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The relationship between public and private R&D funding

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The modelling and results presented here are based on information provided by third parties, upon which Oxford Economics has relied in producing its report and forecasts in good faith. Any subsequent revision or update of those data will affect the assessments and projections shown. To discuss the report further please contact:

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Context and rationale for the study

Innovation enhances productivity and drives long-run prosperity. It can create new and improved products and processes, and generate cost savings for companies and the taxpayer, as well as numerous other benefits. However, a range of market failures mean that if left entirely to the market, the amount of R&D which takes place would be considerably less than optimal. These failures provide a strong case for government intervention to support R&D across the economy.

An important consideration in determining the value of this support, and how it should be directed, is the extent to which public support stimulates, or “crowds in”, privately funded R&D investment that would not otherwise have occurred. This may be the case if public support reduces the costs and risks that firms face in undertaking research, for example by sharing costs on projects with wider value to society, or by putting in place research infrastructure which reduces complexity and up-front costs for private researchers. Another source of leverage may arise if public research makes new discoveries that stimulate private research in related fields.

The extent to which public support leverages additional private R&D has gained particular importance in light of recent policy developments. As part of its 2017 Industrial Strategy, the UK government announced a target for the UK to invest 2.4 percent of GDP in domestic R&D by 2027. A new body, UK Research and Innovation (UKRI), came into existence in 2018, bringing together the seven research councils, Innovate UK and Research England and integrating their research funding functions. UKRI and the rest of the government need evidence-based insights into the wider effects of public R&D funding. A further consideration is the extent to which the R&D funding landscape may change as a result of exiting the EU.

Study objectives

Against this backdrop, BEIS is seeking to deepen understanding of the impact of public R&D investment on private R&D investment. It therefore commissioned Oxford Economics to undertake independent research to update the evidence base in this field using the most recent and comprehensive datasets, and through the application of the latest analytical techniques.

Importantly, our approach seeks to identify a *causal link* to establish the extent to which public R&D *leads to* greater private R&D, as opposed to merely looking at the correlation between public and private R&D (the latter approach would not enable us to establish how changes to public R&D affect private R&D).

We consider different ways of analysing leverage rates and examine how the effects of public R&D on private R&D materialise over time. We explore how impacts vary across different types of public support and we make comparisons across OECD countries

An important objective throughout the study has been to work in a transparent manner, such that our methodology is replicable and updateable by others, and contributes to the wider field of econometric research into the impact of R&D support.

Our approach

We have adopted an approach which enables us to assess the overall impact of public R&D support on levels of private R&D right across the economy. This means that we can estimate the impact of both “direct leverage” on those firms which receive support, and “indirect leverage” on firms which are not directly supported, but nonetheless increase their R&D investment. Such investment may arise, for example, as firms seek to innovate in response to R&D undertaken by clients, suppliers or competitors, or perhaps investigate new applications of knowledge developed in other contexts. We therefore seek to capture the full range of spillover benefits which may result from public R&D support. In contrast to some other studies in this field, we do not seek to draw conclusions in relation to detailed issues of policy design.

Economic Insight previously researched this subject for BEIS in 2015. This study builds on that work, by incorporating the latest datasets and applying alternative econometric techniques in an attempt to overcome some of the challenges faced in the earlier study.

A range of observable and unobservable factors influence private sector R&D decisions, so isolating the influence of public R&D expenditures on private R&D is challenging and requires large datasets. While we explored models based on time series information from the ONS, our preferred approach is based on OECD data. The latter source enables us to assess trends both over time and between countries, thereby providing a much larger dataset, increasing the opportunity for identifying robust results.

What is the best estimate of the leverage rate in the UK?

The “leverage rate” indicates the impact of a 1 percent increase in public R&D investment on private R&D investment. We find that a 1 percent increase in public R&D increases private R&D by between 0.23 percent and 0.38 percent within the same year.

By combining this finding with information on levels of public and private R&D support we are able to estimate the monetary impact of this leverage effect. We find that each £1 of public R&D stimulates between £0.41 and £0.74 of private R&D

within the same year. Public R&D continues to influence levels of private spending in subsequent years. Our analysis suggests that the long-run impact of public R&D on private R&D is more than three times the short-run impact. The long-run leverage rate is estimated to be between 1.01 and 1.32, suggesting that each £1 of public R&D eventually stimulates between £1.96 and £2.34 of private R&D.

Figure 1: Estimates of UK leverage rates

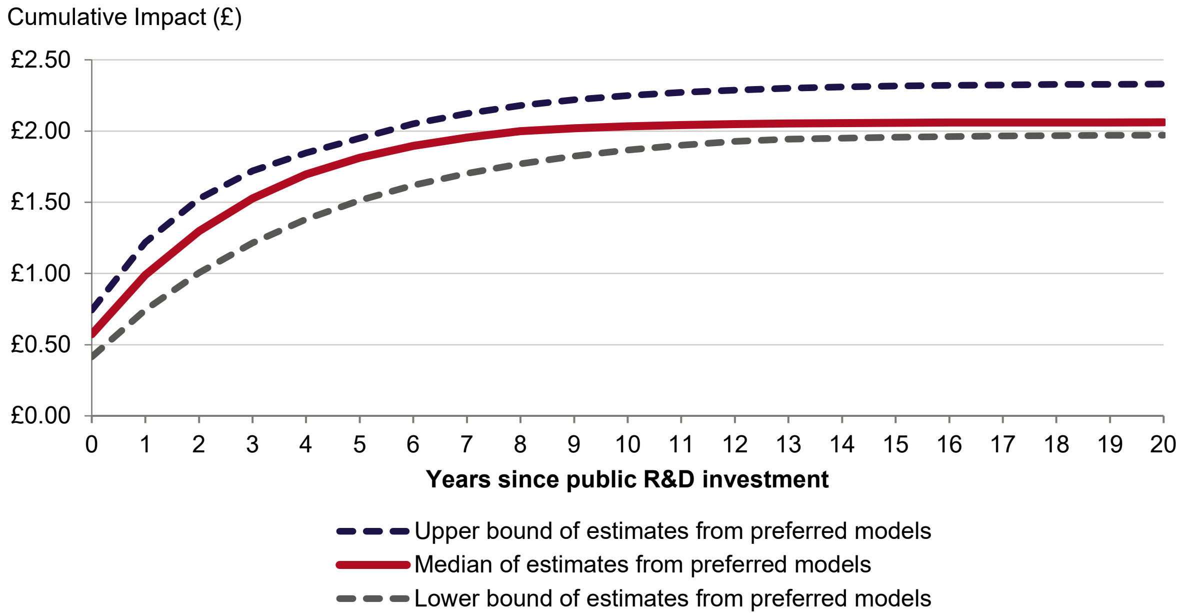
	Leverage rate		Impact of £1 of public support	
	Short run	Long run	Short run	Long run
UK leverage rate	0.23 to 0.38	1.01 to 1.32	£0.41 to £0.74	£1.96 to £2.34

Source: Oxford Economics

Our research suggests that leverage begins within the year that the public investment occurs. The impact is most substantial in that first year and fades over time. Almost all of the effects materialise within around 15 years, and the majority of private investment is crowded in by the fifth year. Figure 2 demonstrates how the monetary impact accrues over time, based on the highest and lowest values from the eight preferred models presented in the report. The chart also shows results for the median finding from the eight models, which suggests a monetary impact of £0.57 in the short run and £2.05 in the long run.

