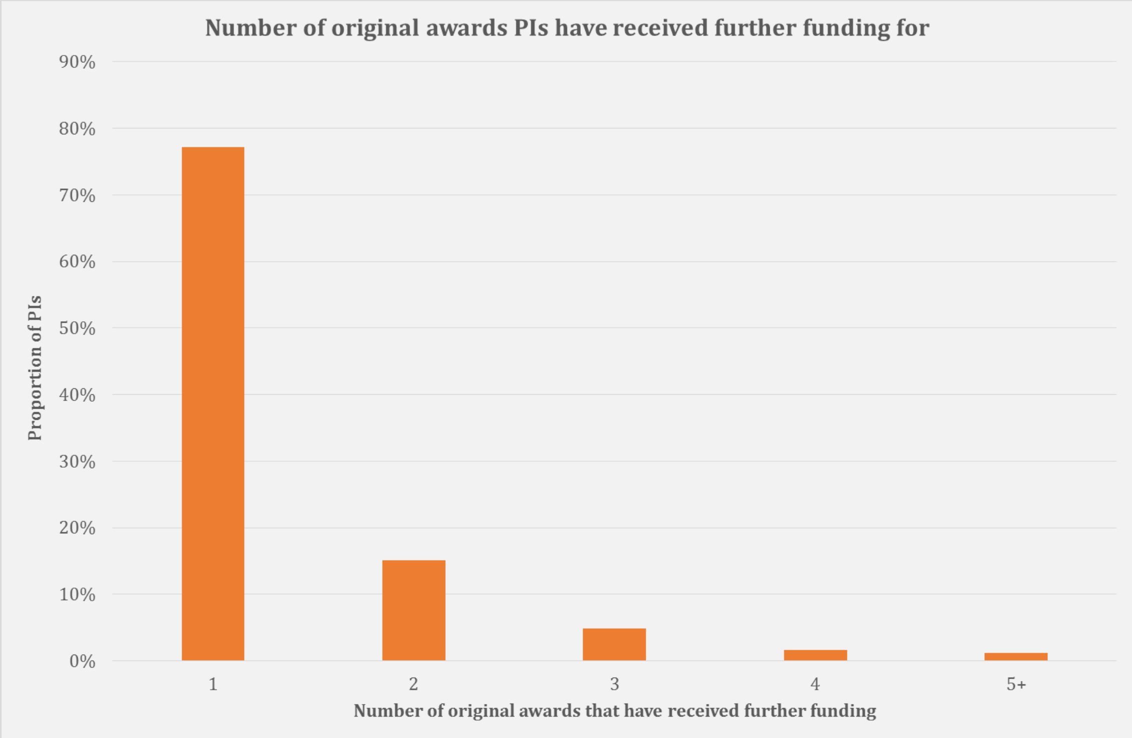
Figure 109.



This gives us an indication of the speed at which further funding is received. The majority of the instances of further funding are received within the first three years of the original award starting, but there are instances of further funding being received much further into the future.

Within the 3,100 original awards that received further funding there are 2,288 unique PIs. That is, within our dataset there are some PIs that led multiple projects that received further funding. The chart below shows the distribution of the number of awards that PIs have received further funding for. As can be seen, the majority of PIs in our dataset have only led one project that has received further funding. 15% of PIs in the sample have led two projects that have received further funding.

Figure 110.

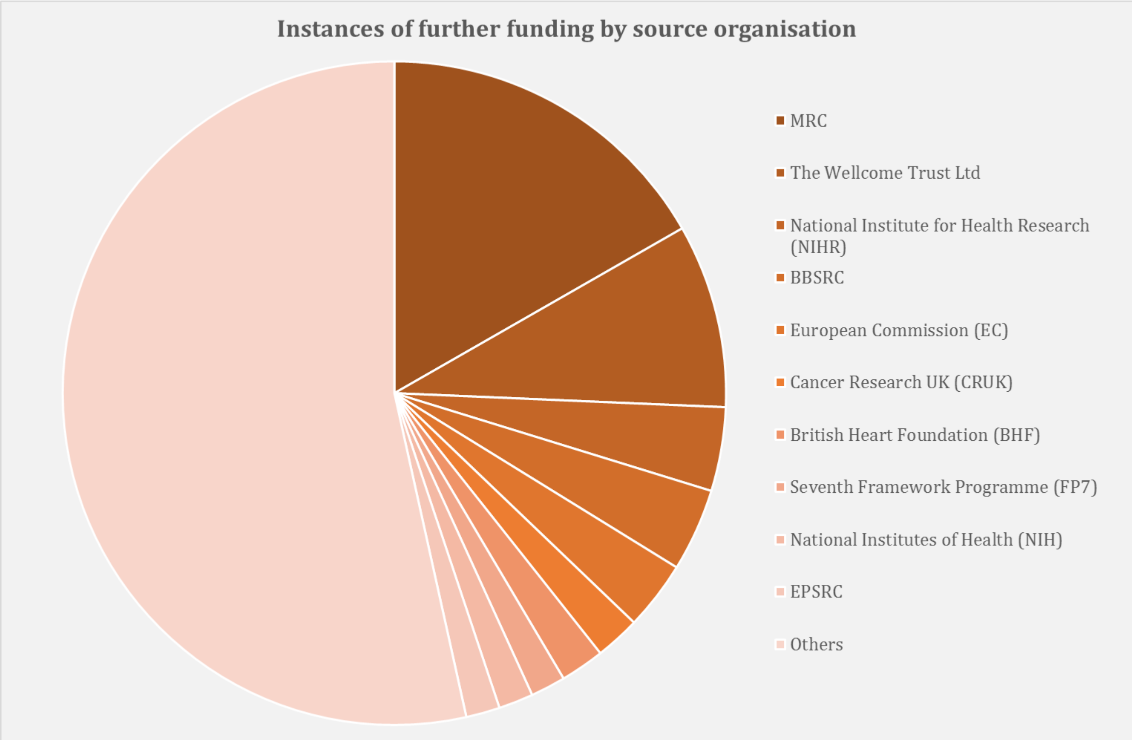


One could reasonably hypothesise that a PI that has received further funding for one award may find it easier to attract further funding for another award. Having successfully done it once, they may be more familiar with the mechanisms through which it is attained – in essence, a learning effect.

The dataset includes a 'funding type' variable, however almost all observations have not been assigned a category. It appears that, when complete, this variable will denote the use of the funding e.g. capital or resource.

The organisation which supplied the further funding is also given. The chart below pulls out the top ten organisations in terms of the number of further funding observations we have. As can be seen, MRC has the highest number of instances of further funding, followed by the Welcome Trust. There is a significantly large number of organisations in the 'Others' category.

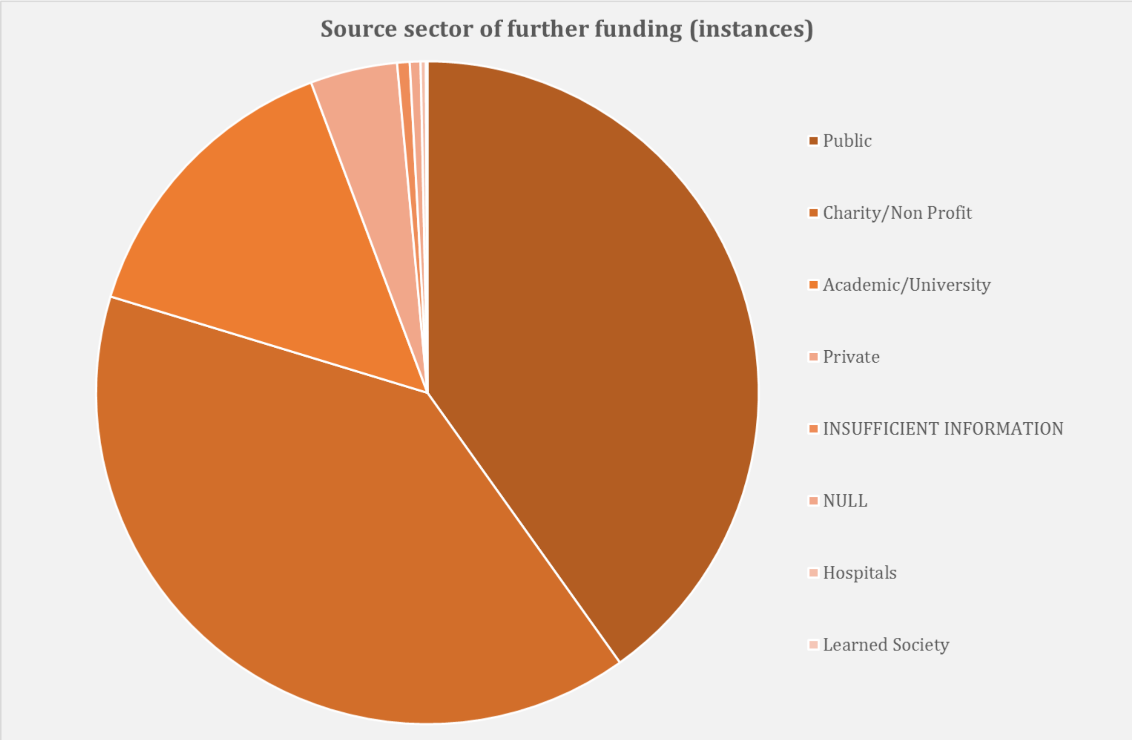
Figure 111.



It is our understanding, however, that a significant proportion of further funding that is reported as coming from MRC is actually part of the original funding – and as such MRC removes these observations from its own analysis. It should also be noted that the MRC category in the chart above is based on only awards that are labelled from as being from "Medical Research Council (MRC)". There are a number of observations labelled as coming from variations of MRC – such as "MRC Cognition and Brain Sciences Unit" and "Medical Research Council (MRC) and GSK". We have not conducted any cleaning of the data to adjust for this.

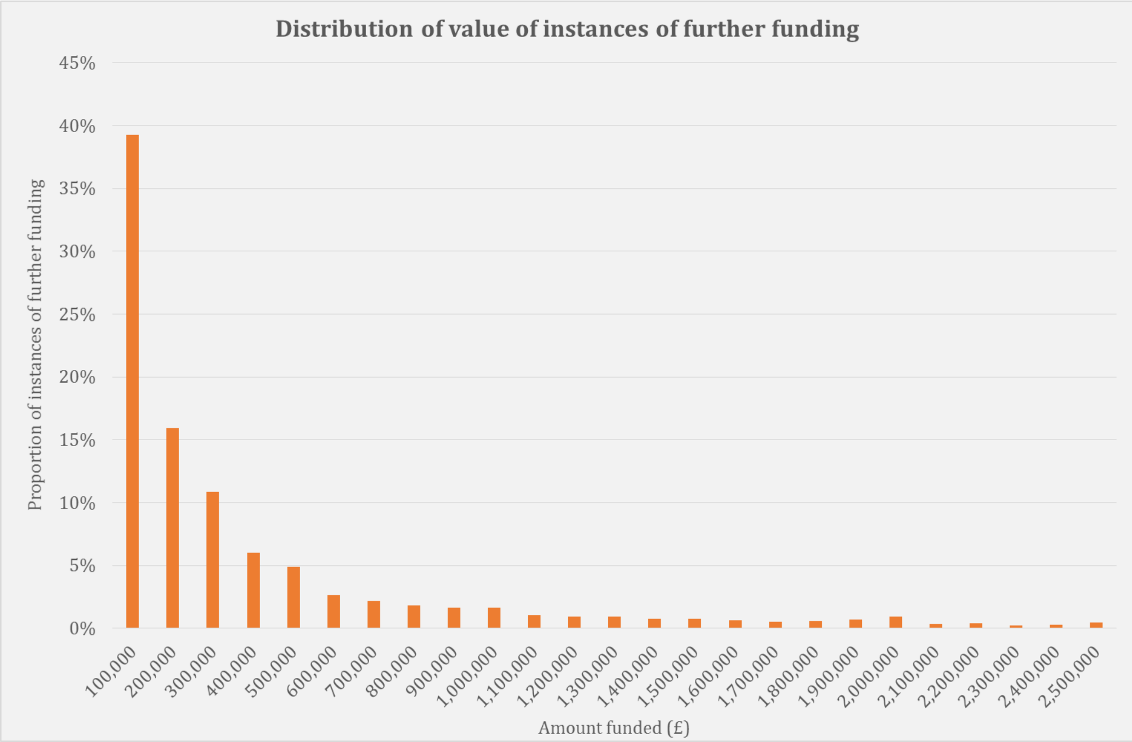
Observations are mapped to sector from which the further funding came from. As can be seen by the chart below, the public sector is the largest source of follow-on funding followed by charities. The private sector accounts for a relatively small number of instances of further funding.

Figure 112.



Importantly, the value of the instances of further funding is given in the dataset. Values vary significantly and the distribution is heavily skewed towards smaller awards – about 40% are less than £100,000 – but there is an extremely long tail. The largest award in our dataset is £95m which is for a biomedical research centre. The chart below illustrates the distribution, and for presentational reasons is cut off at £2.5m.

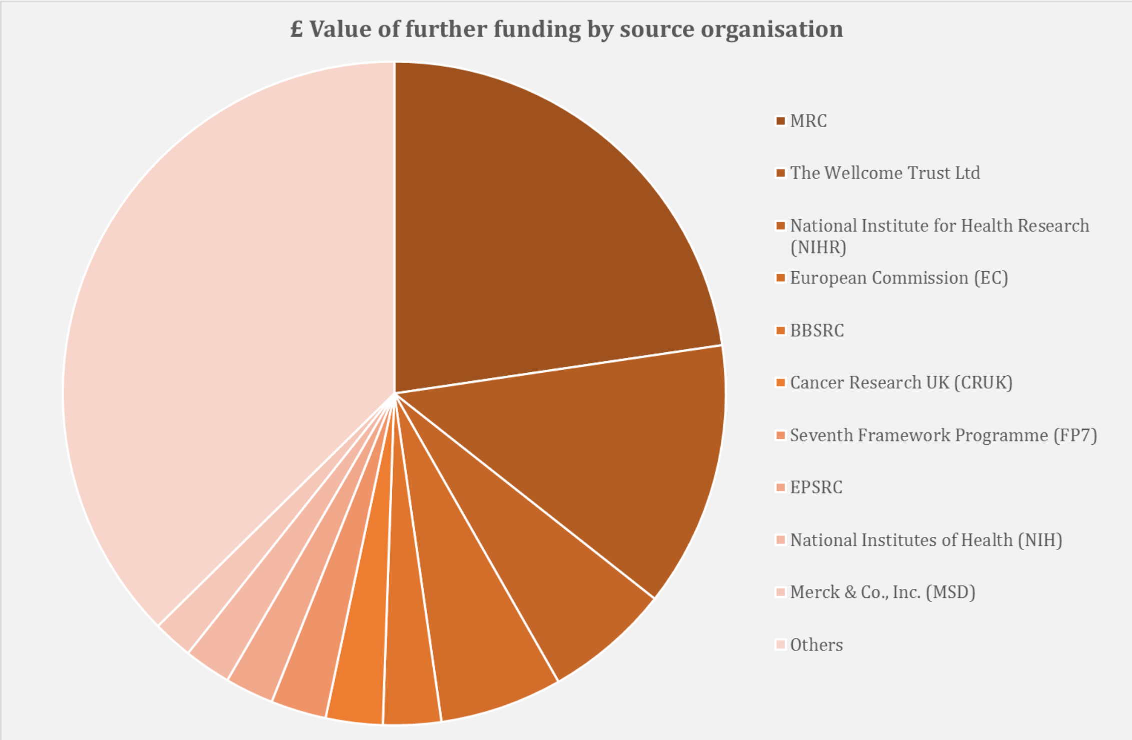
Figure 113.



By reviewing the descriptions of the awards, we are aware that the very small awards, such as those under £1,000, are often travel bursaries (awards of £1,000 or less represent only 3% of observations).

The chart below shows the value of further funding from the top ten contributors, and others. As noted previously, a proportion of the MRC further funding may in fact be part of the original award.

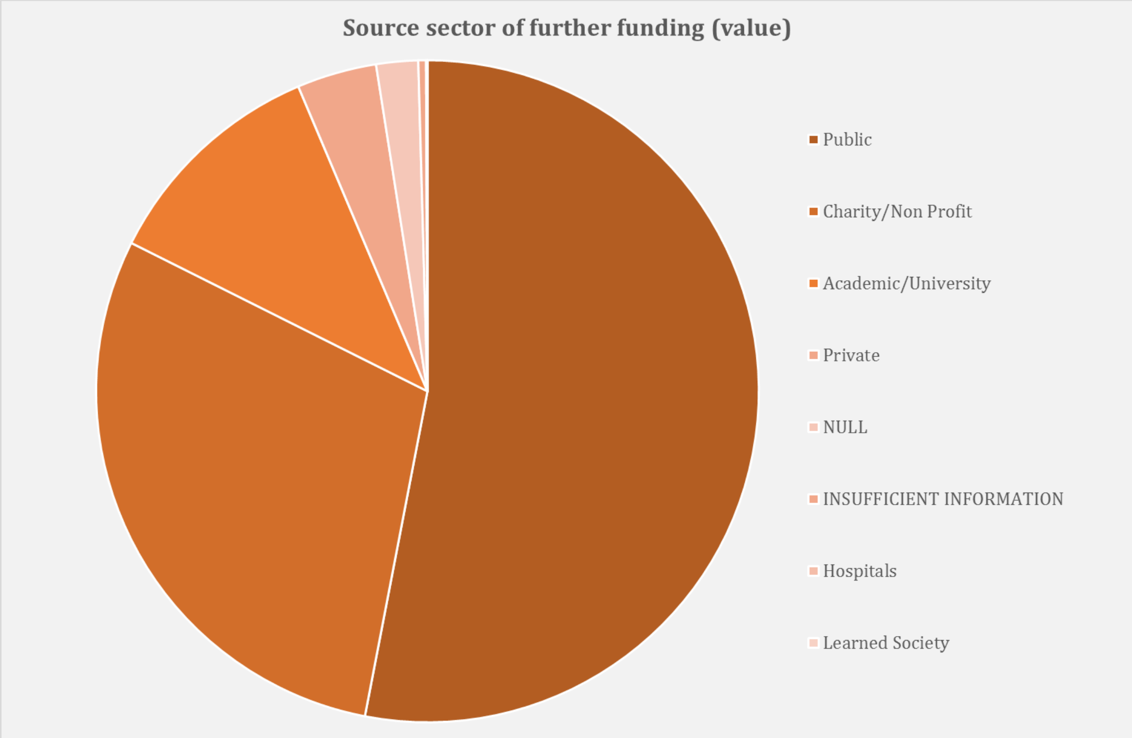
Figure 114.



Comparing this figure with the equivalent figure based on instances of further funding, we can deduce that those who provide more instances of further funding award higher values, compared with those who provide fewer instances of further funding. Put another way, The Welcome Trust, for example, provides more instances of further funding and, on average, higher values of further funding.

The figure below shows the source of further funding on a value basis and is comparable to the equivalent chart on the basis of instances of further funding.

Figure 115.



By comparing the two charts one can see that the public sector accounts for relatively more of the value of further funding compared to the instances of further funding. As such, instances of further funding are on average of higher value than occurrences of further funding from other sources.

In order to make comparisons between awards that have received further funding and those that have not, we have reviewed the MRC managed awards dataset, as set out below.