Figure 2: Time profile of the impact on private R&D investment of £1 of public R&D investment

Based on OECD datasets accessed in June 2018 and October 2018



Source: Oxford Economics

Our findings for the short-run leverage rate are similar to some of those identified in previous research. However, few past studies have estimated dynamic effects. Our modelling suggests that once these are factored in, the leverage rate of public R&D

support could be noticeably higher than suggested by previous studies, although our long-run monetary impact estimates are within the range of those previously identified.

OTHER FINDINGS

How does the leverage rate differ across different types of public support?

We estimated separate leverage rates for public support to universities and research councils, and direct support to businesses using a similar model to the overall leverage results.

The ranges of uncertainty for estimates of the impact of £1 of public support to universities and research councils and to businesses overlap, and so we were unable to draw firm conclusions concerning which type of support may lead to the largest impact on private R&D.

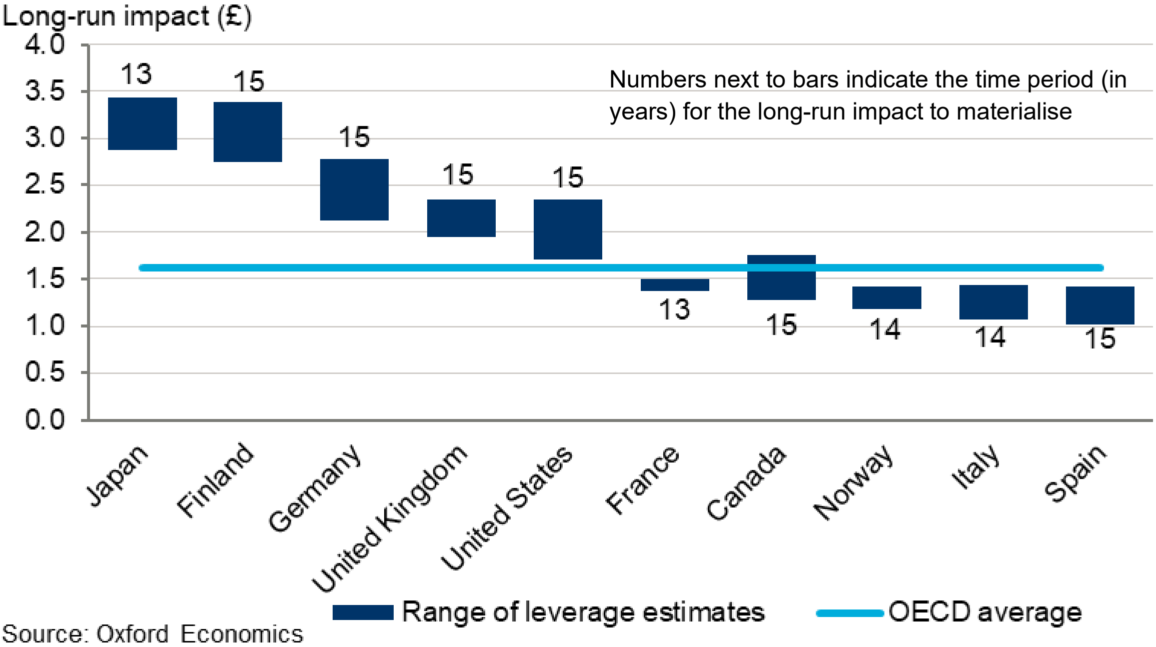
We also investigated the impact of indirect support through R&D tax credits, using a range of models based on data from HMRC, ONS and the OECD. We were unable to obtain robust results in this part of the analysis, most likely because fewer data points are available across fewer countries. As such we were unable to identify the impact of tax credits on privately funded R&D after controlling for the influence of other relevant factors.

How does the leverage rate differ across countries?

Alongside our analysis of the UK, we estimated leverage rates for nine other OECD countries. We found a wide variation in the impacts of public R&D on private R&D across countries. The greatest impact was found for Japan, where £1 of public support is estimated to stimulate £3.16 of public investment in the long term. In contrast, the same £1 of public support in Spain would encourage just £1.21 of private investment.

There is little previous research to explain what may drive differences in leverage rates across countries. We have undertaken indicative analysis of the associations between national leverage rates and a range of institutional factors. We find that countries with strong protection for intellectual property and property rights, access to the latest technologies, and ready access to finance tend to have higher leverage rates. These findings are, nevertheless, tentative since they do not establish that such conditions *cause* higher leverage rates.

Figure 3: Preferred estimates of the long-run impact of £1 of public R&D support across countries



Source: Oxford Economics

How does the UK leverage rate differ across sectors?

Our study investigated whether leverage rates vary across industrial sectors. Data availability is much more limited when disaggregating R&D expenditure at this level of granularity. Despite testing a range of models, approaches and datasets, we were unable to obtain robust evidence of differences.

Limitations

The results presented in this study are based on data stretching back over decades (as far back as the 1960s in some cases). Our results reflect the experience and conditions over this period, during which there have been significant changes in the nature of public support to R&D, as well as the way R&D is conducted. The channels through which public support influences private R&D are likely to have changed over this period, and the dynamism of the R&D sector means that many of the underlying relationships will continue to change in the future. Modelling of the relationships is also subject to data and econometric constraints. As such, there is no guarantee that the past experience reflected in our results will be repeated in future years. We would therefore advise caution if using our findings to inform future policy choices.

1. Introduction

1.1. What is leverage and why is it important?

An important argument in favour of public support to R&D is that it has the potential to stimulate (or “crowd in”) private R&D activity that would not otherwise have occurred. This may be the case, for example, because public investment reduces the costs and risks to firms of undertaking R&D; because the public sector is willing to fund projects that are too risky or complex for private investors to finance on their own; or because public research makes new discoveries that stimulate private research in related fields.[1]

It may also be the case, however, that public R&D “crowds out” private R&D if greater public investment lowers the return on investment for private businesses. For example, public R&D, by increasing the demand for R&D researchers, could push up the cost and therefore lower the returns to businesses engaging in R&D activities. Public money may also lead businesses to substitute public funding for their own, such that the government ends up funding R&D that businesses would have conducted anyway. In such a scenario there would be no “additionality” from the public funding.

The increase (or decrease) in private R&D investment which results from each additional unit of public R&D investment is known as the “leverage rate” and is a key measure used by policy makers to understand the ripple effects of public investment. A wide body of literature has explored leverage by analysing the relationship between public and private R&D investment.

1.2 Context and objectives of this study

The government has committed to a target for the UK to invest 2.4 percent of GDP in R&D by 2027.[2] This target includes R&D investment by the business and non-profit sectors. To inform consideration of how the target can be met, it is essential for the government to have up-to-date evidence of the impact of public R&D funding on private R&D, and to understand where government R&D funding might have the greatest “leveraging” effect on other sectors.

Other recent and emerging developments also point to a need for greater understanding of the benefits of public R&D support. In particular, a new body, UK Research and Innovation (UKRI), came into existence in 2018, bringing together the seven research councils, Innovate UK and Research England and integrating their

[1] There is a full discussion of the case for government intervention to support R&D in: Department for Business Innovation & Skills, *The case for public support of innovation at the sector, technology and challenge area levels* (London, 2014)
[2] UK government https://www.gov.uk/government/news/record-boost-to-rd-and-new-transport-fund-to-help-build-economy-fit-for-the-future [Accessed 1 October 2018]

research funding functions. As UKRI develops in this role it will have a strong need for evidence-based insights into the wider effects of public R&D funding. At the same time, the UK is a net recipient of EU funding for R&D, but the extent to which UK researchers will be able to access EU funding will depend on the outcome of EU withdrawal negotiations. As such, the R&D funding landscape is expected to change as a result of exiting the EU.

In light of these factors, and particularly the target to raise the share of national income dedicated to R&D, it is important to further our understanding of the relationship between public and private investment in R&D.

In this study, commissioned by BEIS, we investigate the impact of public R&D investment on private R&D investment in the UK and other OECD countries across a number of dimensions. In particular, we considered the following questions:

1. What is the best estimate of the leverage rate in the UK? How does this differ over the short term and the long term? This is explored in Chapter 4 (we also present details of alternative model specifications in Appendix 2: Time series analysis and Appendix 8: Econometric modelling outputs and test results).

2. How does the leverage rate differ across the following types of investment?

    - Publicly funded R&D in universities and research institutions
    - Direct support for R&D in businesses (grants and loans)
    - Indirect support for R&D in businesses (tax credits)

    Our findings for these questions are presented in Chapter 5, with information on the models in Appendix 2: Time series analysis and Appendix 3: Leverage rates for indirect support (tax credits).

3. How does the leverage rate differ across UK sectors? (See Chapter 6 and Appendix 4: Do leverage rates differ across sectors in the UK?)

4. How does the leverage rate differ across countries? (Chapter 7)

5. What are the key drivers of leverage rates? (Chapter 8)

Before presenting our findings we briefly explore previous literature on leverage rates (Chapter 2). In Chapter 3 we introduce our methodology and provide an overview of the data available to research this topic. There are further technical details of our approach in the appendices.

Project Terms of Reference

The questions above are abridged versions of those identified in the original invitation to tender. The full list of questions is as follows:

1. What is the best estimate and suitable uncertainty range for average leverage of private sector R&D investment resulting from public R&D investment in the UK?

2. Over what time profile would this best estimate of UK leverage materialise?

3. What is the best estimate and suitable uncertainty range for; leverage of private sector R&D investment resulting from the following types of public R&D investment in the UK:

   - Publicly funded R&D in universities and research institutions

   - Direct support for R&D in businesses (grants and loans)

   - Indirect support for R&D in businesses (tax credits)

4. Can a robust leverage rate be calculated across different sectors? What are the best estimate and suitable uncertainty range for different sectors?

5. Can a robust leverage comparison be made across countries? What are the best estimate and suitable uncertainty range for comparator countries such as France, Germany, the US and Japan? Why do some countries have greater leverage rates than others and what drives greater leverage rates?

6. What are the key drivers of leverage rates?

7. If in any of these areas, robust estimates cannot be made, why not? What further data would be required in order to make robust estimates?

Some further potential areas of enquiry were identified during discussions with the project steering group. These included the estimation of leverage rates for regions of the UK, and for basic versus applied research. It was not possible to identify suitable data sources and/or develop satisfactory models to address these questions, and so they are not discussed within this report.

2. Recent evidence on R&D leverage

The relationship between private and public R&D spending has been the subject of many empirical academic studies. Previous studies have adopted one of two main approaches:

1. **Macro** studies which assess how private R&D across the economy as a whole is influenced by public R&D support. For this study we also consider studies which focus on particular sectors within this definition.

2. **Micro**, or firm-level, studies which investigate whether individual firms which receive public support undertake more privately-funded R&D than would otherwise have been the case.

In taking these different approaches, the two types of study consider different types of leverage. Micro studies usually only assess **direct leverage**, that is whether firms which have received support undertake more privately-funded R&D than they otherwise might have. In contrast, macroeconomic studies can also detect **indirect** leverage—whether support leads to greater R&D investment across the economy or a sector as a whole, not just amongst those firms which directly benefit from support.

In this study, we take a macroeconomic approach to capture the direct and indirect effects of leverage and so we are primarily interested in studies which have adopted a macro approach to assessing R&D leverage. These are discussed in Section 2.1. Nonetheless, comparatively few researchers have previously used macro analysis to analyse leverage, and so in Section 2.2 we take a brief look at recent microeconomic studies. While the methodologies of micro studies are less directly relevant to our work, some of the insights they provide are of interest, particularly in terms of their findings and the control variables adopted.

2.1. Macro studies

2.1.1. Recent studies and findings

A handful of recent empirical papers have explored the issue of leverage from a macro perspective. As summarised by Economic Insight (2015), some of these have looked at individual national economies and studied changes in private sector investment over time (time series analysis), while others have used datasets that include observations for several countries over time (panel data) to explore whether countries which provide more public support to R&D tend to have more private R&D investment, after controlling for other relevant factors.

One of the most recent examples of a macro study is Sussex et al. (2016), which estimates the effect of government and charity biomedical and health research funding on private pharmaceutical sector R&D expenditure in the UK. The study uses time series information comprising UK data for government, charitable and private sector R&D spend between 1982 and 2012 for nine disease areas. Private

R&D spend was sourced from the Association of the British Pharmaceutical Industry. The study finds that a one percent increase in UK public sector expenditure is associated with a 0.81 percent increase in private sector R&D expenditure. It is estimated that every additional £1 of public research expenditure is associated with an additional £0.83-£1.07 of private sector R&D spend in the UK. Some 44 percent of this additional private sector expenditure is found to occur within one year, with the remainder accumulating over decades.

A further important contribution to the macro literature exploring leverage rates was produced by Economic Insight (2015). This finds that an extra £1 of public funding gives rise to an increase in private funding of between £1.13 and £1.60 (giving a mid-point of £1.36). This is an estimate of the long-run increase in private expenditure arising from a £1 increase in public expenditure, or the total increase that would arise over 10 years. The study finds that the majority of private expenditure occurs within the first five years from the public investment (£1.28 out of £1.36), with the remainder accruing over the following five years.

Montmartin (2013) uses an OECD panel dataset covering 25 OECD countries over the period 1990 to 2007, and finds that only tax incentives significantly influence private R&D intensity. Montmartin and Herrera (2015) extend the dataset to cover the 1990 to 2009 period and find a significant non-linear relationship between direct and indirect public support for R&D and private R&D. They also find a substitution effect between various forms of R&D subsidies within a country. That is, increasing the value of one type of subsidy reduces the leverage effect achieved from other types of subsidy.

Guellec and van Pottelsberghe de la Potterie (2001) attempt to quantify the aggregate net effect of government funding on business R&D in 16 OECD countries between 1980 and 1998. They find that direct government funding of R&D performed by firms has a positive effect on business-financed R&D (unless the funding is targeted towards defence activities). Tax incentives have an immediate and positive effect on business-financed R&D. The stimulating effect of government funding varies with respect to its generosity: it increases up to a certain threshold (about 10 percent of business R&D) and then decreases beyond.

Guellec and van Pottelsberghe de la Potterie also find that both direct funding and tax incentives are more effective when they are stable over time: firms do not invest in additional R&D if they are uncertain of the durability of the government support. Finally, they find that that direct government funding and R&D tax incentives are substitutes: increased intensity of one reduces the effect of the other on business R&D.

Becker and Pain (2003) estimate an econometric model of R&D expenditure using a panel of UK manufacturing industries. They find that industry characteristics such as sales and profitability, product market competition, as well as other macroeconomic and labour market variables such as real long-term interest rates and the real effective exchange rate, proportion of skilled labour, have an effect on R&D spending. They find that a rise in the share of R&D funded by the government is found to have a significant positive impact on the aggregate level of R&D expenditure.

Diamond (1998) finds that government funding has not crowded out private funding of science. However, the author warns that aggregate time series analysis must be treated with caution as it may suffer from issues such as unit roots and omitted variable bias.