MRC managed awards

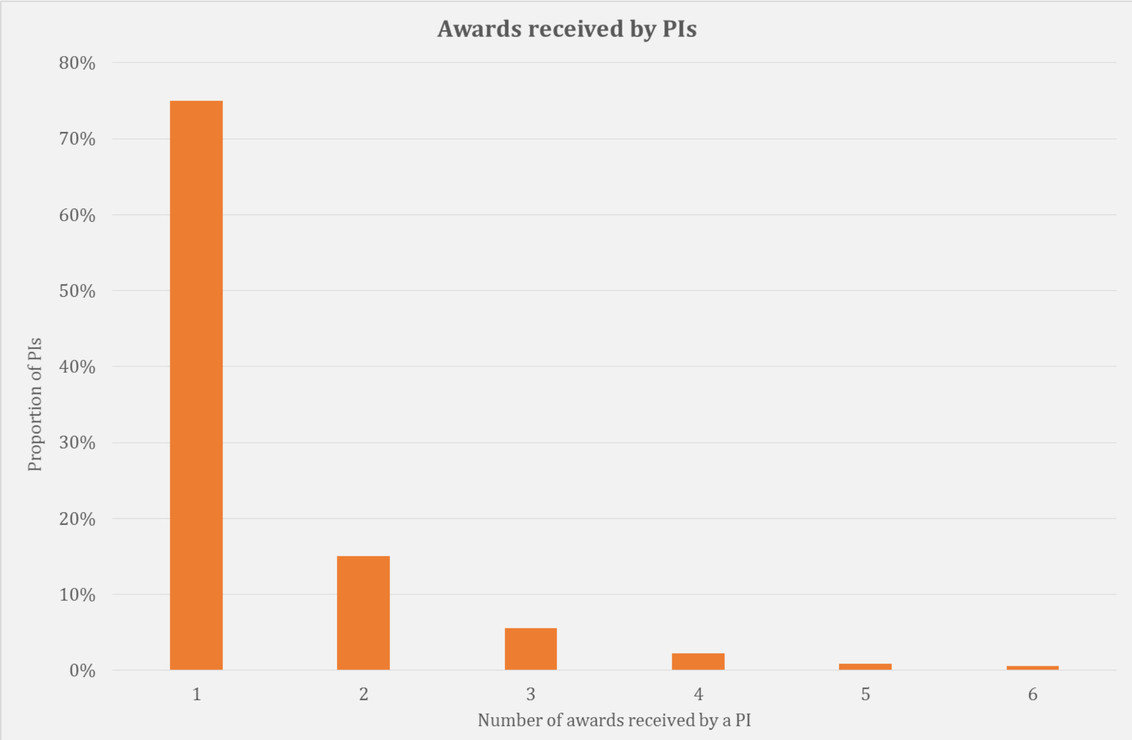
The MRC managed awards dataset contains details of awards managed by MRC that were active from 1st April 2006 onwards. The following variables are included:

- Award title
- Research organisation
- Principal investigator
- Start date
- End date
- Actual spend for 2006-2013
- Total funding amount

Data on 5,661 awards are given, which represents over £3.6bn of spending over the period 2006-2013.

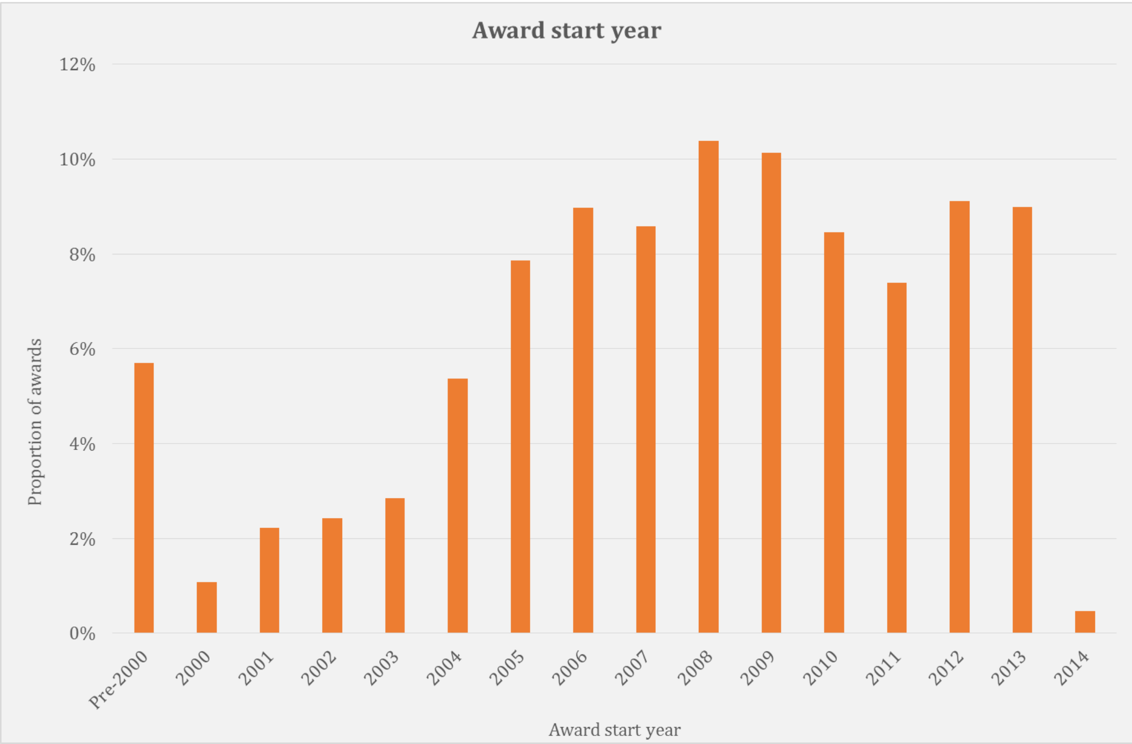
There are 3,926 unique PIs in our dataset i.e. some PIs have received more than one award from MRC in the time period. The chart below shows the number of awards won by PIs. As can be seen, 75% of PIs in our dataset received one award and 15% received two awards. There are a very small number of PIs that have received more than 10 awards (not shown on the chart) - the most being 14.

Figure 116.



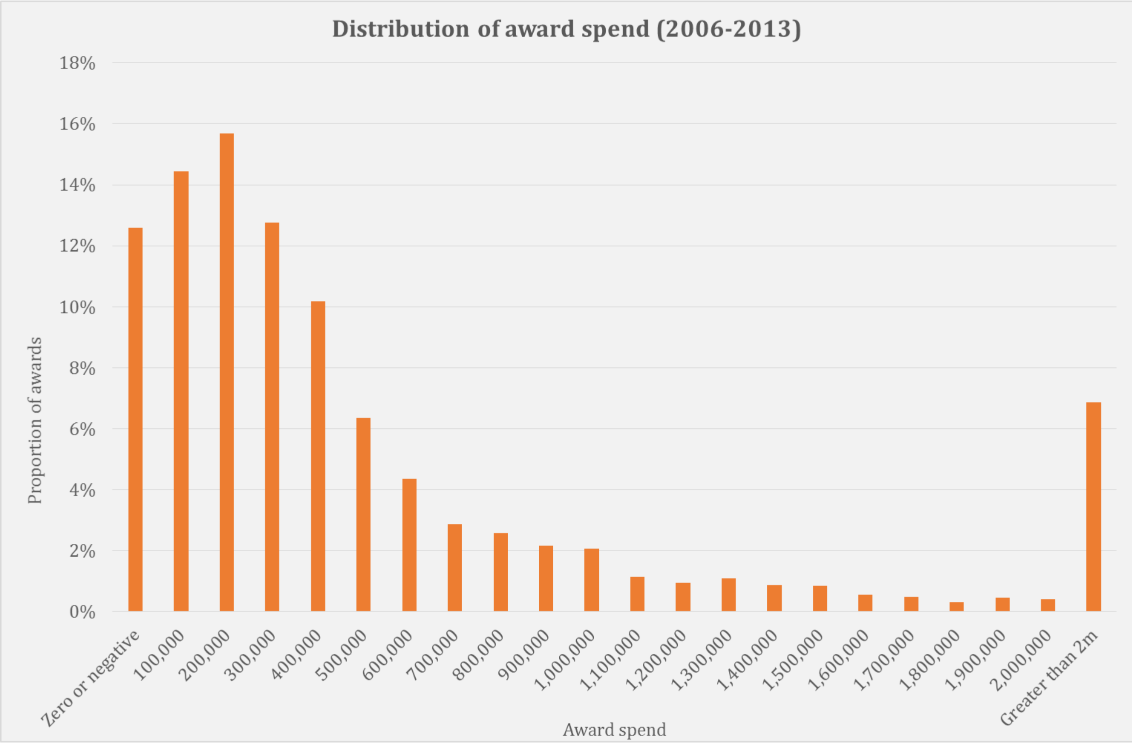
As noted above, the dataset contains awards that were active from 1st April 2006 onwards – some of which started many years before that. The chart below shows the distribution of award start dates within the sample. As can be seen, a significant proportion started before 2006.

Figure 117.



The distribution of award spend (between 2006 and 2013), like the amount of further funding, is heavily skewed. We have been informed that negative values can occur where costs have been reconciled. As can be seen, award spend is concentrated around £100,000 to £200,000 – but there are a number of cases of award spend over £2m.

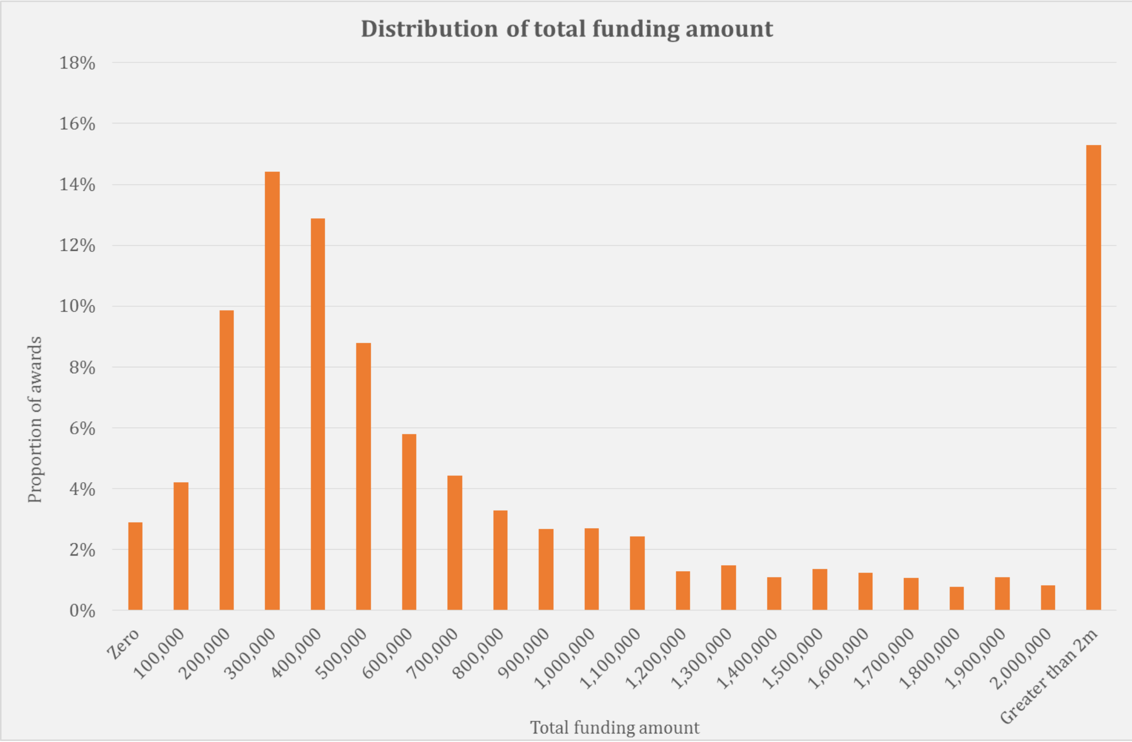
Figure 118.



In addition to actual spend we have also been provided with 'total funding amount'. For extramural awards this is the amount of funding that has been allocated to the award, whether it has been spent yet or is due to be in future years. For intramural awards, though, there is no set funding amount for future years – they are often ongoing laboratories that do not have a specific 'life span'. Therefore, the total funding figure for intramural awards is the sum of funding provided from the beginning of the award to April 2014. As the total funding amount is calculated differently for intra- and extramural awards we look at it out of interest but do not take it forward in the further analysis.

The chart below shows the distribution of total funding amount.

Figure 119



We now turn to additional analysis that we have conducted that combines the MRC managed awards and further funding datasets.

13.2. Further analysis

In this section we provide:

- ***Further descriptive statistics*** that use a combination of the datasets discussed above. This gives us a sense of the amount of original awards that received further funding, the value of further funding compared to the original award, and the correlation between spend on the original award and further funding received.
- An assessment of the ***relationship between original award spend and further funding*** using regression analysis. This demonstrates how research projects can facilitate further research in the future.
- ***Relationship between original award spend and further private sector funding*** extends the above analysis to just private sector further funding.
- ***Charity further funding*** goes a step further and looks just a charity further funding.

Further descriptive statistics

In essence, we have a dataset that contains awards that could have received further funding, and a dataset that contains instances of further funding. The main analytical issue is related to time. Firstly, our MRC managed awards dataset includes awards active on 1st Aril 2006 or after. It does include projects that were started before this date, but, it will not be representative of projects with a start date before 1st April 2006. For this reason, we constrain ourselves to projects that started in 2006 or after.

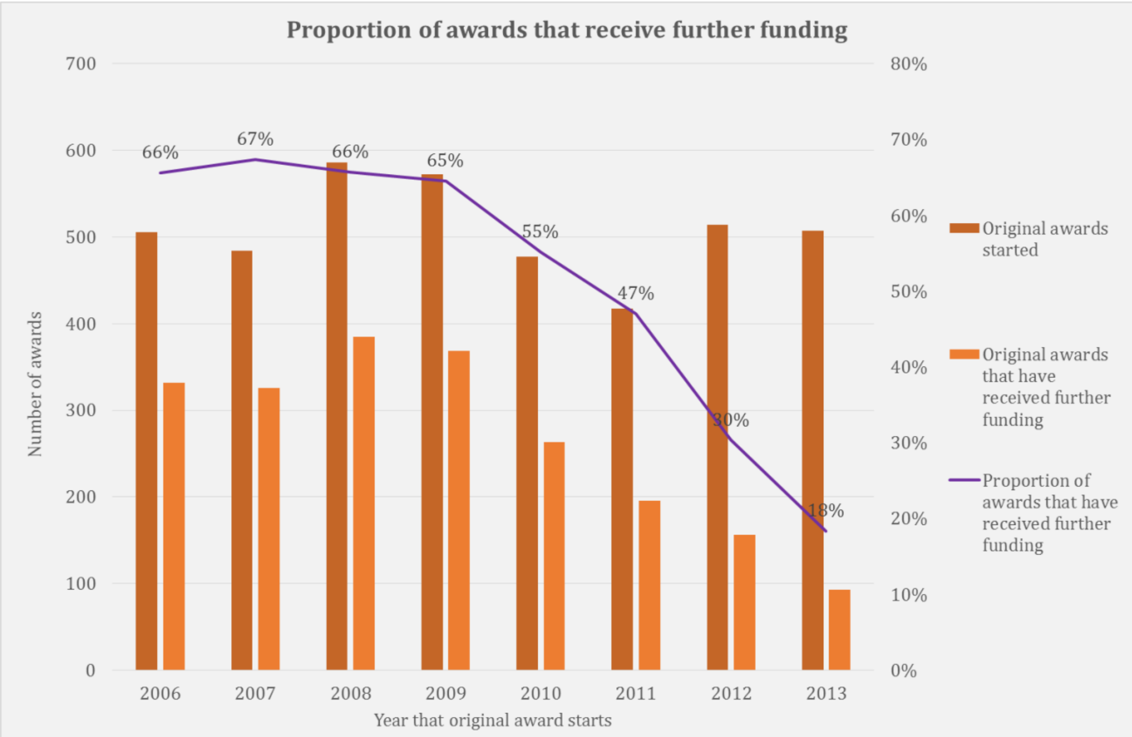
Another timing related issue is that awards that have been active for longer have naturally had more opportunity to attract further funding. Furthermore, the scale of the original award is likely to affect the chances for further funding i.e. more research being conducted could lead to more opportunities for further funding. Both the amount and length of the original award may therefore be linked to further funding. Relatedly, further funding may be related to the point at which the original award is at. For example, some types of award may not attract further funding until the award has finished and results have been published. Alternatively, some awards may be able to attract further funding part way through.

From the descriptive analysis above, we know that 50% of the recorded occurrences of further funding happened within three years of the start of the award. Constraining ourselves to awards that started in 2006 or later means that, at most, awards will have had seven years to attract further funding. As such, we cannot expect to have captured all instances of further funding (i.e. those that have not occurred yet) but believe we have a significant amount of them.

To control for these timing issues we analyse awards by their start date and place more weight on the results of older cohorts. Awards started in 2006, for example, have had the longest to attract further funding and are most likely to give us a true picture of what can be expected from an award.

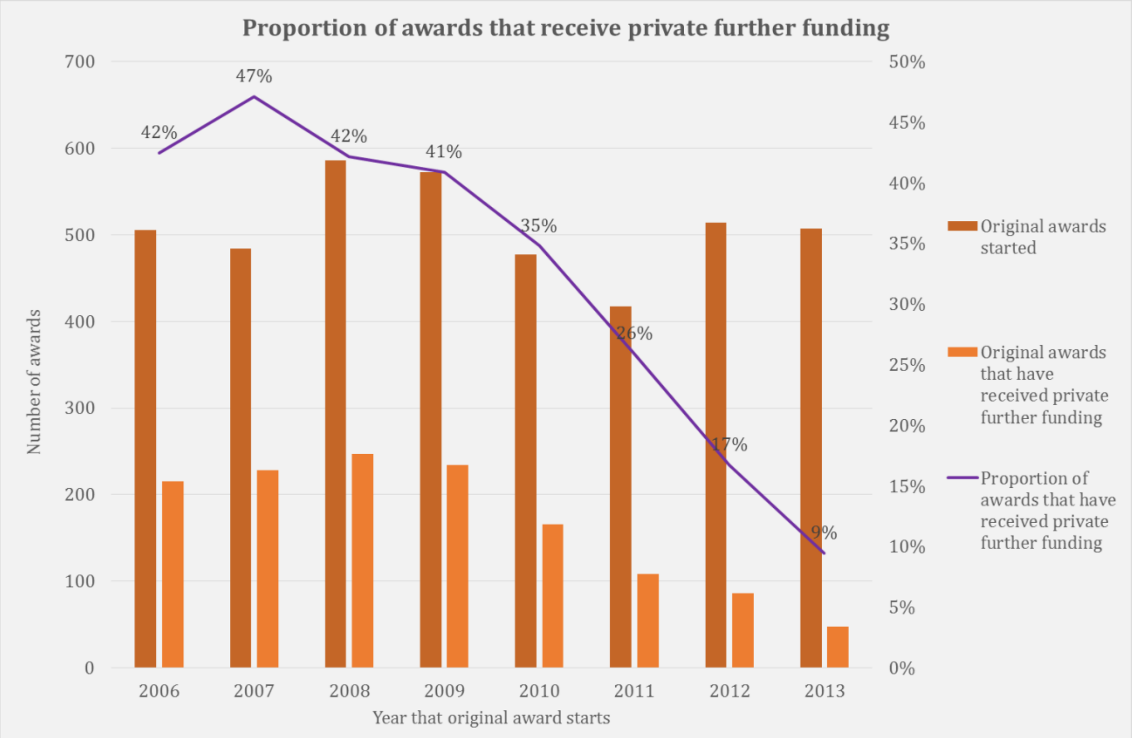
The chart below shows the number of awards that started in each of the given years, and the number of awards that started in each of those given years that received further funding. As can be seen, the proportion of awards that received further funding is around 65% for the earlier award start years, and declines for awards that started later. Due to newer awards having less time to attract further funding, this is what we expect to see.

Figure 120.



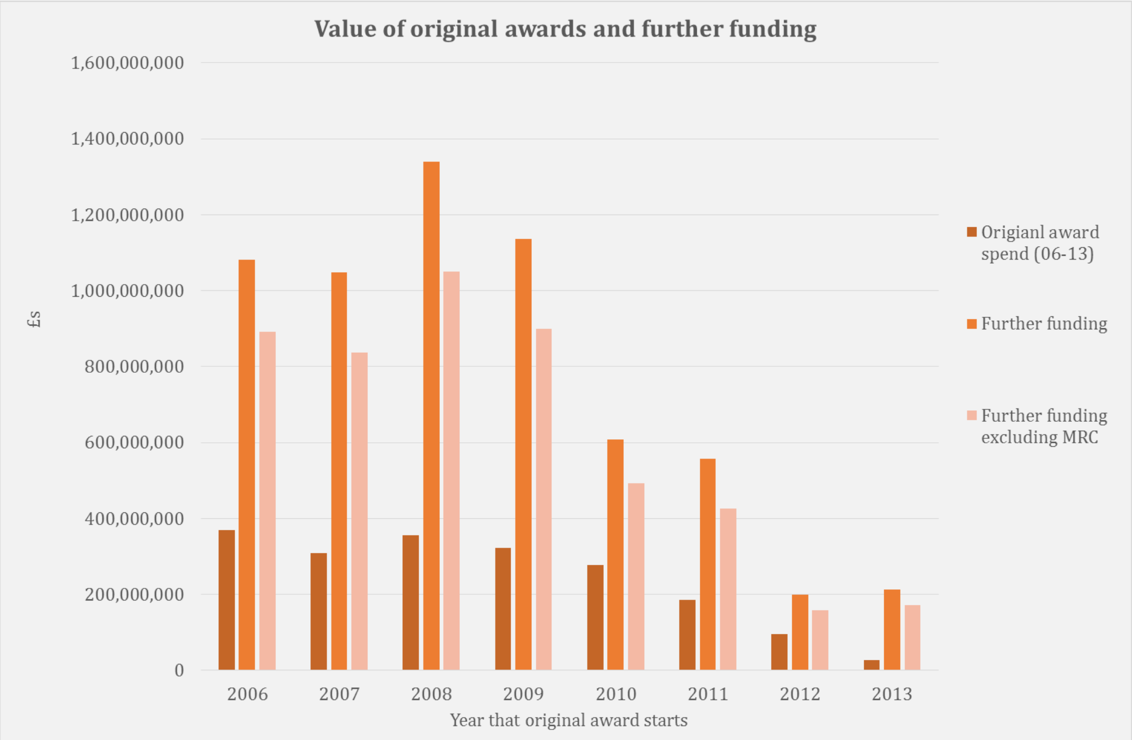
Similarly, the chart below show only private further funding. As can be seen, about 45% of awards in the earlier periods have received further funding from the private sector.