We were only able to identify two relatively recent empirical studies investigating leverage rates for indirect R&D support which adopted a macro approach. Falk (2006) finds that tax incentives for R&D have a significant and positive impact on business R&D spending. The paper also finds that expenditure for R&D performed by universities is significantly positively related to business enterprise sector R&D expenditure, indicating that public and private R&D funding are complements. The author reaches this conclusion using a panel of OECD countries for the period 1975-2002, where the dependent variable is total expenditure on R&D in the business sector as a percentage of GDP. Thomson (2017) measures the effect of tax credits on private R&D investment using data covering a panel of 29 industries in 26 OECD counties over the years 1987 to 2006.This study exploits differences in the average capital-labour ratio of R&D investment across industries and variation in the tax treatment of different expenditure types across countries and over time. The estimated short-run elasticity is 0.50 which is more than twice the previous estimates derived from cross-country analysis.

Bloom et al. (2007) estimate an econometric model of R&D investment using a panel dataset of nine OECD countries between 1979 and 1997. They find that tax incentives are effective in increasing R&D spending. They find that a 10 percent fall in the cost of R&D stimulates just over a one percent rise in the level of R&D in the short run, but an impact of around ten times than in the long run.

The macro studies described above focus on “input additionality”, i.e. the effect of public funding on the *quantity* of overall, or private, R&D funding. Several other macro studies have tackled the question of “output additionality”, to investigate the impact of public support on the *quality* of R&D undertaken. This work has found that subsidies have a positive impact on innovation performance, as measured, for instance, by patenting (Azoulay (2015), Czarnitzki and Lopes-Bento (2011) or sales of innovative products, e.g. Czarnitzki, Hanel and Rosa (2011) for Canada and Hottenrott and Lopes-Bento (2014) for Belgium.

Other studies have looked into the impact of public R&D funding on R&D employment (Thomson, 2013) and country-level productivity (Coccia, 2010). Thomson (2013) found that government R&D subsidies— both tax credits and direct grants—have a positive effect on R&D employment. Coccia (2010) found that private R&D expenditure has to be more than public R&D expenditure to have a positive effect on productivity growth.

The table below summarises the findings of previous studies which have estimated economy-wide leverage rates of the type we explore in this study. The leverage rates indicate the percentage change private R&D investment which results from a one percent increase in the value of public R&D support.

Figure 4: Summary of coefficients of additionality

Study	Estimated effect	Data	Leverage rate
Sussex et al (2016)	Effect of public R&D in the pharmaceutical sector on private sector R&D in the UK	UK panel by 10 disease areas 1982–2012	0.68 – 0.81 (long run)
Montmartin (2015)	Effect of public R&D intensity to private R&D intensity	Macro panel data on 25 countries in the OECD in the 1990-2009 period	0.43 (long run)
Economic Insight (2015)	Effect of public R&D on private R&D in the UK and across countries	Macro ONS data for the UK and Macro panel data on 15 countries	UK: 0.29-0.67 Cross country: 0.49-0.58[3]
Montmartin (2013)	Effect of direct and indirect R&D support on private R&D spending across countries	Macro panel data on 25 countries in the OECD in the 1990-2007 period	-0.005 to 0.004 (insignificant)
Bloom et al (2007)	Effect of the cost of R&D (which is influenced by tax credits) on industry-funded R&D across countries	Macro panel data on 9 OECD countries 1979– 1997	Main specification:[4] -0.14 (short run) -0.96 (long run)
Guellec and van Pottelsberghe de la Potterie (2003)	Effect of publicly performed research on business funded research across countries.	Macro panel data on 16 OECD countries 1980– 1998	0.07 for govt funding (short run) 0.08 for govt funding (long run) -0.06 for govt research (short run) -0.07 for govt research (long run)
Becker and Pain (2003)	Effect of the share of public R&D on R&D expenditure in UK manufacturing industries	UK panel by 11 broad manufacturing product groups 1993–2000	0.62 – 1.70 (long run)
Diamond (1998)	Effect of federal funding of basic research on private funding of basic research in the US.	US macro time series 1953–1993	1.04 (long run)

[3] The cross-country results cover 14 countries: 11 countries that joined the Euro in 1999, the US, China (excluding Hong Kong), Japan and the US.
[4] These elasticities measure the impact of a change in the cost of R&D (which is reduced through an increase in tax credits) on private R&D. These elasticities are therefore not comparable with those from other studies in the table which measure the elasticity of private R&D with respect to public R&D directly. However, it is interesting to note that the long-run impact is seven times the short-run impact.

Lichtenberg (1987)	Effect of federally funded industrial research on privately funded industrial research in the US.	US macro time series 1956–1983	0.045 (insignificant)

Source: Various studies

2.1.2. Econometric approaches

For regressions using UK data, Economic Insight (2015) use simple linear regression (OLS) techniques, but also Vector Error Correction Models (VECM); linear regressions with Auto-Distributive Lags (ADL); and instrumental variable regressions with lagged dependent variables to account for potential two-way causality. Sussex et al. (2016) also use a Vector Error Correction Model (VECM) using time series data for health R&D expenditure in the UK. The VECM model describes the relationship between variables as a combination of a long-term equilibrium and short-term movements.

For regressions based on the Europe-level panel dataset, Economic Insight (2015) use static panel methods (with fixed effects and random effects). To identify whether the UK leverage rate varies from that of other countries, they use an interaction term, which identifies the coefficient for the UK separately from that of other European countries in the study. They also perform the Wooldridge (2002) test for autocorrelation but strongly reject the null hypothesis of no first-order autocorrelation. This suggests that past values of R&D have an effect on current values of R&D expenditure, implying that a dynamic panel method would have been preferable to the static panel approach that the study used.

Further, they perform the Phillips-Perron test for unit roots for each country in the panel separately, and find that the time series of R&D investment is stationary only for five out of 13 countries. However, this test ignores the panel nature of the dataset, and therefore needs to be adjusted using the Bonferroni correction.[5] Without the correction the Phillips-Perron test results cannot be relied upon.

Azoulay (2015) also uses static panel data methods (fixed effects only) with instrumental variables to account for two-way causality. Their study constructs an instrument based on alternate sources of R&D funding to overcome this. An alternate approach would be to use past values of R&D funding as instruments.

Coccia (2010) ignores the panel nature of the dataset and uses a pooled linear regression. However, in the presence of serial correlation, ignoring the effect of past values of R&D on current values leads to estimates which are potentially biased. Falk (2006) recognises this and instead uses dynamic panel methods. Montmartin (2013), Montmartin and Herrera (2015) and Thomson (2013) also use dynamic panel methods.

[5] If multiple hypotheses are tested, the chance of a rare event increases, and therefore, the likelihood of incorrectly rejecting a null hypothesis (i.e. making a Type I error) increases. The Bonferroni correction compensates for that increase by testing each individual hypothesis at a significance level of α/m, where α is the desired overall alpha level and m is the number of hypotheses.

2.1.3. Limitations of macro studies

Limited data points and control variables

Perhaps the greatest disadvantage of using macro analysis is that there is typically only a **limited number of data points** available and this could reduce the robustness of the findings.

As noted in the Economic Insight (2015) paper, a related challenge faced by macro analysis is **controlling for the appropriate drivers of private sector R&D** investment. The limited number of data points restricts the number of explanatory variables that can be included in the model. A large number of explanatory variables reduces the "degrees of freedom", and the coefficients will be subject to a high degree of uncertainty (i.e. they will have large variances). In particular, one effect of public R&D expenditure may be an increase in researchers' wages, and it is important not to attribute increased costs to increases in the amount of private R&D funding. On the other hand, omitting relevant variables leads to "omitted variable bias" and the additionality estimates from the model are likely to be biased.