Figure 121.



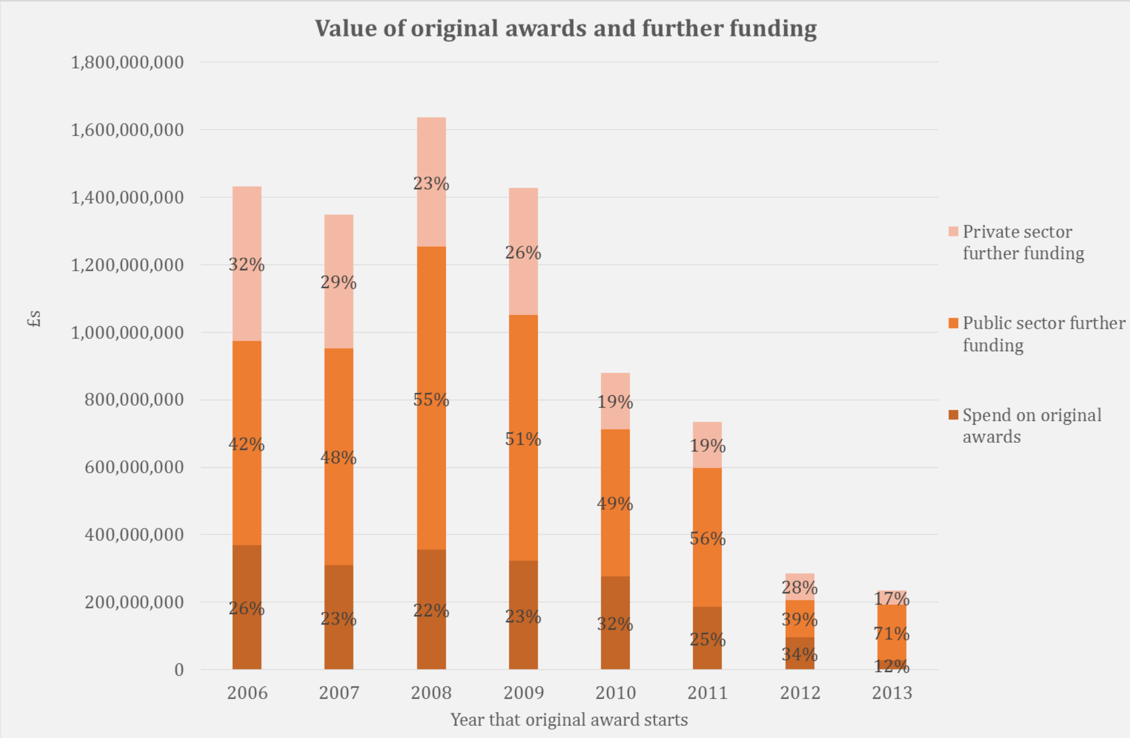
We can also investigate the relative size of the original awards compared to the further funding that has been attracted. The chart below compares the value of original award spend with the value of further funding. Due to the concerns about some MRC funding being incorrectly reported as further funding, we also show further funding excluding that from MRC.

Figure 122.



As can be seen, for those awards that started in the earlier periods, the value of further funding is approximately three times the value of the original award spend. The chart below show the proportion of total spend related to an original award that is from different sources.

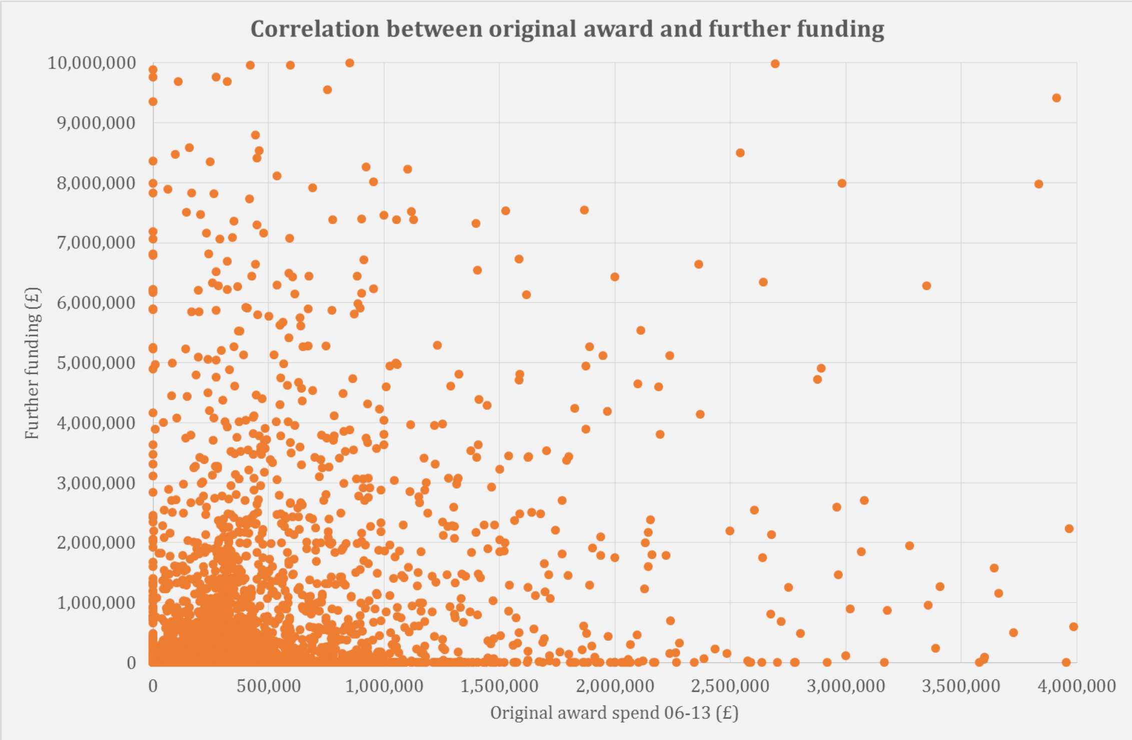
Figure 123.



As can be seen, the private sector contributes 25-30% of the total spend related to an award in the earlier cohorts.

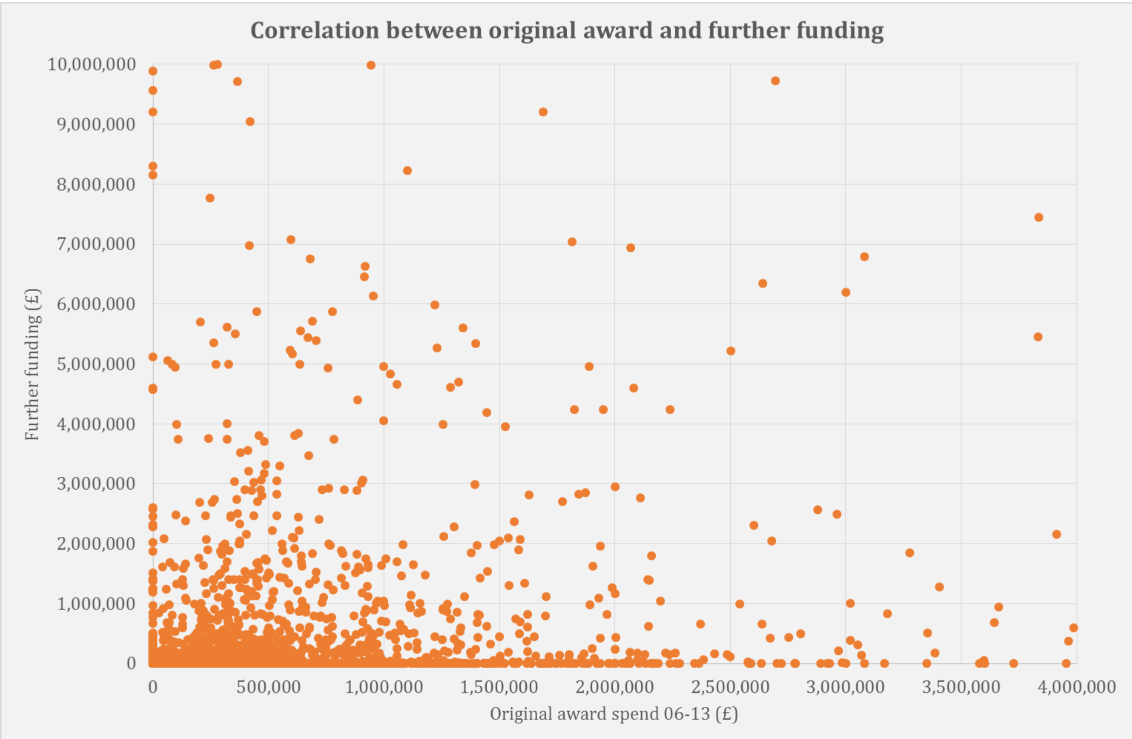
In addition, we have also looked at the correlation between the value of the original award spend and the value of further funding, as shown in the chart below. The correlation coefficient is 0.13.

Figure 124.



The equivalent chart for private sector further funding is given below. The correlation coefficient is 0.10.

Figure 125.



Furthermore, we have also undertake regression analysis using these data, as presented below.

Relationship between original award spend and further funding

We start by looking at the relationship between the original award spend and the amount of further funding that was received. This uses the data points illustrated in the scatter plot above, but excludes observations where:

- no original award spend was reported for the period 06-13 (which removes observations which might not be complete or inappropriate to include); and
- no further funding is reported.

Our subsequent models will therefore look at the relationship between the amount spent on the original award and the amount of further funding that is received by those awards that receive at least some further funding.

The table below shows the results of two regression models: the first regresses the spend on the original award on the amount of further funding received; and the second also includes control variables for the year in which the original award started.

Table 45.

	Model 1	Model 2
Original award spend	1.09*** (0.15)	1.06*** (0.15)
Start year		2.03e+08 (1.87e+08)
Start year squared		-50555.93 (46481.74)
R-squared	0.0274	0.0286

As can be seen, both models indicate a one-for-one relationship between the original award and further funding. That is, a £1 increase in the size of the original award would result in a £1 increase in further funding, for those awards that do receive further funding.

The second model includes controls of the start date of the original award. Based on our other analysis, and intuition, we know that a project that started longer ago has had more chance to receive further funding. However, the coefficients on the controls for original award start date are insignificant, which could be for a number of reasons:

- The model is misspecified e.g. there is not a linear relationship between variables.
- There is too much noise within the data which is not allowing the effect of original award start date to be picked up by the model. Some of this noise may be explained by other potential explanatory variables – but we are limited by the data available to us.
- The model only considers original awards that have received further funding. If, for example, awards only receive one instance of further funding and this amount was not related to the age of the original award, we would not expect to see significant coefficients on start year variables. However, we know from the descriptive statistics presented earlier in this annex that a significant proportion of awards receive multiple instances of further funding, and that instances of further funding may take years to arise.

It should also be noted that the R-squared for both of the models above are very small – this shows that the model explains only a very small proportion of the variation in the data. It would suggest that the model may be misspecified (e.g. omitted variables or incorrect functional form), and due to this the results of the model may not be robust.

To address the potential of a non-linear relationship between variables we have explored expressing variables in natural logs. The results of re-running the models with the £ variables in logs are shown in the table below.

Table 46.

	Model 3	Model 4
Ln(Original award spend)	0.75*** (0.05)	0.73*** (0.05)
Start year		-134.53*** (50.14)
Start year squared		0.03*** (0.01)
R-squared	0.1265	0.1354

As can be seen, all coefficients are now significant. The combination of start year and start year squared has a negative effect on the amount of predicted further funding. That is, awards with a high value for award start date are predicted to have received less further funding. This is as we would expect.

The R-squared for both regressions is still relatively low, indicating that there may be other factors that are not included in the model which are driving a significant proportion of the variation in further funding.

Nonetheless, the models presented above are consist with a positive relationship between the size of an original award and the amount of further funding that it receives. This is not surprising given the intuition that larger projects conduct more research, or more expensive research, that could lead to further research. The results do not however, suggest that larger awards should be favoured over smaller awards.

Relationship between original award spend and further private sector funding

Given the focus of this study, we also estimate the relationship between original award spend and further funding received from the private sector. This is close to the effect of public expenditure on private further funding.

As we understand it, the majority of spend on the original award will be from the public sector, specifically MRC. Spending arising from co-funding relationships will be included, but we understand co-funding to be a small proportion, and private co-funding to be even smaller. As such, we take original award spend as a proxy for the amount of public funding.

The further funding dataset includes a variable which denotes the source of further funding. We have classified public funding as from either “Public” or “Academic/University” and private as either “Charity/Non Profit” or “Private”. We have excluded the other categories (“NULL”, “INSUFFICIENT INFORMATION”, “Hospitals” and “Learned Society”) from this analysis.

The table below presents three regression models:

- Model 5 relates private further funding to public funding of the original award;
- Model 6 relates private further funding to public funding and the start year of the original award; and
- Model 7 relates private further funding to public funding and the start year of the original award, and public further funding.

The models are in a log-log specification.

	Model 5	Model 6	Model 7
Ln(Original award spend)	0.72*** (0.06)	0.76*** (0.09)	0.38*** (0.07)
Start year		-209.16*** (64.79)	-115.23 (75.05)
Start year squared		0.05*** (0.02)	0.03 (0.02)
Ln(Public further funding)			0.35*** (0.03)
R-squared	0.1102	0.1176	0.2062

The models suggest that there is a positive relationship between the amount of spend on the original award and the value of private follow-on funding that is received. Again, the R-squared for each of the models is relatively low, which suggests that there are other factors driving the amount of private follow-on funding that are not included in the model.

The results of Model 5 and 6 are similar in terms of the estimated effect of public expenditure – they give coefficients of 0.72 and 0.76 respectively. Model 6 includes controls for the start year of the award, and the results are consistent with awards that started longer ago receiving more private further funding.

Including the amount of public further funding (Model 7) reduces the coefficient on public expenditure to 0.38. This could be a result of public further funding being correlated with factors that make private further funding appealing. Put another way, public and private further funding may be driven by similar factors. If so, the public further funding variable will act as a control for these factors, similar to the use of fixed capital formation and GDP in our macro analysis. Furthermore, public further funding may make private further funding more attractive due to the sharing of costs i.e. if the private sector contributes to the further research it may be more profitable/viable for a private sector organisation to also invest.

Model 7 may therefore represent a more robust estimate of the additioanlity of public sector spending - it suggests that increasing the level of public spending on an award will increase the level of private sector follow-on funding that it receives by 0.38%.

The MRC data, and the econometric analysis that we have conducted on it, are consistent with there being spillover effects of publicly performed research on the private sector. That is, the analysis suggests that increasing the amount of public expenditure on R&D will increase the amount of private expenditure on directly related projects.

This modelling has been conducted at the micro level and the caveats that come with this should be taken into account when considering these results. Spillover effects that arise that are not connected to the original award (i.e. are not captured in further funding) are not taken account of here. It could be that significant further research is conducted entirely within the private sector, and would therefore not be captured. In such a case, these results would underestimate additionality.

A further caveat is that this micro modelling does not account for substitution effects between awards. It could be that larger public sector awards receive more private funding partly because less is being given to smaller awards. The results do not allude to whether more private funding is achieved from diverting public funds into larger projects at the expense of smaller projects.

Charity further funding

As a further extension, given the relative size and importance of charity further funding, we have also investigated the relationship between public funding and charity further funding. Similarly to above, we have run three models:

- Model 8 relates charity further funding to public funding of the original award;
- Model 9 relates charity further funding to public funding and the start year of the original award; and
- Model 10 relates charity further funding to public funding and the start year of the original award, and public further funding.

Again, the results presented here are for a log-log specification.

	Model 8	Model 9	Model 10
Ln(Original award spend)	0.72*** (0.06)	0.77*** (0.06)	0.34*** (0.11)
Start year		-216.41*** (67.14)	-99.48 (78.29)
Start year squared		0.05*** (0.02)	0.02 (0.02)
Ln(Public further funding)			0.34*** (0.03)
R-squared	0.1102	0.1179	0.1950

The results of these models are very similar to those for total private further funding. This is not surprising given that the majority of further funding is from charities.

Addendum

Model 1

Source	SS	df	MS
Model	3.0780e+15	1	3.0780e+15
Residual	1.0905e+17	1957	5.5725e+13
Total	1.1213e+17	1958	5.7269e+13

Number of obs	=	1959
F(1, 1957)	=	55.24
Prob > F	=	0.0000
R-squared	=	0.0274
Adj R-squared	=	0.0270
Root MSE	=	7.5e+06

ffreceived	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
spend0613	1.086565	.1462002	7.43	0.000	.7998402	1.373289
_cons	1726039	196764.6	8.77	0.000	1340149	2111929

Model 2

Source	SS	df	MS
Model	3.2119e+15	3	1.0706e+15
Residual	1.0892e+17	1955	5.5714e+13
Total	1.1213e+17	1958	5.7269e+13

Number of obs	=	1959
F(3, 1955)	=	19.22
Prob > F	=	0.0000
R-squared	=	0.0286
Adj R-squared	=	0.0272
Root MSE	=	7.5e+06

ffreceived	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
spend0613	1.060673	.1477707	7.18	0.000	.7708685	1.350478
startyear	2.03e+08	1.87e+08	1.09	0.277	-1.63e+08	5.69e+08
startyear2	-50555.93	46481.74	-1.09	0.277	-141714.9	40603.05
_cons	-2.04e+11	1.88e+11	-1.09	0.277	-5.72e+11	1.64e+11

Model 3

Source	SS	df	MS
Model	1106.15197	1	1106.15197
Residual	7636.12917	1957	3.90195665
Total	8742.28113	1958	4.46490354

Number of obs	=	1959
F(1, 1957)	=	283.49
Prob > F	=	0.0000
R-squared	=	0.1265
Adj R-squared	=	0.1261
Root MSE	=	1.9753

lnffreceived	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.7464966	.0443365	16.84	0.000	.6595448	.8334483
_cons	3.451195	.574263	6.01	0.000	2.324964	4.577427

Model 4

Source	SS	df	MS
Model	1183.41893	3	394.472977
Residual	7558.8622	1955	3.86642568
Total	8742.28113	1958	4.46490354

Number of obs	=	1959
F(3, 1955)	=	102.03
Prob > F	=	0.0000
R-squared	=	0.1354
Adj R-squared	=	0.1340
Root MSE	=	1.9663

lnffreceived	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.7331447	.0462191	15.86	0.000	.6425009	.8237886
startyear	-134.5319	50.13634	-2.68	0.007	-232.8582	-36.20563
startyear2	.033463	.0124788	2.68	0.007	.0089898	.0579361
_cons	135218.9	50358.24	2.69	0.007	36457.39	233980.4

Model 5

Source	SS	df	MS
Model	623.452092	1	623.452092
Residual	5034.77317	1248	4.03427337
Total	5658.22526	1249	4.53020437

Number of obs	=	1250
F(1, 1248)	=	154.54
Prob > F	=	0.0000
R-squared	=	0.1102
Adj R-squared	=	0.1095
Root MSE	=	2.0086

lnpriatese~f	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.7151082	.0575245	12.43	0.000	.6022528	.8279636
_cons	3.067264	.752085	4.08	0.000	1.591773	4.542754

Model 6

Source	SS	df	MS
Model	665.402949	3	221.800983
Residual	4992.82232	1246	4.00708051
Total	5658.22526	1249	4.53020437

Number of obs	=	1250
F(3, 1246)	=	55.35
Prob > F	=	0.0000
R-squared	=	0.1176
Adj R-squared	=	0.1155
Root MSE	=	2.0018

lnpriatese~f	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.7593503	.060388	12.57	0.000	.6408769	.8778238
startyear	-209.1595	64.78958	-3.23	0.001	-336.2682	-82.05078
startyear2	.052062	.0161263	3.23	0.001	.0204243	.0836997
_cons	210077.3	65075.08	3.23	0.001	82408.44	337746.1

Model 7

Source	SS	df	MS
Model	696.702734	4	174.175683
Residual	2682.26471	833	3.22000566
Total	3378.96744	837	4.03699814

Number of obs =	838
F(4, 833) =	54.09
Prob > F =	0.0000
R-squared =	0.2062
Adj R-squared =	0.2024
Root MSE =	1.7944

lnpriatesectorff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.3795167	.0716828	5.29	0.000	.2388166	.5202168
startyear	-115.2271	75.04899	-1.54	0.125	-262.5345	32.08024
startyear2	.0286904	.0186809	1.54	0.125	-.0079767	.0653575
lnpublicsectorff	.3455703	.030765	11.23	0.000	.2851842	.4059564
_cons	115697.7	75375.66	1.53	0.125	-32250.89	263646.2

Model 8

Source	SS	df	MS
Model	611.801356	1	611.801356
Residual	4939.58375	1191	4.14742548
Total	5551.3851	1192	4.65720227

Number of obs =	1193
F(1, 1191) =	147.51
Prob > F =	0.0000
R-squared =	0.1102
Adj R-squared =	0.1095
Root MSE =	2.0365

lncharityff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.723559	.0595742	12.15	0.000	.606677	.840441
_cons	2.913642	.779298	3.74	0.000	1.384693	4.442592

Model 9

Source	SS	df	MS
Model	654.702428	3	218.234143
Residual	4896.68268	1189	4.11832017
Total	5551.3851	1192	4.65720227

Number of obs =	1193
F(3, 1189) =	52.99
Prob > F =	0.0000
R-squared =	0.1179
Adj R-squared =	0.1157
Root MSE =	2.0294

lncharityff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.7689587	.0624312	12.32	0.000	.646471	.8914464
startyear	-216.4065	67.14192	-3.22	0.001	-348.1363	-84.67665
startyear2	.0538656	.0167118	3.22	0.001	.0210777	.0866536
_cons	217356.7	67437.58	3.22	0.001	85046.8	349666.6

Model 10

Source	SS	df	MS
Model	648.958669	4	162.239667
Residual	2679.47037	797	3.36194526
Total	3328.42904	801	4.15534213

Number of obs	=	802
F(4, 797)	=	48.26
Prob > F	=	0.0000
R-squared	=	0.1950
Adj R-squared	=	0.1909
Root MSE	=	1.8336

lncharityff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnspend0613	.356578	.0746673	4.78	0.000	.2100101	.5031459
startyear	-99.47505	78.29175	-1.27	0.204	-253.1574	54.20734
startyear2	.0247698	.0194882	1.27	0.204	-.0134844	.063024
lnpublicsectorff	.346026	.0321082	10.78	0.000	.2829995	.4090526
_cons	99875.76	78632.09	1.27	0.204	-54474.7	254226.2

14. Annex H– HEBCI data analysis

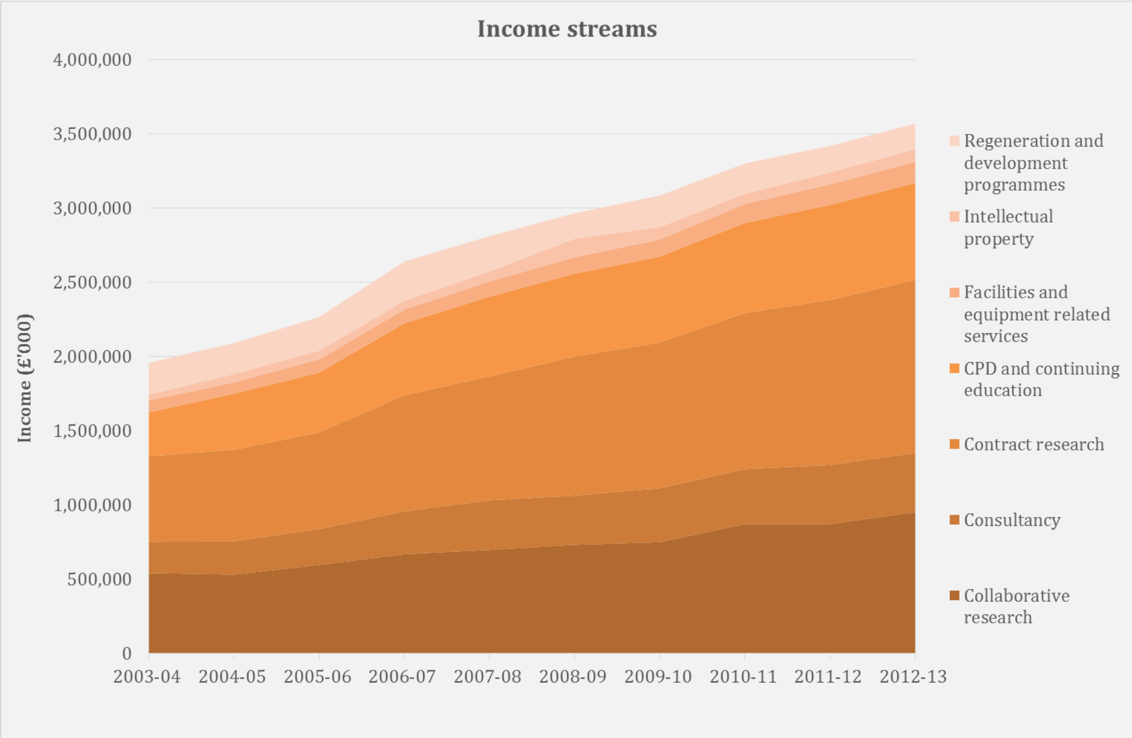
This annex contains our analysis of HEBCI data.

14.1. Overview of data

The annual Higher Education Business and Community Interaction (HEBCI) survey collects information from HEIs relating to interactions with 'the wider world'. Such interactions occur between HEIs and non-academic institutions, for example businesses and charities. All 161 publicly funded UK HEIs report the amount of funding that they receive in relation to these interactions.

As shown in the chart below, incomes are reported in seven main categories.

Figure 126



The table below defines each of these categories.

Table 47

Income stream	Description
Collaborative research	Collaborative research is academic research which has public sponsorship (grant in aid from a Government or public body) and at least one other external partner. It is undertaken with partners such as research organisations, private business, other HEIs, Government or the third sector, and includes at least one other non-academic organisation. The fruits of the research are assumed to be shared among all partners.
Consultancy	Consultancy agreements deliver expert advice and intellectual input to a client to assist in analysing a particular client issue ('the innovative application of existing knowledge'). Consultancy is defined as the provision of expert advice and work, which while it may involve a high degree of analysis, measurement or testing, is crucially dependent on a high degree of intellectual input from the organisation to the client (commercial or non-commercial) without the creation of new knowledge. Consultancy may be carried out either by academic staff or by

	members of staff who are not on academic contracts, such as senior university managers or administrative/support staff.
Contract research	Contract research answers a specific question primarily for the benefit of the external partner. Awards and grants made for proposals from the institution are not included as contract research (e.g. basic research council grants). Income from commercial and non-commercial organisations for contract research may include various projects relating to both Science, Engineering and Technology (SET) and non-SET subjects.
CPD and continuing education	Continuing professional development (CPD) courses are training programmes for learners already in work who are undertaking the course for purposes of professional development/upskilling/workforce development. CPD does not relate to undergraduate courses where, for example, the students go on placement. Learners returned under continuing education are not required to be employed, unlike CPD.
Facilities and equipment related services	Income from use of facilities and equipment includes facilities such as prototyping equipment or digital media suites.
Intellectual property	Intellectual property (IP) may commonly be in the form of licenses granted to private companies allowing them to exploit an invention protected by a patent. IP includes: patents; copyright; design registration; and trademarks.
Regeneration and development programmes	Regeneration income is income from the allocating public body invested into intellectual assets in economic, physical and socially beneficial projects. The majority of regeneration funding comes from European sources (in particular from the European Regional Development Fund (ERDF) and the European Social Fund (ESF).

Source: Information on the HESA website

Most of these categories are further broken down by income from:

- small and medium sized enterprises (SMEs);
- large businesses; and
- public and third sector organisations.

This third category, public and third sector organisations, includes both public and private funders and as such does not align with our public/private distinction.

Collaborative research, as discussed later, is categorise differently.

The two main income streams of interest to us from the HEBCI dataset are ‘contract research’ and ‘collaborative research’. These represent income from HEIs collaborating with, or being directly employed by, non-academic organisations and we provide an overview of each below.

Contract research

Funding for contract research can come from both public and private funders, and the two income streams are split out in the data as described above. The chart below shows the breakdown of the sources of contract research income.

Figure 127

As can be seen, the majority of contract research conducted in HEIs is funded by public or not-for-profit organisations. Not surprisingly, large businesses contract substantially more research than SMEs.

Unfortunately, due to these categories we cannot calculate a private sector percentage for contract research.

Collaborative research

Importantly, collaborative research is broken down into funding received from public funding bodies, cash received from collaborators, and in-kind contributions from collaborators. Public funding bodies provide grant in aid and include Research Councils, other UK government departments, and the EU government. Notably this definition of 'public funding bodies' does not align with our differentiation between public and private funding as it includes overseas (EU government) funding.

Collaborators are non-academic organisations, including charities, public and not-for-profit organisations as well as commercial business. Similarly, this category does not strictly align with our distinction between public and private funding as it appears to include some 'public organisations'. However we assume that any 'public organisations' included would be a small fraction of this category and therefore do not account for this minor definition issue.

Public funding and collaborator cash contributions are monetary investments into the research and as such relate to cash flows. In-kind contributions from collaborators take the form of, for example, staff time, resources, materials, or provision of data. The guidance to completing the survey states that in-kind contributions should be 'contractually explicit' i.e. the external partner should be aware of the financial values assumed for their contribution. Only in-kind contributions that have been formally recorded, for example on Finance or Research Project Management Systems, should be included.

Where projects involve grant in aid from more than one public sponsor (e.g. LINK Projects or TSB Collaborative R&D), the direct contributions are shown against each sponsor category (e.g. Research Councils and government departments). The instructions for completing the survey state that the cash and in-kind contributions from collaborators should be apportioned between these public funders – dependent on the circumstances it is acceptable to assign all cash/in-kind contributions to a single public sponsor, split equally or apportion pro-rata.

Due to the fact that the allocation of cash and in-kind contributions from collaborators is not clear cut, we do not investigate the differences in collaborator funding by public funding body.

The table below shows the income from collaborative research split between public funders and collaborators for the time period available.

Table 48

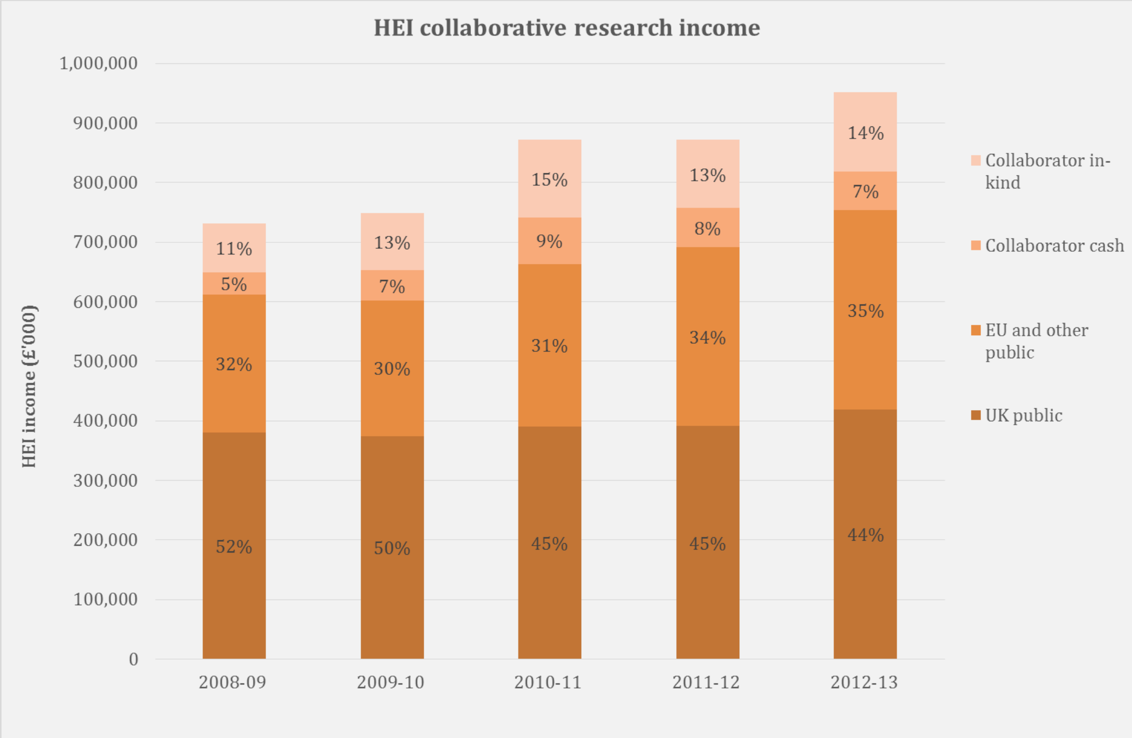
	2008-09	2009-10	2010-11	2011-12	2012-13
BIS Research Councils	**274,124**	**275,205**	**292,325**	**291,236**	**314,763**
Public Funding	232,173	224,522	226,774	225,213	241,563
Cash	10,599	17,002	18,011	23,569	25,635
In kind	31,352	33,681	47,540	42,454	47,565
Other UK Government department	**189,651**	**207,710**	**241,872**	**220,343**	**240,983**
Public Funding	147,595	149,927	163,883	165,919	177,667
Cash	18,213	22,640	44,935	29,113	25,265
In kind	23,843	35,143	33,054	25,311	38,051
EU Government	**213,603**	**231,714**	**288,097**	**311,158**	**329,582**
Public Funding	184,263	201,249	233,196	265,218	290,233
Cash	3,628	4,194	7,220	6,477	6,643
In kind	25,712	26,271	47,681	39,463	32,706
Other	**54,356**	**34,560**	**49,298**	**48,610**	**65,798**
Public Funding	48,026	26,540	39,432	34,515	44,272
Cash	4,841	6,642	8,213	7,439	7,315
In kind	1,489	1,378	1,653	6,656	14,211

As can be seen, this categorisation allows us to distinguish between UK public sector investment and all other sources of funding – in line with the definition we have used for the other pieces of analysis. Summing cash from collaborators and foreign public funding, and diving by the total monetary collaborative research income gives a private sector percentage of 49% in 2012-13. This figure is directly comparable to the private sector percentage of 70% that we calculated for the UK as a whole. Therefore, these data show that, the UK public sector contributes proportionally more to collaborative research performed in HEIs compared to all research conducted in the UK.

The private sector percentage of collaborative research calculated above does not include in-kind contributions. The equivalent figure that does include in-kind contributions is 56%. From this it is clear that in-kind contributions are a significant proportion of the value that interactions with businesses and communities bring.

The breakdown of collaborative research income is further illustrated in the chart below. UK public investment has been grouped together and demonstrates the private sector percentage of 56% (1 – 44%). As can be seen, EU and other foreign public sector spending is a significant proportion of total collaborative research. This chart also demonstrates the significance of in-kind contributions – they are roughly twice the value of cash contributions from business and community collaborators.

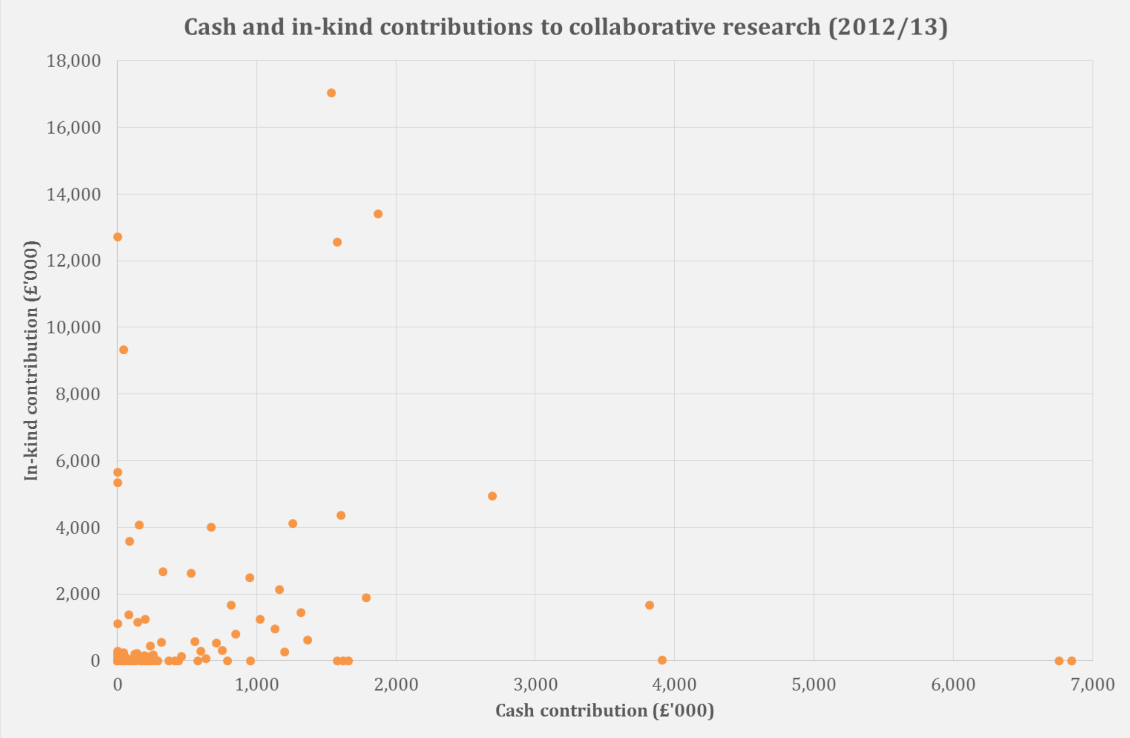
Figure 128



However, although in-kind contributions have to be formally recorded to be included in these data, their value is far from easy to estimate. For example, laboratory time could be measured on a pro-rata basis of the running costs of the facility, or as the cost of renting additional space in such a facility. The value of contributions such as data is even harder to value as the commodity is often unique and does not have any direct comparators to establish a market value from.

The chart below shows the cash and in-kind contributions from business and community collaborators for each HEI in 2012/13. As can be seen, some institutions report very high levels of cash funding but zero in-kind contributions. Others report very high in-kind contributions but zero cash funding. It is unclear why there is this large variation between institutions.