Instead, where panel data (i.e. data on different countries over time) were available, Falk (2006), Thomson (2013), Azoulay (2015), Economic Insight (2015) and Sussex et al. (2016), used fixed or random effects estimators which control for unobservable panel specific factors (i.e. country-specific factors), thereby limiting the need for many control variables and allowing for greater sample size and therefore more degrees of freedom.

Collinearity between different types of public funding

The elasticity of private funding with respect to public funding is likely to vary according to the type of public funding allocated. An empirical challenge associated with conducting this analysis is that the different types of public funding may be highly correlated with one another over time and so separating the effect of one type of funding from another is a challenge.[6] Economic Insight (2015) tackle this issue by combining different types of public funding into two distinct categories— higher education and research council funding and other government funding.

Two-way causality

Two-way causality between private and public investment will make it difficult to isolate a causal link from public R&D investment to private R&D investment. Azoulay (2015), Thomson (2013) and Falk (2006) use instrumental variables to break the link from private R&D investment to public R&D investment, which allows the model to estimate the link between public and private R&D investment without bias. For example, Thomson (2013) uses past values, going back two to five years, of public R&D investment as instruments.

[6] For example, see Economic Insight (2015), Annex B, Table A8.

Selection bias

For cross-country studies, the choice of countries to include in the analysis can affect the results and, in some cases, there may be a **selection bias** (for example because countries that do more R&D may tend to have a better data coverage).

The countries or product groups that receive most support may also be those with the highest leverage rates. This may be the case where the scope for leveraging private funding has been taken into account during the funding allocation process (i.e. because countries or product groups with higher leverage rates are more likely to be successful in their funding applications). While this makes sense from a resource allocation perspective, it is important to understand such factors since they may mean that findings do not hold true across all countries and sectors. While this is recognised in firm-level studies (e.g. Cerulli and Poti, 2012), this may influence cross-country comparisons in macro studies. The use of panel datasets, with fixed or random effects, as used in Falk (2006) and Thomson (2013) would mitigate this risk to a certain extent.

Unit root issues

In time series data, when using ordinary least squares techniques, there is a risk of spurious regressions due to an issue known as “unit roots”, particularly where R-squared values are extremely high. For example, Thomson (2013) identifies that the trend in the levels of R&D investment suffers from the presence of unit roots, and therefore uses dynamic panel methods to mitigate this risk.

Challenges of drawing detailed conclusions in relation to policy design

Macro studies generally estimate an average effect for the countries and time periods included in the analysis. They do not often estimate differences in leverage rates over time, amongst different types of firm, or in response to differences in policy design. This means that the precise mechanisms through which leverage occurs may be less apparent than in some micro studies, and it may be more difficult to draw detailed conclusions in relation to policy design.

2.2. Micro studies

While we are primarily interested in macroeconomic approaches to investigate leverage rates, here we provide a brief overview of the methodologies, findings and limitations of micro studies. We are especially interested in those which assess the impact of indirect R&D support, as we identified only one macro study which tackles this subject (Falk, 2006).

2.2.1. Approaches

Firm-level studies seek to quantify the leverage rate by estimating the difference between the value of R&D undertaken by supported firms and what would have been expected in a counterfactual scenario where no support was provided. Since the R&D spending that would have occurred in the absence of support cannot be observed, the counterfactual is typically estimated based on a control group of non-supported firms. This control group should be as similar as possible to the supported (or "treated") firms. Differences in outcomes between the supported and non-supported firms can then be attributed to the "treatment" received after controlling for differences between supported and non-supported firms.

A commonly adopted methodology is **"Propensity Score Matching" (PSM)**. This reduces several observable characteristics of a firm to a single index, which is used for matching firms in the treatment and control groups. Once the index is calculated for each treated firm, researchers search for firms with a similar score in the control group of non-supported firms. One way of doing this is on a "nearest neighbour" basis. However, in some cases nearest neighbours may still be quite different to a subsidised firm so researchers may use other approaches, such as "Caliper Matching". This specifies that the propensity score of the nearest neighbour must be within a certain pre-specified distance and treated firms for which no suitable neighbour may be identified are dropped from the sample.

A limitation of the PSM approach is that it only enables firms to be matched based on observable characteristics. However, if unobserved characteristics are important, a method called **Difference-in-Differences (DiD)** can be used to account for unobservable but fixed characteristics. The key assumption for DiD is that the outcome (R&D expenditure) in the treatment and control groups would follow the same time trend in the absence of support. This is known as the "common trend assumption" and it is difficult to verify. Researchers often use pre-treatment data to show that the trends are the same before the treatment takes place.

Firms receiving public R&D support are often ones that are also more likely to spend further on R&D. The above techniques do not account for this bias in the selection of firms for public R&D support. Some studies therefore adopt the **"Heckman selection model"**. This accounts for the possibility that unobservable variables affect both the total amount of R&D undertaken and the likelihood of a firm being subsidised.

2.2.2. Micro studies investigating direct R&D support

Regardless of the methodology and data sources used, the main finding of the micro studies we reviewed is that private R&D and R&D support (both tax deductions and direct subsidies) are positively correlated and that there is no evidence of crowding out. The extent to which public support leverages private R&D spending does, however, vary between studies.

For example, applying PSM to firm-level data, González and Pazó (2008) reject crowding out for Spanish firms and find that direct R&D subsidies on average lead to higher private R&D investments. They also find that some firms—mainly those which are small and operating in low technology sectors—might not have engaged in R&D activities at all in the absence of subsidies: 17 percent of subsidised firms would not have undertaken R&D had they not received public support. Several other firm-level studies have adopted PSM methods to firm-level data and arrived at similar conclusions (see for example, Czarnitzki and Licht (2006), Arvanitis et al. (2010), Aschhoff (2009), Hottenrott and Lopes-Bento (2014), Yang et al. (2012), and Czarnitzki and Delanote (2015)).

The rejection of crowding out is also supported by studies using other estimation techniques. Aerts and Schmidt (2008) apply DiD estimation to Flemish and German firm-level data and find that firms receiving subsidies are significantly more active in R&D than non-funded firms. On average, the R&D intensity of German (Flemish) funded companies was 76-100 percent (64-91 percent) higher than the R&D intensity of non-funded companies.

The most comprehensive and recent consideration of this issue is provided by Dimos and Pugh, who undertake a meta-regression analysis (MRA). Meta-regressions analyse the results from different studies and control for characteristics that vary across studies such as sample size, geographic coverage, modelling techniques, etc. After controlling for publication bias[7] and a wide range of characteristics, Dimos and Pugh reject the hypothesis that there is crowding out of private investment. While they find evidence of a small positive effect from public support, they do not regard the additionality identified to be substantial. The MRA finds elasticities of less than 0.01, meaning that a doubling of the subsidy leads to an increase in private R&D of less than 1 percent.

2.2.3. Micro studies investigating indirect R&D support (tax credits)

Other micro studies have focused on indirect public support to R&D, mainly in the form of tax credits. Tax credits tend to be considered the most market-oriented policy in response to underinvestment in R&D, as they leave the decision of which projects to support to the private sector (Beck, Junge and Kaiser, 2017).

As Becker (2015) suggests, there are two main ways to measure the impact of R&D tax credits. The first is a dummy variable which takes the value of one if tax credits are available and zero otherwise. While this approach is simple to apply, it is relatively imprecise, as different firms may receive different levels of support and if this varies over time it is not separately identifiable from time dummies. The second measure, much more frequently used in recent studies, is a price variable such as the user cost of R&D. In such models, the estimated R&D response is understood as an elasticity measure.