Figure 129



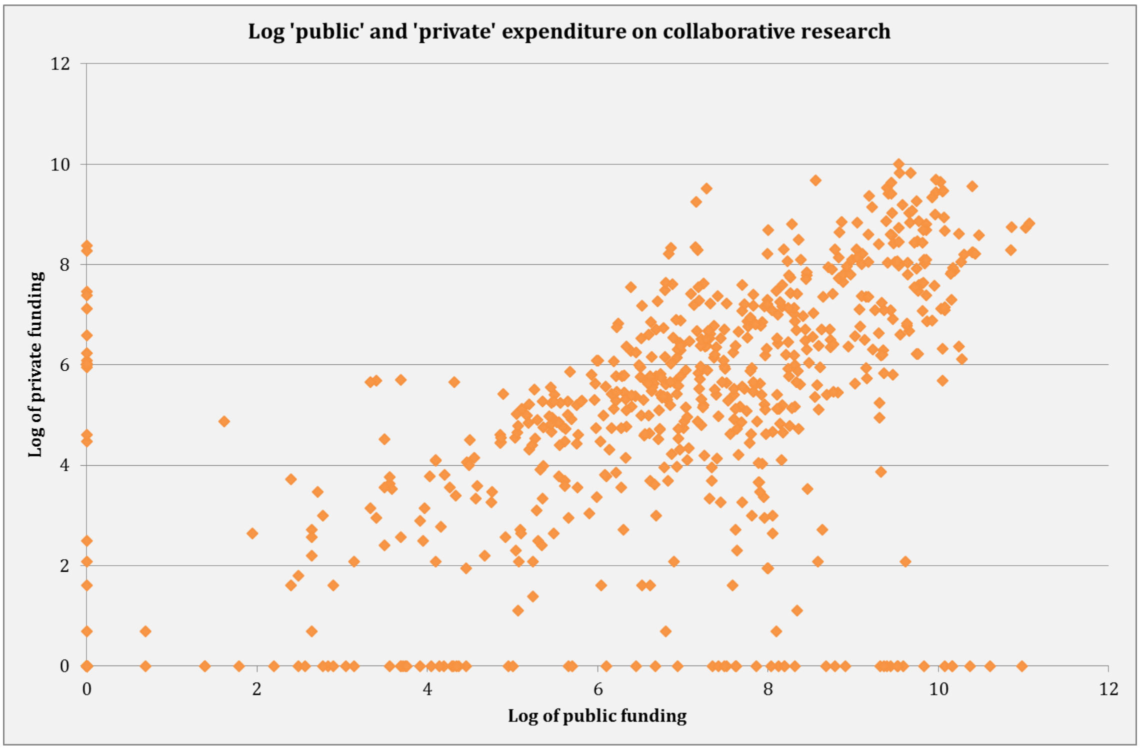
We now conduct econometric analysis to explore the relationships between variables more closely.

14.2. Econometric analysis of HEBCI data

In this section we present econometric models that estimate the relationship between public and private funding, and public and in-kind contributions.

Pooling all observations over time, the chart below shows the (log) relationship between 'public' expenditure and 'private' expenditure. It should be noted that 'public' includes foreign (EU) government funding and 'private' may include some government spending (see above discussion of definitions).

Figure 130



On these data we run three models that relate 'public' to 'private' expenditure: a simple OLS model; a random effects model; and a fixed effects model. In line with the economic analysis of the ONS data, we specify the variables in natural logs. The results of these models are given in the table below.

Table 49

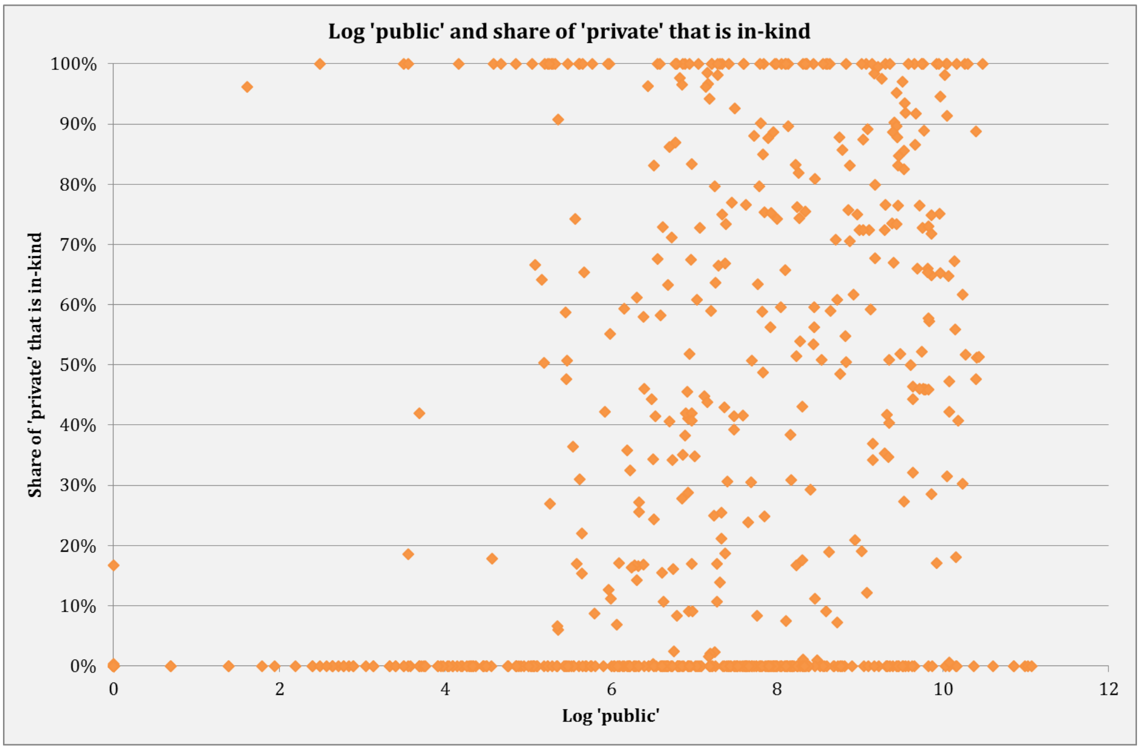
	Model 1	Model 2	Model 3
'Public' expenditure	0.68*** (0.04)	0.50*** (0.05)	0.10 (0.09)
R-squared	0.3910	0.3910	0.3910

As can be seen, the OLS model gives a coefficient of additionality of 0.68 – in line with our analysis of the ONS data. As expected, the random effects model reduces the coefficient as some variation is assigned to HEI specific effect. The fixed effects model does not find a statistically significant effect of 'public' funding. This will be a result of there being only a small variation within individual HEI observations, and the fixed effect explaining the majority of the difference between HEIs.

These results are consistent with our other analysis in that they do not contradict a theory of crowding-in. However, the models do not include any of the control variables that other regressions do and they might simply be picking up the underlying correlation rather than a causal effect. It could be that another, unobserved factor, is driving both 'public' and 'private' investment.

We have also explored the relationship between 'public' expenditure and the in-kind contributions. Specifically, we have looked at whether the level of 'public' investment increases the proportion of 'private' contributions that are in-kind. The chart below shows these two variables.

Figure 131



As can be seen, there is no clear correlation. Furthermore, a significant proportion of observations are either 0% or 100% in terms of the share of 'private' investment that is in-kind. This raises concerns about the accuracy of the data.

Nevertheless, we run the same three models as above: OLS; RE; and FE – the results of which are given below.

Table 50

	Model 4	Model 5	Model 6
'Public' expenditure	0.06*** (0.01)	0.05*** (0.01)	0.03 (0.02)
R-squared	0.0788	0.0788	0.0788

The OLS and RE models are consistent with the level of 'public' funding increasing the proportion of 'private' contributions that are in-kind. The FE model does not find a significant effect, presumably for the same reason as was the case in Model 3.

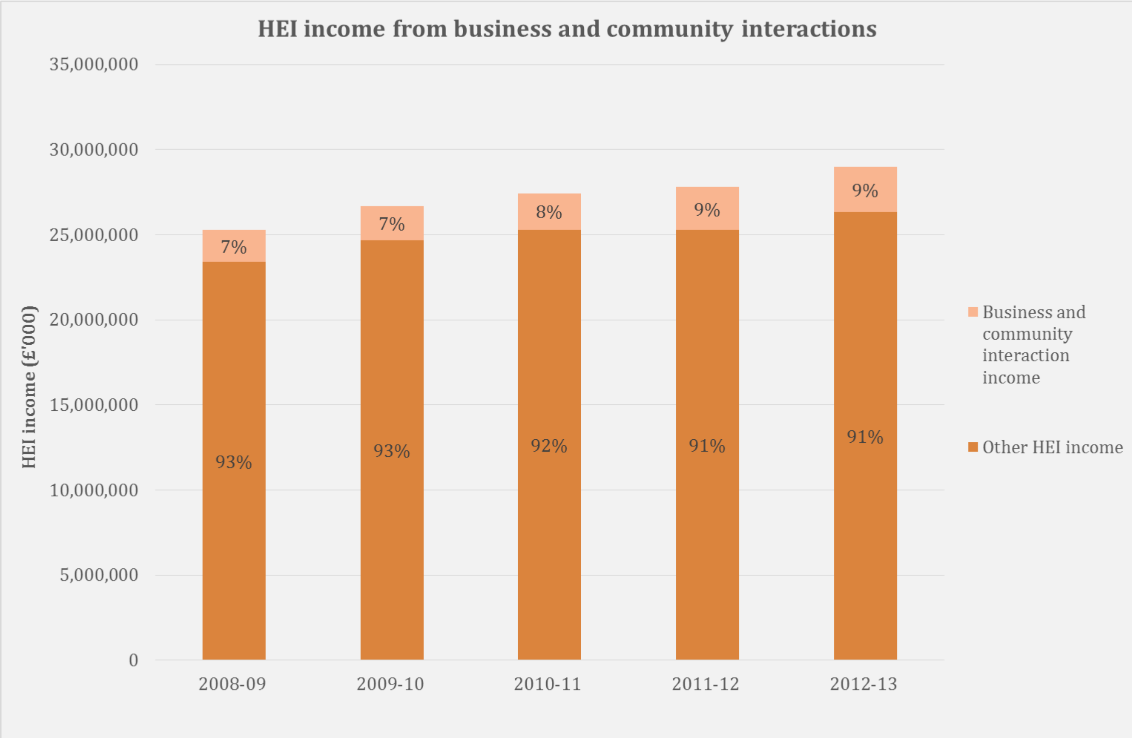
14.3. Comparison with total HEI incomes

To give a sense of the importance of funding from business and community interactions we calculate the proportion of HEIs' total income that is represented by the HEBCI results. These metrics include both private and public sector funding and are a measure of income that is tied to external sources. It is not, however, a causal measure – some of the private sector funding may still be spent on research if not for the public sector's participation.

As discussed above, the HEBCI figures include in-kind contributions from collaborators and is therefore not directly comparable to total HEI income as reported by HESA (which only includes monetary cash flows). We therefore differentiate between in-kind and monetary income to compare on a like for like basis.

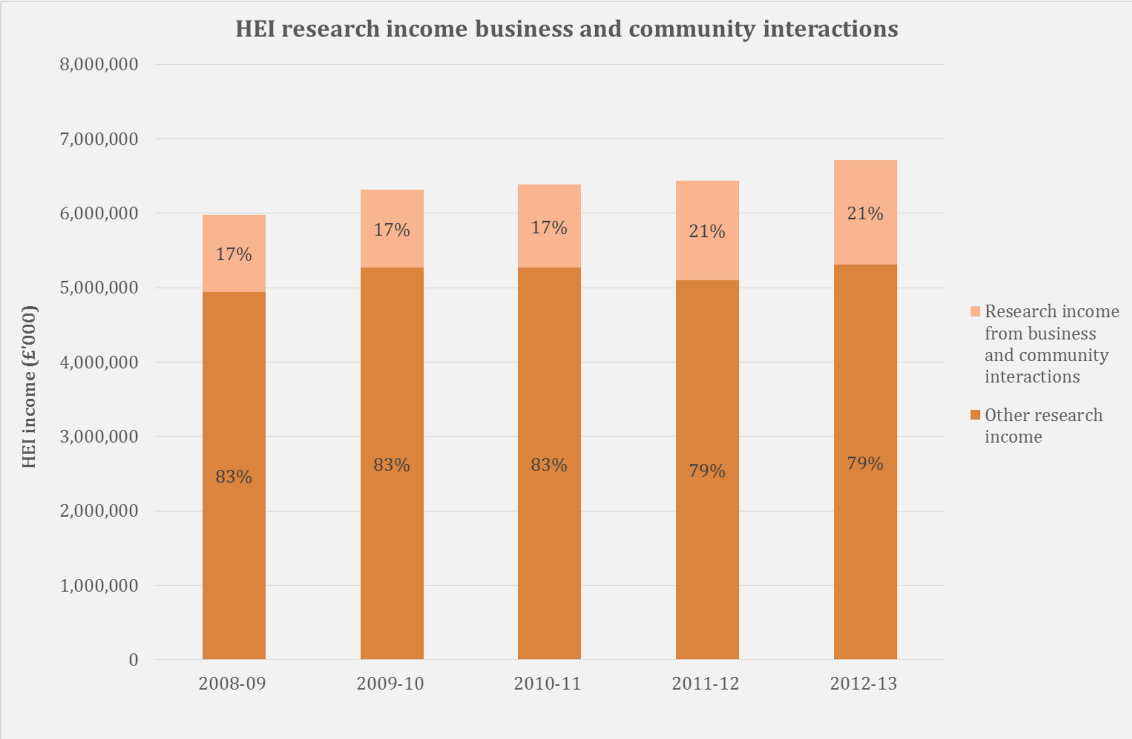
The chart below shows the proportion of HEI income that is attributable to business and community interactions. It includes all sources of HEI income (including teaching) and all sources of income from interactions with the wider world (including, for example, CPD courses). As can be seen, business and community interactions account for nearly 10% of HEIs' income.

Figure 132



For a more accurate picture of the scale of research that is conducted as a result of collaborations and contracts with non-academic organisations the chart below shows the proportion of HEI research income that is from such interactions.

Figure 133

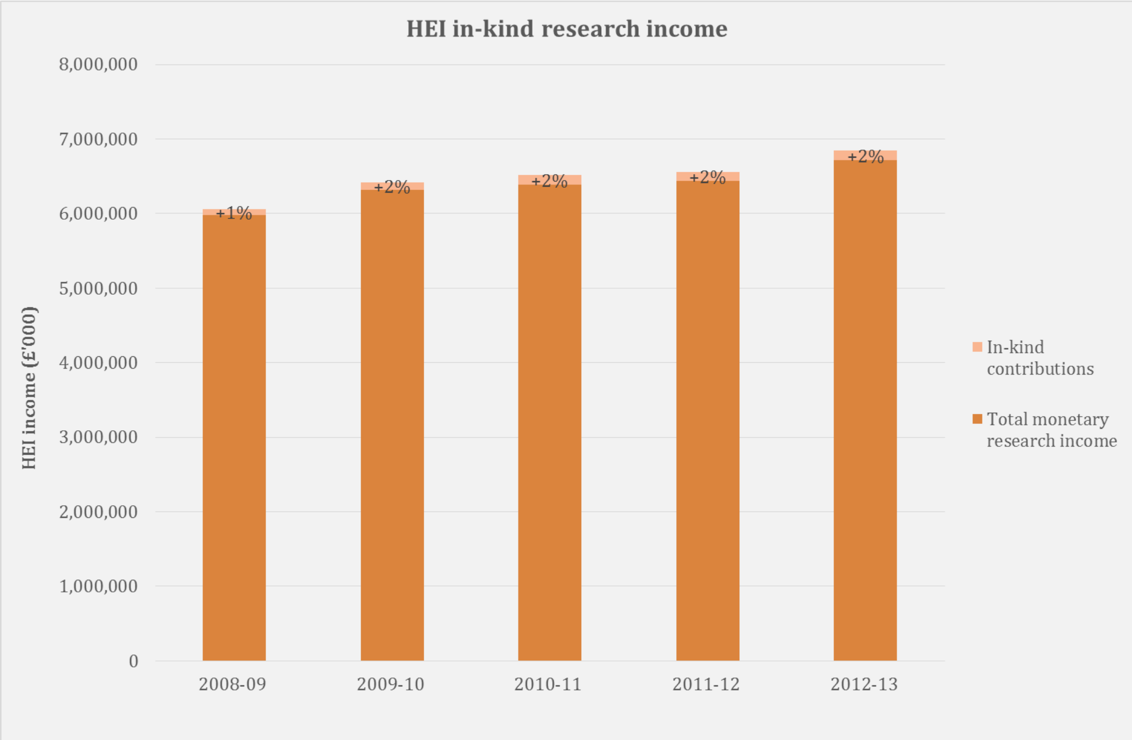


The total research income includes all public and private funding that HEIs receive for research. The proportion denoted as research income from business and community interactions is the sum of collaborative and contract research from the HEBCI survey (and excludes in-kind contributions).[44] As can be seen, research income from business and community interactions accounts for approximately 20% of HEIs' research income.

We can also calculate how much extra research income HEIs receive from in-kind contributions. The chart below compares the total research income HEIs receive (reported by HESA) and compares it to the value of in-kind contributions (as reported by HEBCI). As can be seen, the chart below suggests that in-kind contributions increase HEIs' research income by about 2%.

[44] *Consultancy income is not included in the HEBCI figure here as the total research income from the HESA dataset does not include it either.*

Figure 134


HEI in-kind research income
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
HEI income (£'000)
+1%
+2%
+2%
+2%
+2%
2008-09
2009-10
2010-11
2011-12
2012-13
In-kind contributions
Total monetary research income

15. Annex I– Details of interviews

This annex contains details of how we selected interview participants and the discussion guide.

15.1. Selection of interview participants

We interviewed a total of 21 individuals connected to research that has received both public and private funding. The table below sets out the 11 HEIs and subject areas / schemes that we spoke to individuals from.

#	HEIs and subject area / scheme
1	5G Innovation Centre at University of Surrey
2	Aerospace, Transport Systems and Manufacturing at Cranfield University
3	Cancer Research UK
4	Chemistry and Biochemistry at Queen Mary University
5	Earth Science & Engineering at Imperial College London
6	Engineering & Physical Sciences at Heroit-Watt University
7	Molecular and Clinical Cancer Medicine at University of Liverpool
8	National Composites Centre at University of Bristol
9	Psychology at University of Oxford
10	Sociology at Lancaster University
11	WMG at University of Warwick

The selection of interview participants was based partly on suggestions from the steering group and partly on our analysis of HESA data. This analysis consisted of ranking each department within each HEI in terms of the level of private research funding that is received per FTE member of staff. We only considered institutions that were in the top 50 in relation to total research funding.

From this ranking exercise we selected a number of departments and institutions ensuring a good mix across:

- HEIs;
- subject areas;
- public funders; and
- private funders (including charities and overseas).

We had varying degrees of success in relation to arranging interviews with institutions. For some of the institutions listed we only spoke to one individual, for others we spoke to two or three. These individuals included:

- researchers who have been successful in securing private funding;
- PVCs of research;
- senior staff in Catapults; and
- representatives from the private sector funder.

15.2. Discussion guide

The rest of this section presents the discussion guide that was sent to each candidate before the interview took place.

Background

Economic Insight has been commissioned by the Department of Business, Innovation and Skills (BIS) to conduct a study of the relationship between public and private investment in R&D. The aims of this project are to categorise and measure the different types of leverage achieved in the UK and analyse the conditions under which leverage can be increased.

A key stage in this study is to conduct interviews with those involved in projects and schemes that have attracted both public and private sector investment. We will be speaking to public funders, private funders, and individual researchers. The purpose of the interviews is to help **develop a practical understanding** of what factors affect private sector investment in R&D, and how it can be increased.

Interview details

The interviews will follow a broad structure that is set out in the following 'discussion guide', and will be tailored to your specific role. We do not necessarily intend to cover every question, but rather use them as a guide to have an open two-way discussion. The purpose of sharing these with you is to enable you to give prior thought to the areas we would like to discuss, to enable the most productive conversation possible.

The discussion guide has been written to cover all individuals that we are going to speak to and as such some questions will be less applicable to you than others.

As noted, our objective is to develop a practical understanding of what factors influence the private sector funding of a project or scheme, and ultimately how to increase the amount the private sector contributes. In order to achieve this objective we would like to discuss your experience of the project / scheme ('engagement') we have primarily contacted you regarding. We are also interested in you wider experiences and views. These two aspects are separated in the discussion guide.

We welcome **comparisons between the current engagement and your experience of others**. For example, you will see that we ask questions about how the objectives of public and private sector organisations align. To help answer this we could discuss how different parties' objectives compare between the engagement we are primarily interested in and other collaborations you have been involved in.

Each interview will last approximately 45 minutes to 1 hour. Thank you for your participation, we look forward to meeting you.

Discussion Guide

Introduction and background

It would be helpful to first confirm some general background relating to the primary engagement and your role:

- What are its objectives?
- What organisations are involved and what are their roles? Specifically, who are the public and private sector funders?
- What proportion of total funding is from the private sector? For example, is the majority of cash coming from a Research Council or from an individual business?
- Do the private sector funders provide any in-kind contributions? This could be, for example, researchers' time or the use of specialist equipment. How important / valuable are such contributions?
- Could you describe your role in the engagement?
- Do you have responsibilities outside of the engagement? E.g. does it take up half or all of your professional time?

The rest of the areas we would like to discuss are divided into two sections:

» In the ***primary engagement*** section we would like to hear about the engagement we have specifically come to talk to you about. Making comparisons to other projects however is encouraged – this will provide context and points of comparison.

» In the ***general views*** section we would like to hear more broadly about your experiences of publicly and privately funded research, along with your opinions on how the level of private funding could be increased.