Becker (2015) summarises several studies in this area and concludes that fiscal policy measures that reduce the price for private R&D activities, such as tax credits, increase private R&D investments. Castellacci and Lie (2015), for example, show that R&D tax credits are particularly effective for SMEs and firms in the service sector, concluding that tax credits constitute an effective means for firms with low R&D intensities rather than for highly R&D intensive firms in high-tech sectors.

[7] Publication bias occurs in published academic research when the outcome of an experiment or research study influences the decision whether to publish or otherwise distribute it. Publication bias matters because literature reviews regarding support for a hypothesis can be biased if the original literature only includes studies which have found a positive result.

2.2.4. Limitations of micro studies

Despite its prevalence, micro analysis of the impact of public R&D support presents several limitations. Most notably:

3. Results are specific to the type of support and geography studied. It is unclear whether they can be generalised to other types of support in other locations.
4. The approach only captures the impact of increased R&D investment amongst those firms which have received support, that is, they only assess direct support. There is good reason to believe that R&D might also increase in firms which did not receive support (for example due to spillovers between firms who are clients, suppliers or competitors, or as unrelated firms identify applications of new knowledge in other contexts). As such, approaches which look at whether supported firms invest more in R&D than unsupported firms may tend to underestimate overall leverage rates. Economic Insight (2015), for example, found a lower leverage rate from their firm level analysis than from their macro analysis.
5. Micro studies are very data hungry and require access to firm-level data, which is often only available in restricted circumstances. For results to be robust, a large number of treated firms is needed.
6. If data are available over a short period of time, it is not possible to estimate long-term effects.
7. There is also a reliance on self-reported data, which may be subject to bias.

2.3. Conclusion of our literature review

In light of our literature review we retain our view that a macro approach offers the best way of addressing the research questions set for this study. This is because:

1. Macro analysis enables a more complete and generalisable estimate of leverage rates at the economy-wide level, including through spillovers to firms and sectors which do not themselves receive support. **That is, macro approaches capture the impact of both direct and indirect leverage.** In contrast, micro studies are able to account for direct leverage only.
2. The body of existing literature is much smaller for macro level studies. We believe there is scope to add to this strand of literature through the application of sophisticated dynamic panel econometric techniques.
3. The data required for macro approaches are more readily available within the time available for our study.

Our literature review did, nonetheless, identify that previous macro studies have encountered challenges such as a lack of data points and control variables; the risk of omitting relevant variables; the high correlation between different types of public funding; two-way causality; selection bias; the issue of unit roots; and challenges in drawing detailed conclusions with reference to policy design. The use of panel data can help to mitigate a number of these challenges, by controlling for unobservable country/industry-specific factors and increasing the sample size. The dynamic panel data approach adopted by Falk (2006) appears particularly promising for our study, given the use of historic values of private R&D investment and instruments in the model specification to overcome the challenges identified.

3. Analytical framework

3.1. Defining public and private R&D

The value of R&D investment can be considered from the perspective of the funding organisation and the organisation performing the research. The diagram below illustrates the source of funding and sector of performance for all R&D conducted within the UK in 2016 (Figure 5).

To investigate the impact of public funding on private funding it is necessary to define "public" and "private" R&D expenditures. Consistent with Economic Insight (2015), we have adopted the following definitions:

- **Public** R&D includes R&D funded by the government, research councils and higher education sectors;
- **Private** R&D is that funded by the business[8], private non-profit and foreign sectors.

Based on these definitions, public R&D is represented by the top four rows of data in the table below and private R&D is represented by the following three rows. This matrix will be used in subsequent chapters as a visual guide to demonstrate the types of R&D considered in each part of the modelling.

Figure 5: Source of funding and sector of performance of UK GERD (£m, 2016)

Performed by / Funded by	Government	Research councils	Higher education	Business	Private non-profit	All
Government	1,136	137	483	1,730	98	**3,584**
Research councils	47	554	2,107	5	197	**2,909**
Higher education funding councils (HEFC)	0	0	2,207			**2,207**
Higher education	2	17	299		131	**449**
Business	15	25	350	16,742	18	**17,151**
Private non-profit	13	42	1,242	188	170	**1,655**
Overseas	122	60	1,346	3,560	85	**5,174**
All	**1,335**	**837**	**8,035**	**22,224**	**699**	**33,130**

Source: ONS GERD

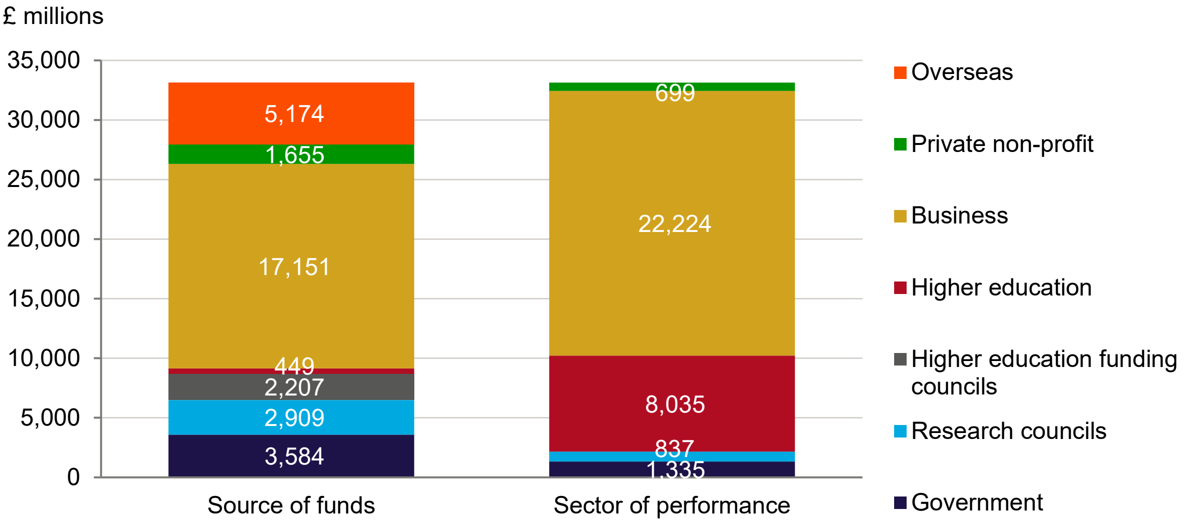
Of the £33 billion of R&D conducted in 2016, over half was funded by UK businesses and a further £5 billion was funded by foreign businesses. The public sector funded a

[8] Note that the business sector includes private and public (government controlled) enterprises.

total of £9 billion of R&D split across government, research councils, higher education funding councils and higher education.

Viewed according to the sector of performance, it is UK businesses that conduct the largest proportion of R&D, totalling more than £22 billion or 67 percent of the total. Higher education institutions conduct 24 percent of R&D, with the remainder accounted for by government, research councils and private non-profit organisations.

Figure 6: Source and sector of performance for UK R&D (2016)



Source: ONS GERD

The definitions of private and public R&D outlined above are motivated by the specific research questions set for this study and vary from those often used elsewhere in the literature. Previous studies often focus on the relationship between R&D performance (BERD or business-funded BERD) and public support (government-financed BERD and/or tax support proxied by the user cost of R&D, the "B-Index"[9]). By contrast, this paper looks at the impact on private-funded GERD (funded by business, private non-profit and foreign sources) of public-funded GERD (funded by government, research councils and higher education institutions). This definition allows us to estimate the overall extent to which broad categories of public support create leverage, either directly or indirectly. We wish to estimate the full range of spillovers which may lead to leverage effects, but we are not seeking to draw conclusions in relation to the specific mechanisms through which leverage effects manifest themselves.