Primary engagement

Discussion topic	Primary questions	Secondary questions
Motivations for the engagement	1. How did you become aware of the other participants in the first instance, and the opportunity to engage with them? 2. What was the expectation of the benefits of engaging in the project/scheme? What were your objectives? 3. How did your objectives align with those of other parties in the first instance? 4. Was overseas investment considered? What are the comparative costs and benefits?	– Did you instigate the engagement? – Were all the participants already connected to a particular research facility, for example? – Did personal relationships exist between parties before the engagement? – What were the key considerations when choosing whether to partner with them? – Did future public sector investment in this area factor in to your decision? – What was funding/support needed for? e.g. buildings and equipment, researchers time, access to resources that only external parties possess?
Agreeing terms and conditions	5. Did compromises need to be made to agree on a final set of objectives? 6. How was it decided how much each party would invest? 7. How do the terms and conditions agreed compare with other projects? Specifically those that are entirely publicly or privately funded?	– How much time did the administrative element (i.e. paperwork) of setting up the engagement take? Does this prohibit such engagements? – Was the desired level of flexibility achieved? i.e. were there restrictions around when funding could be spent, or who specifically could conduct the research? – Did one party have a larger degree of bargaining power than another? Why was this? – How was ownership of intellectual property decided? Was this an issue? – How important were in-kind contributions to reaching an agreement? How do you estimate the value of in-kind contributions? – For you, what were the most and least important aspects of the private funding? For example, the absolute size of the funding, any constraints around how it could be spent.

Outcomes	8. Compared with the expected benefits at the start of the engagement, how did/do the actual benefits align? 9. In relation to the funding of the engagement, could anything have been done differently to deliver better outcomes for you? 10. Were there any benefits of the engagement that were not expected? Were there any unexpected costs?	– If the engagement were to start again, would you do anything differently? – Will you be seeking further engagements in the future? If so, how will they differ?

General views

Discussion topic	Primary questions	Secondary questions
General experiences	11. Why do foreign organisations want to invest in UK R&D? 12. Is there competition between public and private sector funders, and researchers to engage in collaborations? 13. Does your organisation actively seek out opportunities – whether this is at a project level or, for example, high level strategic partnerships (either domestically or abroad)? 14. What are the advantages and disadvantages of high level strategic partnerships compared to PI-led industry collaborations?	– What is the nature of competition between private sector organisations? i.e. is it on the basis of: the amount of funding; in-kind contributions; intellectual property rights? – Similarly, what do public sector organisations and researchers compete on? – Do you invest in R&D abroad? If not, have you considered it and why has it been ruled out? – What are your expectations about future public sector investment in this area? Does this affect investment decisions? – Do you do anything to stay aware of potential opportunities to participate in jointly funded research? – Is the degree of trust between public organisations the same as it is between public and private organisations? – Do you see any differences between small and large companies with respect to how they engage with HEIs?
Increasing private sector funding	15. How can the level of private sector investment on UK R&D be increased? 16. What changes could be made to the way that public funding is provided that may increase the amount of private funding received? 17. How can research investment from abroad be increased?	– What could be done to better align the objectives of public and private sector investors, and researchers? – What is limiting your investment / you attracting more investment? – Does the administrative burden deter or limit private investment? Does it put off individuals seeking jointly funded projects? – How important are private funds compared to private in-kind contributions? When does this differ? – Are there any barriers to international investment in R&D performed in the UK?

16. Annex J– Literature review

This annex summarises the main texts that have been used to inform our methodological report.

16.1. Literature review

16.1.1. Abramovsky et al. (2007), 'University Research and the Location of Business R&D', The Economic Journal

Abramovsky et al. (2007) investigated the relationship between universities and the location of business R&D in the UK. Using data from the Research Assessment Exercise (RAE), they distinguish between research departments that perform world-class research and others. Even when controlling for the presence of science parks and a high skilled labour force, econometric results show that foreign-owned R&D labs in the pharmaceuticals industry are particularly likely to locate in the same area as high quality research chemistry departments. They find much weaker co-location effects in other industries such as machinery and communication equipment.

16.1.2. Abreu et al. (2008), 'Universities, Business and Knowledge Exchange', The Centre for Business Research

This report shows the results of a case-based study of knowledge exchange processes involving 33 UK companies and universities. The cases covered a wide range of sectors and different firm sizes with help of a semi-structured questionnaire. Case studies included:

- Transitive – a spin out company from Manchester University;
- GlaxoSmithKline collaboration with the University of Dundee; and
- Rolls-Royce directing the majority of its academic research into selected University Technology Centres, amongst others.

They found that there is a considerable variation in how academics and the business sector are involved in knowledge exchange activities. This is in part due to the differences in roles of various universities.

The cases were helpful in understanding the expected variability in the ways in which interactions arose and proceeded, and the perceived or assessed nature of their impact upon the company value chain.

According to the case studies, most relationships between companies and universities were formed through common networks, or contacts were already familiar with each other. This underlines the importance of both, the organisational history and individuals' personal history and contacts.

The report identifies many different ways of interaction between universities and companies. These are dependent on the nature of the work/ project and of the resources available to all involved. Collaborative research, whereby a company and university join in a research project which is of interest to the company and usually supported by public funding (from RCs), is just one of those possible ways of interacting. Consultancy projects, graduate and student placements, recruitment and staff development, networks and technology, and licensing of technology are just some other forms of interaction between businesses and universities.

16.1.3. Abreu et al. (2009), 'Knowledge Exchange between Academics and the Business, Public and Third Sectors', The Centre for Business Research

This report addresses the lack of quantitative evidence of the interactions that academics have with external organisations, by analysing the responses of 22,170 UK academics to an engagement survey. It gives a detailed picture of: the activities of academics, how they are interacting with external organisations, what motivates or constrains interactions, and how academics see the role of academia in society. The report shows evidence that academics are engaging with society in a variety of ways, and that it is not only just those from the STEM disciplines, but also those from the arts, humanities and social sciences that engage.

One aspect of the survey covered the commercialisation of research. Most respondents (70%) believed that their research was relevant for non-commercial external organisations and 34% considered their research to be in a general area of commercial interest to business. Only 11% felt that their research had no relevance for external organisations. A better indicator of commercial activities are taking out patents, licensing research outputs to companies, forming a spin-out company and forming or running a consultancy. Patenting activity is most wide-spread amongst engineering and material sciences. Similarly, licensing research to companies and forming a spin-out company is more prevalent in engineering and material sciences, nonetheless such activity still occurs in the social sciences, arts and humanities. The most common way of externalising and commercialising research activity is forming or running a consultancy. Engineering and material sciences still has the highest percentage in this indicator, however it is closely followed by the social sciences.

The report identifies four different ways in which HEIs interact with external organisations:

- People based activities – which cover such things as attending conferences, participating in lectures, giving invited lectures and sitting on advisory boards.

- Community based activities – including lectures for the community, school projects, public exhibitions and community based sports.
- Commercialisation activities – include mechanisms such as patents, licences and spin-outs.
- Problem solving activities – encompasses informal advice, joint research, joint publications, consultancy services and contract research, amongst others.

Overall, it appears that there is a substantial degree of connectedness between the UK university sector and external organisations.

HEIs interact with private, public and the third sector. More than 40% of academics from all disciplines interact with private sector businesses. Of these, more than three-quarters of academics from engineering interact with the private sector. Nonetheless, 40% of social science academics and 30% from the arts and humanities interact with the private sector. The interaction with the third sector – charitable or voluntary organisations – is similarly high across all disciples, with 44% of academics interacting with the third sector. Here, the disciplines with high degrees of engagement are the health sciences (57%), social sciences (48%), and the arts and humanities (47%). Contrary to private sector engagement, only 26% of the engineering and material sciences academics interact with the third sector.

An important insight from this report are the ways in which these interactions with external organisations are developed. Most interactions start because individuals are associated with the external organisation (80%), followed by mutual actions following up informal contacts, own actions in approaching the external organisation directly, mutual actions following up a contact at a formal conference or meeting, and finally through the university's technology transfer officer (TTO). The latter is mostly used when interactions require a significant legal or contractual component.

It also sheds light on the motivations and impacts of knowledge exchange, concluding that engagement with external organisations strengthens the two core missions of academics – research and teaching. Besides, constraints to such interactions also need to be considered, especially as it is believed that "companies and universities are not natural partners: their cultures and their missions are different" . The main constraint appears to be lack of time (66%), bureaucracy (32%) and insufficient rewards (29%).

An interesting section of the report analyses the variations in interactions by different types of institutions and by different regions. The authors divide the universities into four groups: (i) the Russell Group, (ii) older universities established before 1992, (ii) younger universities established post-1992, and (iv) specialist institutions with focus in particular on the media and the creative arts. In general, they find little difference between these four groups regarding the forming or running of consultancies based on research. The differences arise when taking a patent is considered, whereby the Russell Group universities have a clear advantage. The Russell Group excels again with licensing research output to companies and forming a spin-out company, closely followed by the older universities. This indicates that there is a clear relative specialisation in terms of research oriented activities by the Russell Group, and more people based and teaching activities by the younger universities. Geographically, they find that younger universities have a higher proportion of academics involved in regionally based external actions based around people, whereby Russell Group academics are more likely to be engaged in international interactions.

In conclusion, this report finds that academics from all disciplines are widely engaged with external organisations.

16.1.4. Almus and Czarnitzki (2003), 'The effects of public R&D subsidies on firms' innovation activities: the case of Eastern Germany', Journal of Business & Economic Statistics

This paper analyses the effects of public R&D policy schemes on the innovation activities of firms located in Eastern Germany. It focuses on whether public funds stimulate R&D activities or simply crowd-out privately financed R&D. The authors investigate empirically the average causal effects of all public R&D schemes in Eastern Germany by using a non–parametric matching approach. This addresses the issue of selection bias – that projects that receive public funding may have been selected because they are likely to attract private sector funding - and allows for a like-for-like comparison with less bias. They find an overall positive and significant effect of R&D subsidies on investment in R&D by firms in Eastern Germany. Compared to the case where there is no public investment, firms increase their innovation activities by about four percentage points.

The paper presents the following results:

- The causal effect identified is significantly positively different from zero, i.e. firms that received public funding achieve on average a higher R&D intensity than firms belonging to the selected control group.
- The causal effect amounts to about four percentage points on average. For example, a subsidized firm

with a turnover of 100,000 monetary units would on average have invested 4,000 monetary units less if it did not participate in public R&D schemes.

16.1.5. Atkinson (2007), 'How Do Companies Choose Where to Build R&D Facilities?', presented before the Committee on Science and Technology Subcommittee on Technology and Innovation U.S. House of Representatives

This speech addresses the question of R&D offshoring. It shows that in the last decade the share of US firms' R&D sites located in the US dropped from 59% to 52%, while the share in China and India increased from 8% to 18%. It further demonstrates that over 60% of US companies surveyed invest in R&D in China, 50% in India, and 20% in Eastern Europe. 65% of US firms are increasing their R&D investments in Asia, whereas just 29% are doing so in higher-cost Western Europe – the traditional destination for US corporate R&D.

Atkinson shows that R&D performed by US companies outside the US increased considerably in low-wage nations like Mexico, China, and Malaysia, but also in mid-wage nations like Ireland, Israel, and Singapore between 1994 and 2003.

He shows that it is not only US companies offshoring R&D, but also their European and Japanese counterparts. The percentage of R&D conducted outside firms' home countries increased throughout the 1990s, even before the rapid increase in R&D offshoring to developing nations after 2000.

Furthermore, the United Nations Conference on Trade and Development (UNCTAD) reported that of the 1,773 greenfield R&D projects set up between 2002 and 2004, projects in developing nations by companies based in developed countries accounted for over half (953) of total projects, 70% of which were in China and India.

16.1.6. Becker and Pain (2007), 'What determines industrial R&D expenditure in the UK?', The Manchester School

This paper identifies some of the factors behind the UK's comparatively poor R&D performance in the 1990s, where R&D intensity in the business sector declined steadily. The authors investigate the effect of government funded R&D using a panel of UK manufacturing industries with lagged dependent and independent variables. They identify five main categorise of determinants of business investment in R&D:

i. Specific firm/ industry characteristics, such as sales and profitability;
ii. Product market competition;
iii. Public policies, such as direct funding of research projects performed in business, beneficial tax policy, and investment in other research that has spillover effects for private business;
iv. Endowment and location, and spillovers from other sectors; and
v. Other determinants of R&D expenditures such as support by foreign funds, and macroeconomic factors such as interest and exchange rates.

Further, they find that an increase in the share of government-funded or foreign R&D has a positive impact on aggregate R&D expenditure.

Overall they find that public funding has a positive effect on short-run and long-run private R&D expenditure.

16.1.7. Blank and Stigler (1957), 'The Demand and Supply of Scientific Personnel', National Bureau of Economic Research

This study was one of the first empirical academic studies into the relationship between public and private investment in R&D. It analysed the methods that explain the movements in the supply and demand for scientific personnel.

The authors examined this based on the technological professions in the US up to 1955. They faced data limitations in their analysis regarding data on salaries and fringe benefits, types of activities of engineers, sources of non-graduate engineers, and several other aspects of the issue.

Their main output was a considerable list of further data collection and research necessary to progress in the understanding of the rapidly growing professions of this review.

16.1.8. Bloom et al. (2001), 'Do R&D tax credits work? Evidence from an international panel of countries 1979–94', Public Economics

This paper analyses the impact of fiscal incentives on the level of R&D investment.

The authors employ an econometric model of R&D investment, which is estimated using a new panel of data on tax changes and R&D spending in nine OECD countries over a 19-year period (1979–1997). They find evidence that tax incentives are effective in increasing R&D intensity. This results holds even after allowing for permanent country-specific characteristics, world macro shocks and other policy influences.

They estimate that a 10% fall in the cost of R&D stimulates just over a 1% rise in the level of R&D in the short-run, and just under a 10% rise in R&D in the long-run.

16.1.9. CBI (2011), 'Making the UK the best place to invest'

This report is the summary of interviews with business leaders and analysis of data on blockers and drivers of business investment in the UK.

It found that the UK has a strong reputation as a place to invest, as it has great strengths such as its science, university and R&D base, dynamic culture and quality of life and a flexible labour market. All these factor together attract domestic and foreign investment.

16.1.10. Cohen and Levinthal (1989), 'Innovation and learning: The two faces of R&D', The Economic Journal

This paper suggests that that R&D not only generates new information for the company, but also enhances its ability to assimilate and exploit existing information. The authors analyse the implications of this dual role of R&D for the companies' incentive to invest in R&D. They postulate that recognising this second role of R&D will ease the character of learning within an industry and will affect R&D expenditure and condition the influence of appropriability, whereby intra-industry spillovers may actually encourage private R&D investment.

16.1.11. Cohen and Levinthal (1990), 'Absorptive capacity: A new perspective on learning and innovation', Administrative Science Quarterly

Here, Cohen and Levinthal argue that a company's ability to recognise the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. They label this capability as 'absorptive capacity' which relates to a firm's ability to access, understand and apply the results of research carried out elsewhere. In other words, a lack of absorptive capacity will result in 'system failures'.

An individual's absorptive capacity is mainly based on prior related knowledge and diversity of background. Factors influencing this capacity occur at an organisational level - how an organisation's absorptive capacity differs from that of its individual members, and the role of diversity of expertise within an organisation.

They argue that the development of absorptive capacity, and, in turn, innovative performance are history- or path-dependent and argue how lack of investment in an area of expertise early on may foreclose the future development of a technical capability in that area.

They model company investment in R&D, in which R&D contributes to a firm's absorptive capacity, and test predictions relating a firm's investment in R&D to the knowledge underlying technical change within an industry.

16.1.12. Correa et al. (2013), 'The Impact of Government Support on Firm R&D Investments – A Meta-Analysis', World Bank

This paper provides a meta-analysis of 37 studies from 2004-2011. The wide range of papers they analysed employed different techniques and investigated different sectors.

Their analysis suggests that public funds do not crowd-out but incentivise firms to revert funds into R&D. Results show that the effect of public investment in R&D is predominantly positive and significant. The coefficient of additionality impacts on R&D ranges from 0.166 to 0.252, with reasonable confidence intervals at the 95 percent level, due to different model specifications (i.e. WLS, WLS Full Specification, Fixed Effect (Region), Random Effects).

16.1.13. Czarnitzki and Fier (2001), 'Do R&D subsidies matter? Evidence for the German service sector', Centre for European Economic Research

This paper seeks to analyse the impact of public innovation subsidies on private innovation expenditure in the German service sector. It does so by using cross-sectional data at firm level, applying a non-parametric matching approach. The authors find evidence that rules out the complete crowding-out effects between public and private funds.

Their matching analysis estimates the impact of public R&D subsidies on private innovation activities. Their approach uses a control group of companies which did not receive any subsidies, besides the funded service firms. From this control group, they build a matched sample which resembles the subsidised group except for the fact of reception of public innovation subsidies. The research question they seek to address is the following: "How much would an enterprise which participated in at least one public policy scheme in 1996 have spent on innovation if it had not received an grants or public sources?".

They start by estimating a probit regression on participation in public innovation schemes, and find that participation probability increases with firm size. Then the matching algorithm picks one observation of the potential control group as nearest neighbour for every participant and calculates the Mahalanobis distance. The potential neighbour with the smallest Mahalanobis distance is then picked as the chosen twin, and after this matching procedure there is a properly constructed control group. Once the control group is properly defined the effect of public funding is estimated. The average effect is the difference of the outcome variable – innovation intensity, between both groups. They find that the mean innovation intensity of subsidised firms amounts to 13.7%, whereas the mean of the controls amounts to 8.0%. Hence, the innovation intensity of 5.7% is caused by participating in public innovation programmes. The authors reject the hypothesis of full crowding-out effects between public and private innovation funds, based on these results. Nonetheless, although full crowding-out is ruled out, the amount of partial substitution of the two financial resources that has occurred remains undefined and unquantifiable.

16.1.14. David and Hall (1999), 'Heart of Darkness: Public-private interactions inside the R&D Black Box', Nuffield College Oxford, June, Economic Discussion Paper

This paper analyses interactions between public and private R&D expenditures, and their joint effects on the economy.

The authors find that econometric studies in this area report a plethora of sometimes confusing and often contradictory estimates of the response of company financed R&D to changes in the level and nature of public R&D expenditure. However, the necessary theoretical framework within which the empirical results can be interpreted is very rarely at hand.

They find that a major cause of "inconsistencies" in the empirical literature is the failure to recognise key differences among the various policy "experiments" being considered – depending upon the economy in which they are embedded, and the type of public sector R&D spending that is contemplated.

They use a simple, stylised structural model, identifying the main channels of impact of public R&D. Thus they characterise the various effects, distinguishing between short-run and long-run impacts that show up in simple regression analyses of nominal public and private R&D expenditure variables. Within the context of their model it is possible to offer interpretations that shed light on recent cross-section and panel data findings at both high (i.e. national) and low (specific technology area) levels of aggregation.

Their basic proposition is that: whenever the market supply of R&D inputs is less than infinitely elastic, as is likely to be the case in the short-run, increased public sector demands for those resources must displace private R&D spending, unless it gives rise to spillovers that also raise the aggregate private derived demand for R&D inputs. In a simple two-sector model that they developed, the nature of the relationship between private and public R&D investment depends upon four parameters of the system.

Complementarity, rather than substitution effects are likely to dominate where:

» the relative size of the public sector in total R&D input use is smaller;
» where the elasticity of the labour supply of qualified R&D personnel is higher;
» where the grant–contract mix of public outlays for R&D performance is skewed more towards the former; and
» where the rate at which the private marginal yield of R&D decreases more gradually with increased R&D expenditures.

Without being able to fully specify both the magnitudes of the elasticities and the shifts in schedules due to spillover effects, it is not possible to determine the net effect of public expenditure on R&D.

The authors argue that the major effect of government R&D funding is an increase of the wage of researchers. When faced with higher research costs, firms will shift their funding to alternative investments – thus crowding-out privately funded research. However, when looking at the statistics this negative effect may be masked by the fact that higher prices result in the appearance of more research. As the quantity of research is measured in monetary terms, even when adjusted for general inflation, increased wages may result in the amount of research appearing to have increased. Whether the 'nominal' amount of research increases or decreases as a result of increased wages will depend on firms' price elasticity of demand.