[9] The B-index is a measure of the level of pre-tax profit a "representative" company needs to generate to break even on a marginal, unitary outlay on R&D, taking into account provisions in the tax system that allow for special treatment of R&D expenditures.

3.2. Types of data

Broadly speaking, datasets can be categorised as follows:

- A **time series** dataset is a one-dimensional dataset which records repeated observations for one sector or country over time.
- A **cross sectional** dataset is also one-dimensional, but records observations for many countries or sectors at a single point in time.
- A **panel** dataset is two-dimensional, comprising multiple observations for the same sectors and/or countries over time.

The impact of public R&D on the level of private R&D is unlikely to be immediate as businesses will take time to react to public investment and adjust their R&D expenditure accordingly. Such adjustments are likely to involve costs, such as to hire staff or purchase equipment. These adjustment costs imply that the relationship between public and private R&D may manifest over time, and therefore, time series data or panel data are perhaps most appropriate for our analysis where data permit.

Further, econometric techniques that use panel data allow us to capture unobservable factors which are specific to a sector or a country, such as cultural factors, differences in business practices, and policy or other considerations which influence the business environment. Cross-sectional data do not capture effects over time or allow us to control for variables that cannot be measured or observed, and are therefore unsuitable for our analysis.

Below we outline potential approaches based on time series or panel datasets respectively.

3.3. Time series analysis

Where we have only time series data, we have attempted to use time series econometric methods to capture, observe and measure how changes in public support and other factors influence private investment over time. As discussed above, private businesses are unlikely to respond instantaneously to public R&D investment but will take time to determine their level of investment in R&D. The structure of time series data enables this dynamic relationship to be investigated.

When using UK time series data, the coefficients of interest are specific to the UK. By comparison, the coefficients from panel data analysis may, depending on the model specification, reflect the average across countries in the sample and further analysis is needed to obtain UK-specific findings.

However, time series approaches also have limitations. For example, when using ordinary least squares techniques, there is a risk of "spurious regressions". In other words, the regression may provide misleading statistical evidence of a relationship between variables that are trending in the same direction over time. This is due to an issue known as “unit roots” which can lead to invalid estimates from regression analysis. Time series data therefore need to be tested for “stationarity” to check that they have no tendency to move towards a long-run path.

Failing to account for the presence of unit roots in our modelling could lead to the estimates indicating causality between investment in public R&D and investment in private R&D when they are merely correlated. It will be important for our analysis to not only identify that there is a correlation between public R&D support and private R&D investment, but that the former *causes* the latter.

As part of this study we investigated using time series techniques to the ONS Business Enterprise Research and Development (BERD) and Gross Domestic Expenditure on Research and Development (GERD) datasets, which are discussed in more detail in the boxes below. An important limitation of BERD data is that the source of funding is only available for a 24-year period from 1992 to 2016, which means that only a relatively short sample is available for our analysis.

A further consideration when using the BERD and GERD data is that they record R&D funded through tax credits as privately-funded R&D, even though it has been funded by an offsetting tax reduction (a form of indirect support to R&D). We incorporated an adjustment into the data to exclude the estimated value of tax-credit-funded R&D. Our approach to doing this is also discussed in the box below.

ONS BERD AND GERD DATASETS

The ONS publishes detailed R&D expenditure data within the Gross Domestic Expenditure on Research and Development (GERD) and Business Enterprise Research and Development (BERD) datasets. These identify the value of R&D investment split by source of funding and sector of performance across industries, product groups and regions. The main features of these datasets are summarised below.

Figure 7: Main characteristics of the ONS BERD and GERD datasets

	BERD	**GERD**
Funding sectors	Government, Overseas, Own Funds, Other	Business, Government, Research Councils, Higher Education, Non-Profit, Overseas, Higher Education Funding Councils
Performing sectors	Business	Business, Government, Overseas, Research Councils, Higher Education, Non-Profit

Industries / product groups	34 product groups, available by source of funding. 60 SIC codes, not available by source of funding.	Civil, Defence
Regions	Government Office Regions (12 regions), not available by source of funding.	Government Office Regions (12 regions), not available by source of funding.
Maximum time series length	1981-2016	1985-2016

It is important to note that while the data can be broken down into a number of dimensions, data are not available by all possible combinations of these dimensions, and where data are available, time series length is often shorter than is available for the headline metrics. Important limitations of the datasets in relation to our analysis are as follows:

- The BERD dataset includes 34 unique product groups for R&D performed by business with varying levels of data coverage between 1981 and 2016. We are able to identify the source of funding for product groups between 2001 and 2016. This split does not include "higher education" as a funding sector, but coverage is reasonable across groups for each time period.
- Estimates of R&D expenditure on an industry basis, according to the Standard Industrial Classification (SIC), were first introduced in the 2011 BERD statistical bulletin. These do not, however, identify the various funding sources, limiting their usefulness for our analysis.
- At the regional level there is good coverage of data from 1993 for all Government Office Regions at the aggregate expenditure level, but once again the regional data are not broken down by funding source.
- Aggregate GERD data at the national level are complete from 1985 (although the data series also reports a value for 1981). The data are further split by Government Office Region from 2001 with complete coverage. However, as with the BERD data, there is no regional breakdown by source of funding.
- In contrast to the BERD data, GERD is only available for two industry groups: Civil and Defence. The time series for these sectors begins in 1989.

THE IMPACT OF TAX CREDITS ON BERD AND GERD

A feature of the BERD and GERD datasets is that they record R&D funded through tax credits as funding by the private sector. This is because the BERD survey does not ask respondents to separately identify R&D funded by tax credits. This creates complications for our analysis, because we are seeking to understand the impact of public support on business R&D, where the latter excludes R&D funded through tax credits.

One possibility is to adjust the GERD data to remove the component of business funded R&D which is actually funded through tax credits. However, this is not straightforward because the HMRC data on tax credits includes companies' funding of R&D undertaken overseas. To make the adjustment accurate we would need information on R&D funded through tax credits and undertaken in the UK. HMRC does not currently provide such a dataset.

To overcome this limitation, and following discussion with BEIS analysts, we adopted a proxy based on two alternative estimates of the proportion of tax credit support which funds R&D performed overseas:

- Proxy 1 was estimated as the share of total GERD performed by UK businesses that is performed abroad. The numerator for this estimate will not include UK businesses which fund R&D abroad but not in the UK, and is therefore likely to **underestimate** the total value of R&D funded by UK businesses and performed abroad.
- Proxy 2 was based on bespoke ONS analysis for BEIS to estimate the value of R&D purchased from overseas. This enables the following calculation:

$$\frac{R\&D\ purchased\ from\ overseas}{R\&D\ purchased\ from\ overseas + R\&D\ performed\ in\ the\ UK\ by\ businesses\ who\ als}$$

  In this case, the denominator for this estimate only relates to those businesses who purchase R&D from overseas, and excludes businesses which perform R&D in the UK but do not purchase from overseas. Therefore, it is likely to **overestimate** the overall proportion of R&D funded by business which is performed abroad.

To mitigate against the risk of under- or over-estimating the share of tax-credit funded R&D performed overseas, we took the midpoint between these two estimates.

Figure 8 presents the estimates for the two proxies over time. The unweighted average of the yearly averages over the 2010-2016 period is 23.9 percent. We adopted this value as the best available estimate of the proportion of tax credit-funded R&D which is undertaken overseas.