16.1.15. David et al. (2000), 'Is public R&D a complement or substitute for private R&D? A review of the econometric evidence', Research Policy

This paper provides the first wide scale survey of studies on the relationship between public and private R&D –covering the periods from 1966 to 1999. The paper analyses econometric studies which explore the relationship between public and private R&D funding. Public funding of R&D can contribute indirectly, by complementing, and hence stimulating private R&D expenditures, even if it has been undertaken with other purposes in view – "spillover" effects. Central rationale for government support of R&D is the correction of the market failures in the production of scientific and technological knowledge, arising from the "incomplete private appropriability" problems identified by Nelson (1959) and Arrow (1962). David et al. identify two policy responses: (i) direct procurement and/ or production in public facilities (i.e. public funding of HEIs, etc.) or (ii) incentives for greater amount of private investment (i.e. tax incentives or direct subsidies). This paper only deals with the effect of the latter on private R&D investment. Tax incentives reduce the cost of R&D and allow private companies to choose projects, whereas direct subsidies raise the private marginal rate of return (MRR), but are usually accompanied by a government directed project choice.

The studies examined have been divided into four broad groups:

- Pure cross-section studies at the micro level: firms/ industries with different levels of government R&D are compared
- Panel data studies at the micro level within a given industry, with controls for time-invariant differences among firms
- Aggregate macroeconomic studies: changes in private R&D funding over time are a function of government R&D funding, controlling for macroeconomic factors
- Studies (micro or macro) that attempt to control for the simultaneity between private and public R&D spending using instrumental variables.

The majority of studies surveyed in this paper draw the following conclusions:

- Government R&D and tax incentives stimulate private R&D investments.
- Government grants and contracts, and government spending on basic research do not displace private R&D funding except when R&D inputs have inelastic supply. The outcome depends on market demand and supply conditions, which are unobserved most of the time.
- About two-thirds of studies surveyed conclude that public funding is complementary to private financing (i.e. crowding-in occurs), while one-third point to a substitution between the two sources (i.e. crowding-out).

Different econometric analyses have been undertaken and can be broken down into four types of observational units: line-of-business or laboratory, firm, industry, and national (or domestic) economy. The typical econometric approach is to regress some measure of private R&D on the government R&D, along with some “control” variables.

- A positive coefficient on the public R&D is interpreted as revealing the predominance of complementarity between public and private investments
- A negative coefficient is taken to imply that public R&D and private R&D are substitutes
- Magnitude of the estimate is often used to make statements to the effect that “a one dollar increase in public R&D leads to an X dollar increase in private R&D investment”

At the line of business and laboratory level, they find elasticities ranging from 0.06 to 0.336. At the firm level they find both positive and negative elasticities, ranging from -0.13 to 0.48. At the national level they find elasticities ranging from 0.045 to 1.04.

They identified five papers that studied the relationship between public and private investment at the individual national level. All those papers found evidence of crowding-in and they report elasticities from two papers:

- 0.045 (although insignificant) from Lichtenberg (1987); and
- 1.04 from Diamond (1998).

Whilst there have been a number of studies at the individual national level, there have been very few studies that look at use data across time and national economies. However, the authors report on two such papers: von Tunzelmann and Martin (1998), a working paper, undertakes an analysis of R&D time-series for 22 OECD countries over the period 1969–1995. Using the panel data, they fitted a linear model relating the changes in industry-financed R&D to the changes in government-financed R&D, and the previous level of both private and public R&D expenditures, allowing country-specific differences in all the coefficients. In only 7 of the 22 countries did they find that changes in government-funded R&D have any significant impact on changes in industry-funded R&D, with the sign being positive in five of those seven cases.

Moreover, the authors report elasticities of five micro level studies, ranging from -0.13 to 0.336.

In order to understand how public R&D affects private sector R&D funding decisions, the authors adapt the model o firm-level investment behaviour to reflect the R&D investment decision.[45]

Furthermore, the authors identify factors that determine the position of the MRR and MCC curves. They give the following features that will influence the MRR curve:

- The ‘technological opportunities’ that are present in the firm’s market.
- The level of demand for potential products.

[45] *For a more detailed description of the firm-level R&D investment decision and MRR and MCC curves see discussion of Howe and McFetridge (1976), also detailed in this annex.*

- Institutional and other conditions affecting the 'appropriability' of innovation benefits.

Correspondingly, the features that affect the MCC curve are given as:

- Policy measures that affect the private cost of R&D projects such as the tax treatment of that class of investment, R&D subsidies, and government cost-sharing programs.
- Macroeconomic conditions and expectations affecting the internal cost of funds.
- Bond market conditions affecting the external cost of funds.
- The availability and terms of venture-capital finance and the tax treatment of capital gains.

16.1.16. Diamond (1998), 'Does federal funding crowd-out private funding of science?', Contemporary Economic Policy

This paper studies the effect of federal funding of basic research on private funding of basic research in the US over 43 years. The author identifies three components of R&D: basic research; applied research; and development. He focuses on basic research defined, by the National Science Board, as: research with the objective "to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind".

Diamond's dependent variable is the first difference in levels of private funding of basic research. Independent variables are the federal funding and GDP (or an alternative income measure). All nominal dollar amounts are transformed into real 1992 dollars using the GDP implicit price deflator.

As the author notes, the results of this study should be interpreted with caution. The high elasticity (1.04) could be a product of both public and private expenditure being driven by an omitted variable – such as the cost of performing research or potential returns to research. Furthermore, the estimate is in relation to expenditure on basic research, which naturally have a higher elasticity compared to all research expenditure.

16.1.17. Driffield and Love (2005), 'Who gains from whom? Spillovers, competition and technology sourcing in the foreign-owned sector of UK manufacturing', Scottish Journal of Political Economy

This paper explores 'technology sourcing' for foreign firms in the UK. The principal theory is that multinational companies may choose to locate in a given country to benefit from knowledge spillovers. The paper finds evidence that firms choose to locate in the UK not just to benefit from spillovers of domestic firms, but also those of other foreign firms locating in the UK. This is similar to the presence of 'network effects' and thus attracting foreign investment could have a snowball effect.

16.1.18. González et al. (2005),'Barriers to innovation and subsidy effectiveness', RAND Journal of Economics

This paper explores the effects of commercial subsidies to R&D. It employs a model of firms' decisions about performing R&D when some government support can be expected. The model is estimated with an unbalanced panel sample of more than 2,000 performing and non-performing Spanish manufacturing firms.

The authors compute trigger subsidies required to induce R&D spending for the non-performing firms. Among the performing firms, they detect those that would cease to perform R&D if subsidies were eliminated. They control for the probability of obtaining a subsidy based on a set of observable firm characteristics (e.g. size, age, industry, location, capital growth).

Moreover, they explore the change in the privately financed R&D effort of the performing firms. They find that subsidies stimulate R&D activities, and show that some firms would stop performing these activities in their absence. Nonetheless, their research also reveals that most actual subsidies go to firms that would have performed R&D otherwise. In these firms, however, subsidies are found to increase R&D spending with no crowding-out of private funds.

Overall, there is no evidence of funding crowding-out, displacement or slackness. What is implied then by our model with regards to the overall effect of subsidies on Spanish manufacturing?

As their sample has a known representativeness, this can be roughly computed from the following exercise. Taking (predicted) R&D expenditures in the presence of subsidies and in the absence of subsidies, they distinguish between those firms whose R&D performance decision is not affected by subsidies, and firms that the model detects as those who begin carrying out R&D thanks to subsidies. They build manufacturing aggregate numbers (for the whole period), which say that aggregate R&D expenditure increases by about 8% as the result of subsidies. Interestingly enough, total expected subsidies (observed subsidies) amount to 4.4% (5%) of total R&D expenditure. Hence subsidies are helping to increase total expenditure by slightly more than their amount. The 8% increment can be decomposed in two parts: 4.4% comes from the increase in expenditures of firms which would perform R&D in any case, and 3.6% comes from the R&D contributed by firms which the model predicts as non-performers in the absence of subsidies. It is interesting to further decompose these numbers according to the size of the firms. The percentage increase in the R&D of the smallest firms (≤ 200) is higher, 10.8%, with a contribution of the firms stimulated to perform R&D as high as 6.9%. The percentage increase in the R&D of the largest firms (> 200) is 5.9%, with a component due to the switching firms of only 0.9%. Subsidies during the period are thus estimated to increase total R&D expenditure by more than their amount, with almost half of the effect coming from the firms stimulated to perform R&D, which are mainly small firms.

16.1.19. Goolsbee (1998), 'Does government R&D policy mainly benefit scientists and engineers?', American Economic Review

This paper addresses the issue of government efforts failing to increase inventive activity, as the majority of R&D expenditure relates to salary payments to R&D workers. Labour supply in R&D being quite inelastic, a significant amount of government funding of R&D goes directly into higher wages.

Goolsbee argues that the major effect of government R&D funding is an increase of the wage of researchers. When faced with higher research costs, firms will shift their funding to alternative investments – thus crowding-out privately funded research. However, when looking at the statistics this negative effect may be masked by the fact that higher prices result in the appearance of more research. As the quantity of research is measured in monetary terms, even when adjusted for general inflation, increased wages may result in the amount of research appearing to have increased. Whether the 'nominal' amount of research increases or decreases as a result of increased wages will depend on firms' price elasticity of demand.

This paper shows that government R&D raises wages significantly using CPS data on wages of US scientific personnel, particularly scientists' related to defence such as physicists and aeronautical engineers. Goolsbee estimates that the elasticity of the R&D worker wage with respect to government spending is 0.09 in the long term.

He concludes that previous estimates of effects of government R&D spending may be overstated by as much as 30 to 50%. Furthermore, altering the wages of scientists and engineers, even those not receiving federal support, would result in government funding directly crowding-out private inventive activity.

16.1.20. Görg and Strobl (2007), 'The effect of R&D subsidies on private R&D', Econometrica

Gorg and Strobl investigate the relationship between government support for R&D and private expenditure on R&D within the manufacturing sector in Ireland.

Their empirical strategy combines a non-parametric matching method with Difference-in-Differences (DID) estimation, hence controlling for a self-selection bias. Their regression included explanatory variables according to the size of the R&D subsidy (split between small, medium and large grants). The results suggest that for domestic plants while grant provision at a small or medium scale does not crowd-out private spending, and in the case of small amounts may even create additionality effects, too large grants may act to finance R&D activity that would have been taking place anyway. In contrast, they find that there is no evidence of such additionality or crowding-out effects for foreign multinationals regardless of grant amount size.

Whilst Gorg and Strobl do account for the potential selection bias, their approach, as with all micro studies, does not take account of substitution effects across the whole economy. Public spending may attract more private funding in one area, but simultaneously take it away from others.

They find that in the long-run, the additionality effect is positive for small grants and negative for large ones.

16.1.21. Guellec and van Pottelsberghe de la Potterie (2003), 'The impact of public R&D expenditure on business R&D', Economics of Innovation and New Technology

This paper assesses the effect of government spending on R&D that is funded and performed by business in 17 OECD countries. It seeks to answer the questions of whether public performed research, direct funding and fiscal incentives stimulate business-funded R&D, whether the stimulation effect dominates the crowding-out effect and how policy instruments interact with each other.

The authors classify three types of policy instrument that governments can use to support private investment in R&D: publicly performed research (government or university); government funding of business-performed R&D; and fiscal incentives.

Their empirical model considers business-funded R&D as a function of output, the policy instruments (government funding of R&D performed by business, tax incentives, government intramural expenditure on R&D, research performed by universities), time dummies, and country-specific fixed effects. The model also has a lagged dependent variable to account for short- and long-run elasticities.

The authors identify that an issue of analysing additionality at the macroeconomic level may be that both business and government expenditure could be influenced by common factors, which would bias the estimated relationship. Two factors are likely to be important:

- First, changes in the business cycle affect the financial constraints of government and business. To account for this problem, they use GDP growth as an explanatory variable for business funded R&D.
- Second, changes in the cost of R&D may affect both sectors. For instance, wages and other input prices may increase when the public sector expands its spending, leading to a growth in business spending that is only nominal in character. This factor is examined by accounting for the reaction of R&D prices to demand, as estimated by Goolsbee (1998).

Box 5. Adjustment from wage inflation

Guellec and de la Potterie (2003), whilst estimating the impact of public funding on private R&D expenditure, make an adjustment to their elasticity to account for the rising cost of wages.

Goolsbee (1998) uses CPS data on wages of US scientific personnel and shows that government R&D spending raises wages significantly. They conclude that previous estimates of effects of government R&D spending may be overstated by as much as 30 to 50%.

Goolsbee (1998) estimates the elasticity of the R&D worker wage with respect to government spending is 0.09 in the long term. Guellec and de la Potterie (2003) subtract this price effect from their coefficients, leading to an elasticity of -0.01 for direct funding in the long term and therefore making government funding neutral with respect to business R&D. However, they point out that Goolsbee's estimate is based partly on a period when government spending was a much higher proportion of total R&D than in the period that they are studying. They therefore conclude that Goolsbee's estiamte must be an overstatement for their purpose.

They find that both fiscal incentives and direct funding stimulate business-funded R&D, whereas they find that research performed by government has a crowding-out effect, and research carried out by the higher education sector has no effect. So, overall direct financial support is more effective than the indirect supply of knowledge for enhancing businesses expenditure on R&D. A more detailed analysis shows that only defence government-performed research has a negative impact on business funded R&D, whereas civilian R&D has no impact.

Moreover, the effectiveness of these different policies is affected by different factors. Countries providing too much or too little direct funding to businesses stimulate private R&D less than countries with an intermediate level of public funding. The effectiveness of government funding of business R&D appears to have an inverted U-shape, whereby it increases up to an average subsidisation rate of about 10%, decreasing beyond. Over a level of 20%, additional public money appears to substitute for private funding.

Besides, the authors also find that stable policies are more effective than volatile policies, and that the effectiveness of each of the various policy tools depends on the use of the others – government funding of business R&D and tax incentives are substitutes: greater use of one reduces the effectiveness of the other.

They find short-run elasticities of 0.07 for government funding and -0.06 for government research and long-run elasticities of 0.08 and -0.07 respectively.

16.1.22. Haskel et al. (2014), 'The Economic Significance of the UK Science Base', UK-IRC

This paper identifies two concepts relevant to the justification of public sector investment in R&D:

- spillover effects resulting in firms not being able to realise the full benefit of their investment and therefore underinvesting; and
- 'system failures' resulting in diminished knowledge flows from pure to applied research.

They analyse how public sector funding of the science base in the UK affects private sector funding, using HESA and HEBCI data for the period 2003 to 2012. Their regression models take the form:

$$ln(private_t) = \alpha + \beta ln(private_{t-1}) + \gamma ln(public_{t-1})$$

It relates the level of private funding in an HEI in 2008-12 to the level of private and public funding achieved in the period before (2003-07). Levels of funding are adjusted for the number of full time equivalent staff. Three measures of public sector funding are used: total QR funding; Research Council funding; and the sum of the two.
The results suggest that if total public funding would have been 1% higher in the first period, private sector funding would have been 0.10% higher in the second period. As the lagged dependent variable is included

as an explanatory variable this should be considered as a short-run effect. The implied long-run effect is 0.28%, although because only two time periods were used this constitutes an extrapolation and thus may not be a robust estimate of long-run dynamics.

In light of these results, they analysed the extent to which involvement with the private sector is related to either the receipt of a RC grant or being located in a department which received a high quality rating. They find a strong set of actual and potential linkages between publicly funded university research and the private sector. They also find that holding a RC grant is associated with higher levels of such activity.

Furthermore, they develop a model that analyses the relationship between TFP and public sector science funding in the UK period 1995-2007 and find a variety of positive impact links between the science base and the private sector. They find that a link from the science budget to TFP growth in an industry depends crucially on R&D performance, or cooperation with the university sector, of the industry itself.

Overall, their report restates the complementary relationship between industry and public sector R&D.

They also state that (multinational) firms benefit from knowledge that comes from within the company (in the UK), outside the company (but in the UK), or from outside the company (outside of the UK). These knowledge flows, along with economic (macro-economic, financial markets) and institutional factors (legal and institutional rules, IP) will affect the company's performance. That knowledge comes in first place from UK universities, therefore they look at the funding of UK university research.

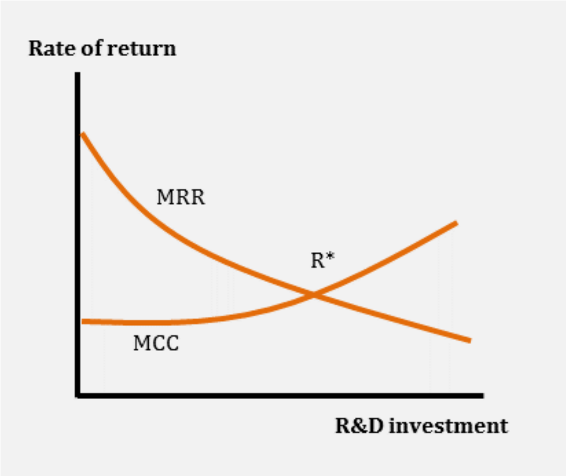
The R&D investment location decision of multinational companies is linked to the science base in the UK, as there is a desire to make use of the strong UK technological capabilities in areas of science, for instance. The UK's outstanding university sector should be a strong attractor for overseas funding of R&D in the private sector and the location of R&D activity in the UK, and overall they find that public sector funding "crowds in" private sector R&D from abroad. They also analyse different ways in which university funding leads to External Income Generation (Third Stream Income), namely by:

- IP: patents and licences
- Collaborative and contract research
- Consultancy
- Continuing and professional development and continuing education
- Regeneration and development programmes
- Facilities and equipment related services

16.1.23. Howe and McFetridge (1976), 'The determinants of R&D expenditures', Canadian Journal of Economics

Private firms invest in R&D for profit and will invest so long as the expected revenues outweigh the expected costs. One simple but effective framework for determining the level of investment by an individual firm is attributable to Howe and McFetridge (1976). It postulates that at any given time a firm has a range of potential R&D projects available to it. The firm assesses the expected cost and revenue streams of each project – which can be thought of as giving rise to the internal rate of return. Projects can then be ranked in order of return which forms the marginal rate of return curve (MRR) shown in the figure below.

Figure 135. A firm's optimal level of R&D investment



Source: Based on Howe and McFetridge (1976)

The marginal cost of capital (MCC) curve is assumed to be an increasing function and the optimal level of investment in R&D is given by point R*. More technical aspects of this model are discussed further in the following box.

Box 6. Technical specifications of model based on Howe and McFetridge (1976)

The MRR schedule is constructed by ranking projects in order of anticipated yield. Each project is presented as being infinitely divisible so that the MRR schedule is continuous and continuously differentiable. This simple model does not take account of complication around the firm's ability to access and use the relevant knowledge base. That is, a certain amount of investment will be needed to understand and evaluate the relevant project possibility set. Such a dynamic specification is relatively easy to implement in a mathematical formulation.

The MCC schedule represents the opportunity cost of funds at different levels of R&D investment. The level of other investment by the firm is implicitly held constant. The expected return of a project is compared against the MMC without taking into account risk. In reality, if two projects have the same expected return but one is more risky (the level of return is less certain), a higher hurdle MCC will tend to be used for the riskier project. The upward slope of the MCC curve is reflective of the fact that firms will have to move from using internal funds (e.g. retained earnings) to external funding (i.e. issuing debt and equity) which are more costly.

16.1.24. Hughes and Kitson (2012), 'Pathways to impact and the strategic role of universities', Centre for Business Research, University of Cambridge Working Paper

This paper addresses key aspects of the technology transfer and knowledge exchange processes. It analyses the results from two unique surveys – a survey of over 22,000 UK academics and a business survey with over 2,500 responses. The authors show that there are many knowledge exchange mechanisms, such as commercialisation processes, and that it involves academics from all disciplines, not only from science and engineering, involving many partners from the public, third and private sectors.

They conclude that the academic "ivory tower" is a myth (for the UK) and that strengthening connections between academia and the rest of society could generate benefits for the whole society.

16.1.25. Hughes and Martin (2012), 'Enhancing Impact – The Value of Public Sector R&D', UK-IRC

This report reviews the evidence relating to the impact of publicly funded research, more specifically UK university research funded by the Higher Education Funding Councils (HEFCs) and the Research Councils (RCs) through the dual support system. The introduction of policies requiring publicly funded research to reflect the needs of users and to have an "impact" has led to concerns that basic research may be threatened. Publicly funded research is affected by the capacity of other actors in the economic and innovation system to access, understand and use the research outputs produced with public sector support. This will depend on the R&D that the private sector is itself carrying out, which has mainly two purposes: creating new knowledge in itself, but also enhancing the firm's "absorptive capacity " – i.e. the ability of a company to identify, understand and exploit knowledge developed elsewhere in the innovation system, including the public sector (Cohen and Levinthal, 1989 and 1990).[46]

The issue here is how to manage the boundaries between these two specialised organisational forms, so that they do not damage the role played by each other. Hence, it is of importance to understand the transitional pathways and the ways in which scientists are motivated or influenced by problems and areas of research stimulated by interactions through these pathways.

This report builds on Hughes and Kitson (2012) survey and recognises the important pathways to knowledge exchange between academia and the private sector, such as people-based activities, community-based activities, commercialisation activities and problem-solving activities.

Another pathway of knowledge exchange are the so-called Knowledge Transfer Partnerships (KTP), whereby a graduate student, known as an associate, works for a company during two years on a specific knowledge transfer project, central to the firm's development.

The report also picks up on the complementarity issue between public sector R&D and private sector R&D. There are arguments for public sector R&D crowding-out private sector R&D, by, for instance, raising the price of resources required for R&D (usually skilled and highly qualified labour). In this

[46] *'Innovation and Learning: The Two Faces of R&D', Cohen, W.M. and Levinthal, D.A., Economic Journal 99 (397), pp.569-596, 1989.; 'Absorptive Capacity: A New Perspective on Learning and Innovation', Cohen, W.M. and Levinthal, D.A., Administrative Sciences Quarterly 35 (1), pp.128-152, 1990.*

case, public sector R&D would be a substitute for private sector R&D. On the other hand, public sector R&D may be augmenting the extent to which private sector R&D may be expected to yield returns, by expanding the pool of available information and knowledge. This could lead to a crowding-in effect, i.e. more private sector R&D being undertaken, as there more opportunities and more information and knowledge, arising from the public sector R&D.

16.1.26. Ito & Wakasugi (2007), 'What factors determine the mode of overseas R&D by multinationals?', Research Policy

This paper investigates the factors affecting the expansion of support-oriented R&D and knowledge sourcing R&D by using qualitative data which indicate the modes of R&D conducted at a plant site and a laboratory.

They that (i) the export propensity of affiliate firms, relative abundance of human resources for R&D, and accumulated technological knowledge have a positive effect on both the modes of R&D at a plant site and a laboratory; and (ii) the stronger enforcement of intellectual property positively affects the expansion of knowledge sourcing R&D.

These results further show that not only firm-specific but also country-specific factors positively affect the overseas expansion of R&D.

16.1.27. Jaumotte and Pain (2005), 'From ideas to development: the determinants of R&D and patenting' OECD

This paper investigates the effects of innovation policies and framework factors on business R&D intensity and patenting for a sample of 20 OECD countries over the period 1982-2001 using panel regressions.

The authors found that even though increased public expenditure on R&D can push up wages, it is more than offset by a positive impact on the efficiency of labour in the private sector that arises through the public investment in basic research. This would suggest that although the cost per employee rises, the cost of labour per unit of output effectively remains constant. If such a case were true, no adjustment for wage inflation would need to be made as prices would rise with productivity. However, they found that the rise in wage rate was equal to the increase in efficiency, and as such no adjustment would be needed.

16.1.28. Lambert (2003), 'Lambert Review of University-business Collaboration, Final Report', HM Treasury

This report, commissioned by HM Treasury, identifies two main trends:

- R&D is moving towards a more collaborative and open form of innovation; and
- Business R&D is going global.

The report finds that business R&D intensity in the UK is low compared to other developed economies. It recognises that R&D intensity is higher than the international average in two area: pharmaceutical/biotechnology and aerospace/defence. Nonetheless, this business research base is fragile and dependent on a couple of large companies active in those two areas.

Furthermore, the report identifies human interaction as the best form of knowledge transfer, encouraging research collaborations and ease of transfer of IP rights from universities to businesses.

It also analyses different regional issues and the strengths and weaknesses of the current dual support system of university funding.

16.1.29. Levy (1990), 'Estimating the impact of government R&D', Economic Letters

This paper estimates the impact of government R&D on private R&D using a sample of nine OECD countries for the period of 1963–1984. The author uses a specification that distinguishes among three geographic regions within which it is assumed that there would be strong spillover effects: the US, Europe, and Japan. He regresses national private R&D investment on aggregate public R&D investment in each region, aggregate regional GDP, and individual country dummy variables. Among the nine countries in his panel, Levy finds that five countries exhibit significant overall crowding-in, whereas two countries show significant crowding-out (amongst those, the UK). The reasons for the differences remain unexplored.

16.1.30. Lewin et al. (2009), 'Why are companies offshoring innovation? The emerging global race for talent', Journal of International Business Studies

This paper empirically studies the determinants of the companies' decisions to offshore product development activities (i.e. R&D, product design and engineering services).

It employs a logit model using survey data from the international Offshoring Research Network (ORN) project on offshoring administrative and technical services initiated by US firms between 1990 and 2006, to estimate the probability of offshoring product development. The independent variables include several strategic objectives (managerial intentionality), past experience with offshoring (path dependence), and exogenous (environmental) factors.

The results show that the emerging shortage of high skilled science and engineering talent in the US, which drives the need to access highly qualified talent globally, partially explains offshoring of product development. Furthermore, the findings also suggest that, although firms use offshoring to improve the efficiency of the innovation process, contrary to other functions, labour arbitrage is less important than other forms of cost savings with respect to product development activities. Additionally, the managerial objective of increasing speed to market is another major reason underlying product development offshoring decisions.

In conclusion, the authors discuss the changing environmental and competitive dynamics underlying offshoring of innovation activities, suggesting that companies are entering a global race for talent.

16.1.31. Lichtenberg (1987), ' The effect of government funding on private industrial research and development: a re-assessment', The Journal of Industrial Economics

This paper develops arguments and econometric evidence in support of the hypothesis that, previous estimates of the effect of federal industrial R&D on private R&D funding are seriously upwardly biased, due to a misspecification of the private R&D equation. The misspecification occurs through the failure of distinguishing government sales from other sales.

The author finds an elasticity of 0.045 (although inisginifcant).

16.1.32. Main (2013), 'Leverage from public funding of science and research', BIS

This report looks at the various sources of R&D funding and how they leverage funding from other sectors. The main findings are that:

- Of the £26.4bn spent on R&D in the UK in 2010: 33% came from public funds, 44% from business enterprise, 5% from charity, and 18% from overseas
- 57% of publicly funded and 76% of charitably funded R&D was carried out in HEIs
- 95% of the R&D funded by business and 77% of the R&D funded from abroad was carried out in UK businesses.
- UK received €4.4bn from the European Framework Programme 7, equivalent to 15% of the total fund and second only to Germany

It underlines that government, with partners in the public science and research sector (RCs, HEFCs) has a range of policies that stimulate activities that generate leverage from the private and charitable sectors, e.g. the Technology Strategy Board, Higher Education Innovation Funding, Research Partnership Investment Fund, Charities Research Support Fund.

From its own literature review it draws the conclusion that there is a positive relationship between total government investment in research and business enterprise R&D, and that UK public investment in R&D has shown to be complementary to private investment in R&D. It often reiterates that private and charitable investors cannot replace public funding of the research base in response to a withdrawal of government funds, as it is not within their remit or capability. The private sector and charities would not be expected to ever fully fund research and innovation because of a number of market failures including the inability to capture all the benefits.

Furthermore, it recognises that the UK research base is valuable to the UK economy and attractive to foreign investors. The author identifies a number of sectors contributing to the UK research base, such as:

- Public: HEFC QR research funds, RCs, National Academies, Public Sector Research Establishments
- Industry: physical and technological industry (engineering, computing, manufacturing); biomedical industry (pharmaceutical, diagnostic devices); data and services; contract research
- Charity: 85% of charity investment is in medical research; other charitable research investment are in the arts and humanities, social welfare, environment and conservation, international development, education and philanthropic support
- Overseas: European funding (FP programme), Foreign Direct Investment, research performed in the UK by companies owned overseas

There are different ways in which public funding levers additional investment from other sectors in the research base, including providing:

- a 'skill base' of highly trained graduates and post-graduates for recruitment into research industries and academia
- a framework for the UK's long term strategic interests in science and research that sign-post the UK's interests to business, charity, and overseas investors

- large scale national resources and platforms for research which are accessible to the research base but which no individual funder could provide or coordinate
- convening power to bring members of the research community together to address problems of national need
- an environment for high-risk discovery research whose results provide innovation for industry and step changes in understanding
- excellent publicly-funded research environments with access to facilities, services, resources, capital investment and infrastructure for research
- breadth of investment across all scientific disciplines to catalyse multidisciplinary research to tackle emerging research needs
- incentives and tools for leverage, e.g. Charity Support Research Fund, the UK Research Partnership Innovation Fund, Biomedical Catalyst

The main analysis is based on BERD and GERD trends by sector. There seems to be a delay in private sector, as a one year lag shows the existence of public sector leverage (in electrical machinery and service sector BERD). A linear regression is used to assess the relationship between the service sector public and private BERD, using GDP as a control variable. Without adjustments a 1% increase in public BERD leads to 10.8% decrease in private BERD. However, with a one year lag a 1% increase in public BERD leads to 13.7% increase in private BERD.

Further analysing the sources of R&D funding, public funding in 2010 (335) can be broken down into 12% Government funding, 11% RCs, 9% HEFCs, and 1% HEIs.

16.1.33. More Partnership (2012), 'Review of Philanthropy in UK Higher Education', Report to HEFCE

This report, commissioned by HEFCE, assesses the state of play in 2012 in philanthropic giving to higher education in the UK. It identifies the very real progress made across the sector over recent years, highlighting the opportunities that will benefit students and further knowledge, through increased engagement between institutions and donors. It addresses its recommendations to donors, to institutions and to government.

16.1.34. MRC (2014), 'Outputs outcomes and impact of MRC research: 2013/14 report'

This report focuses on the importance of collaboration and further funding. It analyses how MRC funding recipients have leveraged further investment from other RCs/ private sector/ charities, and so on. Here we focus on two chapters of the report, namely the sections on collaborations and further funding.

In the realm of collaborations, MRC reports that recipients of 52% of awards (2917) stated that they had established a collaboration which they could evidence, for example with co-publications, co-funding or exchange of materials and expertise. As collaborations take time for researchers to set up, there will be fewer collaborations resulting from more recent awards. 22% of awards reported at least one collaboration within one year of the award starting, compared to 52% after five years. The biggest part of collaborators were from the UK (55%), followed by the rest of Europe and North America with 17% and 12% respectively. The majority of collaborators were from academia (58%), followed by the public sector (15%), hospitals (8%) and the private sector (7%), according to Researchfish data.

Regarding further funding, researchers reported instances of further funding in 46% of awards, and 9355 instances of further funding were reported. Similarly to collaborations, further funding takes time to come into place. Recipients of 65% of grants starting in 2006 or earlier had reported further funding, compared to 16% of grants starting in 2013. 11% of awards reported instances of further funding within one year, compared to 54% after five years. Researcher reported a total value of £3.2bn in further funding. A total value of £700.7m was reported to have been leveraged in 212/13, which is an increase on last year's total of £562m.

The majority of further funding reported in Researchfish was reported from the UK between 2006 and 2013 – 68% of further funding (£21bn). 14% of further funding (£447m) was obtained from the rest of Europe. The largest value of further funding between 2006 and 2013 came from the public sector (£1.4bn – 46% of the total further funding reported). This was closely followed by non-profit organisations (£1.2bn -37% of the total further funding reported). 6% of further funding (£197m) was leveraged from the private sector between 2006 and 2013. In 2012/13 this figure was £33.5m, 7%. The Wellcome Trust provided the largest value of further funding, contributing£435m between 2006 and 2013. This was followed by the National Institute for Health Research (£195m). The largest overseas funder was the European Commission, contributing £120m between 2006 and 2013, followed by the National Institutes of Health (£95m). The largest single private sector funder was Merck & Co Inc, providing around £88m in this period.

16.1.35. MRC (2012), 'Outputs outcomes and impact of MRC research: 2012 report'

This report focuses on the importance of collaboration and further funding. It analyses how MRC funding recipients have leveraged further investment from other RCs/ private sector/ charities, etc.

Again, regarding collaborations, the recipients of 61% of awards (2900) reported that they had been part of a collaboration between 2006 and 2012. The majority of collaborations involved partners in the UK (54%), followed by the rest of Europe (19%), and North America (11%). The majority of collaborations was with academia (59%), followed by the public sector (16%), and then the private sector (8%). In December 2011 the UK Government launched Life Sciences Strategy to bolster UK life sciences: importance of MRC collaborations with private sector; establishment of the £180m Biomedical Catalyst, an integrated translational research programme allowing the MRC, in conjunction with the Technology Strategy Board (TSB), to provide support for projects ranging from "confidence in concept" studies through to late stage R&D up to, and including phase 2 clinical studies.

Regarding further funding, there are many potential sources of funding for medical researchers. Here, information on funding which was gained as a result of obtaining MRC support is analysed. HESA estimate that in 2011/12 UK universities received £1.5bn from RCs, BIS and the learned societies, £900m from UK-based charities, £800m from central government bodies/ local authorities, health and hospital authorities, £280m from industry, £600m from EU sources, and £320m from non-EU sources for research; a total income to UK universities of approximately £4.4bn in grants and contracts for research across all disciplines. There is an issue with over-reporting (EC and MRC funding) and duplicate reporting of grants. According to MRC Researchfish, out of the £562m of further funding that was estimated to have been spent in 2011/12, £14.1m (3%) was found to be from the private sector, and £124m (22%) from non-private sector sources outside the UK overall. Researchers reported receiving further funding in 48% of awards, 7919 instances of further funding were reported (of those who received further funding, the average number of instances was between 3-4) + recipients of 128 awards reported more than ten instances of further funding.

The majority of further funding was leveraged from the UK between 2006 and 2012: 71% of further funding (£1.6bn), 14% (£319m) was obtained from the rest of Europe. The largest value of further funding between 2006 and 2012 came from the public sector (£1.1bn – 47%), then not-profit organisations (£916m – 40%), and only 3% of further funding (£14.1m) was leveraged from the private sector in 2011/12. Leveraging of further funding from 957 different funders, where 791 contributed £10k or more in six FYs between 2006/07 and 2011/12, where the Wellcome Trust provided the largest value of further funding - £397m between 2006 and 2012, the EC was largest overseas funder - £261m between 2006 and 2012, and multiple funders represented £28.5m of funding.

16.1.36. PACEC (2012), 'Strengthening the Contribution of English Higher Education Institutions to the Innovation System: Knowledge Exchange and HEIF Funding'

This report draws on evidence from the HEIs' funding strategies for knowledge exchange (KE) and analyses the current state and future development of KE in the English HE sector. HEIF is an important funding source for KE, and this report purports that "for every £1 of HEIF invested, it returns £6 in gross additional KE income" (p.84). That is, for every £7 of total funding, £6 is from the private sector – giving a private sector percentage of 85%. This is believed to be an underestimation of the total benefits to the society and economy, as the KE impacts are more long-term.

PACEC define the additionality of the funding as the attribution of outputs to the inputs.

16.1.37. Science & Technology Facilities Council (2010), 'New Light on Science – The Social & Economic Impact of the Daresbury Synchrotron Radiation Source'

The Synchrotron Radiation Source (SRS), located at the Science and Technology Facilities Council's Daresbury Laboratory, was the world's first 2nd generation multi user X-ray synchrotron radiation facility. It ceased operations after 28 years of operation in 2008. This report examines the social and economic impacts of a large science facility over its whole lifetime. Among other assessments, it analyses the impacts SRS had on the UK industry and economy more widely. Users of the facility included large multinational companies and SMEs: ICI, BP, Unilever, Shell, GSK, AstraZeneca and Pfizer. A significant amount of knowledge exchange between SRS staff and industry occurred during the lifetime of SRS. Besides, SRS helped in the creation of nine new companies and one commercial service provider. The direct financial impact of the facility is estimated at £600m, whereas due to the multiplier effects, the total financial impact to the North West of England is estimated at around £1bn. In addition, 100 high tech businesses from a wide range of commercial backgrounds are now located at the Daresbury Innovation Centre, delivering £14.9m in sales in 2008/09, securing £20.5m in investment and having an average growth turnover of 67%.

The technology from the SRS has been commercially exploited through direct sales, patents, licences and spin-out companies. This illustrates how the skills, expertise and technology from the SRS have been exploited to create new businesses, hence creating more jobs and a wider impact in the economy.

The main users of the SRS were academics and public sector scientists. The SRS was funded from the Science Vote by the UK Government, by the Science and Engineering Research Council (SERC), and through Service Level Agreements with other RCs (EPSRC, BBSRC, MRC, NERC).

16.1.38. Thomson (2013), 'National scientific capacity and R&D offshoring', Research Policy

This paper presents new evidence regarding the role of national scientific capacity in driving patterns of R&D offshoring using a large and comprehensive dataset and applying it in a gravity model framework.

The results unambiguously support the importance of inventor country scientific capacity in attracting offshored R&D. As expected, the home country's scientific capacity is also found to play a positive role. The author finds that in fact, on average, firms source technology from less technologically advanced nations, suggesting that firms offshore to access niche skills.

16.1.39. Thursby and Thursby (2006), 'Here or There? A survey of factors in multinational R&D location', The National Academies Press

This report presents the results from a survey of over 200 multinational companies across 15 industries regarding the factors that influence decisions on where to conduct R&D.

The majority of companies replying had their headquarters either in the US or Western Europe. However, almost 90% had some R&D facility outside of their home-country, with roughly 20% of the companies having more than half of their R&D employees there. The results demonstrate that R&D location decisions are very complex and influenced by a plethora of factors. Furthermore, they find that four factors are essential in the R&D location decision:

- Output market potential;
- Quality of R&D personnel;
- University collaboration; and
- Intellectual property protection.

A striking result from this survey was the importance of universities in the global innovation system – being as important as costs in emerging economies and more important in developed economies.

Finally, the authors report that over 75% of US firms that invest in overseas research do so for the purpose of expansion. Firms are seeking to adapt their technology to local conditions so that they are able to sell into new markets.

16.1.40. Von Tunzelmann and Martin (1998), 'Public vs. private funding of R&D and rates of growth: 1963–1995', Working Paper, Science Policy Research Unit, University of Sussex

This working paper undertakes an analysis of R&D time-series for 22 OECD countries over the period 1969–1995. Using the panel data, they fitted a linear model relating the changes in industry-financed R&D to the changes in government-financed R&D, and the previous level of both private and public R&D expenditures, allowing country-specific differences in all the coefficients. In only 7 of the 22 countries did they find that changes in government-funded R&D have any significant impact on changes in industry-funded R&D, with the sign being positive in five of those seven cases.

16.1.41. Wallsten (2000), 'The effects of government-industry R&D programs on private R&D: The case of the small business innovation research program', Journal of Economics

This paper analyses whether government-industry commercial R&D grants increase private R&D. It does so by regressing some measure of innovation on the subsidy, which establishes a correlation between grants and R&D, but fails to determine causation, i.e. whether grants increase firm R&D, or whether companies that do more R&D receive more grants. The author uses a dataset of 367 firms involved in the Small Business Innovation (SIBR) programme between 1990 and 1992.

The regression takes on the following functional form:

$$y = \alpha + \beta^*(subsidy) + \delta X + \lambda Z + \varphi G + \varepsilon$$

Where y is the log of employment in 1993, *subsidy* relates to all the SBIR Phase 2 awards a firm won between 1990 through 1992, X is a vector of firm specific variables, such as log of age, the number of patents applied for, etc., Z is a vector of industry dummy variables, and G is a vector of four geographic dummy variables.

To correct for endogeneity he reestimates a multi-equation model to test these hypotheses, instrumenting for the endogenous awards variable.

The results show that companies with more employees and that seem to do more research win more SIBR grants, whereas grants do not appear to affect employment directly. Furthermore, the paper demonstrates that grants crowd-out firm-financed R&D expenditure dollar for dollar.

16.1.42. Warda (1996), 'Measuring the value of R&D tax provisions, in OECD', Fiscal Measures to Promote R&D and Innovation

This author developed the B-index: a measure of fiscal generosity towards R&D. The more favourable a country's tax treatment of R&D, the lower its B-index. Specifically:

$$B\text{-}index = \frac{1 - A}{1 - \tau}$$

Where: A = the net present discounted value of depreciation allowances, tax credits, and special allowances on the R&D assets; and τ = statutory income tax rate.

17. Annex K– Bibliography

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