Figure 8: Estimates of the proportion of tax credits funding foreign R&D[10]

	2010	2011	2012	2013	2014	2015	2016	**Average**
Proxy 1	13.1%	10.2%	11.1%	16.3%	22.1%	26.2%	23.1%	**17.4%**
Proxy 2	21.9%	17.4%	20.6%	30.2%	40.2%	43.6%	38.7%	**30.4%**
Average	17.5%	13.8%	15.8%	23.2%	31.2%	34.9%	30.9%	**23.9%**

Source: BEIS

We therefore reduced the HMRC tax credits time series by 23.9 percent to remove the estimated value of R&D funded through tax credits that is performed overseas. We then reduced GERD funded by the business sector by this reduced HMRC tax credits series. The results from time series model specifications which include the tax credits adjustment are shown in Appendix 8 (Figure 108 to Figure 122).

While we attempted to apply a range of time series techniques to the ONS datasets described above, we were unable to obtain satisfactory, robust models. The approaches attempted are discussed in more detail in Appendix 2: Time series analysis.

In an attempt to overcome the limitations of the time series datasets, we turned to panel datasets which incorporate values across both countries and time, and thus offer a much larger number of observations to work with.

3.4. Panel regressions

3.4.1. Introduction to panel modelling techniques

Most of our modelling effort was based on a panel data framework, which has several advantages over time series analysis. Firstly, it allows us to control for systematic differences between countries and sectors, the omission of which can lead to biased results under standard time series approaches. Secondly, it allows us to observe and measure how changes in public support and other factors influence private investment over time. These benefits should enable us to develop more consistent and efficient models than is possible with time series techniques, and provide a stronger basis for establishing causality (i.e. not only that there is an association between public R&D support and private R&D investment, but that the former *causes* the latter).

[10] The HMRC series was adjusted to transform accounting periods into calendar years to make the tax credits data comparable with the GERD data.

We considered three types of panel data models:

- Fixed and random effects estimators (static models);
- Dynamic panel data within the Generalised Method of Moments (GMM) framework;
- Multi-level mixed-effects models.

Figure 9 below provides a brief overview of the advantages and disadvantages of each technique. The degree of modelling complexity increases moving down the table. There is further discussion of these techniques in Appendix 1: Further details of Econometric techniques.

Figure 9: Overview of panel data modelling techniques

Techniques	Advantages	Disadvantages
Instrumental Variable-based fixed and random effects estimators (static models)	Capture time series and cross-sectional elements. Capture unobservable factors within each country and sector. Allow the use of proxy variables to account for two-way causality and data measurement errors.	Do not capture dynamic effects (where past values have an impact on present values). Do not account for unobserved factors common to the same sector across countries.
Dynamic panel data within the Generalised Method of Moments (GMM)	In addition to the above, captures dynamic effects (past values influence present values).	Model statistics are not accurate if dynamic effects are not present.
Multi-level mixed-effects models	In addition to the above, accounts for cross-country sector effects or national effects across sectors.	Large sample sizes required.

3.4.2. Panel modelling approach for this study

It is important to select the most appropriate model specification in order to produce robust estimates of the relationship between public and private R&D.

As a first step, we determined whether a static or dynamic panel approach was needed. This decision rests on whether private R&D investment in the current period might be affected by past trends in private R&D, as well as public support and the control variables. Where such “autocorrelation” arises, it can create complications within the modelling process which can be overcome through the use of dynamic panel models. To test whether the data are autocorrelated, and therefore whether a dynamic panel specification is needed, we ran the "Wooldridge test for autocorrelation".[11, 12]

For most of our modelling, we included all available countries and years (and product groups where relevant). This maximised the size of the available sample, and therefore the robustness of our estimates. The drawback to this approach is that many countries and industries are missing from the international R&D datasets available for this type of modelling. Such gaps are magnified under dynamic panel methods which adopt the "Difference GMM/System GMM" approach because variables are translated into "first differences", i.e. the change in value from the previous year. This means that a missing data point for one year leads to two missing data points (the difference in the current year and the difference in the following year). To mitigate this risk, we used an alternate transformation process called "orthogonal deviations", where instead of subtracting the difference between values in two consecutive years, the model subtracts the average of all future available observations of a variable. This approach minimises data loss.

SYSTEM GMM AND DIFFERENCE GMM

There are two approaches to dynamic panel modelling: the Difference GMM approach and the System GMM approach. The Difference GMM (Arellano-Bond) starts by transforming all regressors, usually by differencing, and uses the generalized method of moments (GMM). The Arellano–Bover/Blundell–Bond estimator (System GMM) augments Arellano–Bond by making an additional assumption that first differences of instrument variables are uncorrelated with the fixed effects. This allows the introduction of more instruments and can dramatically improve efficiency. It builds a system of two equations—the original equation and the transformed one. The assumption of no correlation between the first differences of instrument variables and fixed effects in System GMM allows for the inclusion of time-invariant regressors, which would disappear in Difference GMM.

We selected the System GMM approach over the Difference GMM approach as the instruments generated by the former allow for the use of time-invariant instruments, thus enabling a wider choice of potential instruments than is possible under the Difference GMM approach, potentially allowing for a more efficient model.

[11] The Wooldridge test was implemented using the *xtserial* command in Stata using a specification comprising of dependent and independent variables. We tested for serial correlation in the data using multiple specifications with different independent variables.

[12] Even where a dynamic model is the preferred specification, there are still potential risks, such as "reverse causality" that we may need to correct for. This is discussed further in Appendix 1: Further details of Econometric techniques.

A further risk, which is not specific to panel data techniques, is that results are distorted by smaller countries, or countries with exceptionally high levels of public R&D. To check our results are not distorted by such effects, we ran sensitivity tests which weighted each country according to the value of public R&D investment or GDP. Results from our sensitivity testing are presented in Appendix 8: Econometric modelling outputs and test results. We also ran sensitivity tests to explore whether public R&D intensity has a causal impact on private R&D intensity, but were unable to find a satisfactory model under this approach.

Our panel data analysis relies on R&D data from the OECD. The main features of this dataset are outlined in the box below.

OECD DATA

We sourced intramural BERD and GERD for 42 countries from the OECD Research and Development Statistics dataset, which provides R&D expenditure by source of funding and sector of performance. The main features of this dataset are outlined in Figure 10.

Figure 10: Main characteristics of the OECD R&D Statistics dataset (as of June 2018)

	BERD	GERD
Funding sectors	Government, Own Funds, Higher Education, Non-Profit, Rest of the world	Government, Business, Higher Education, Non-Profit, Rest of the world
Performing sectors	Business	Business, Government, Higher Education, Non-Profit
Industries	16 broad industries with a further 25 disaggregated industries	No industry breakdown
Time series length	2007-2016	1981-2017
Country split	42 countries (23 of which are EU)	42 countries (23 of which are EU)

This dataset is available for major developed economies such as the US, Japan, and Canada, in addition to developed European economies including the UK, Germany and France. As of June 2018, the GERD data are generally available for 1981-2016 with varying levels of completeness: countries may have missing data points for certain years, although this becomes less of an issue in more recent years. For example, R&D performed by business and funded by government contains 27 countries out of 42 with 10 years of consecutive data for 2006-2015, but a longer consecutive time series dating back to 1985 is available for a smaller subset of 10 countries.

The OECD provides a separate data table in its Research and Development statistics database that provides a breakdown of R&D expenditure by source of funding for 16 broad industries, as classified by the International Standard Industry Classification (ISIC). Time series from this database are generally shorter than in the more aggregated dataset and are available between 2007 and 2015. Coverage across industries and countries is limited, particularly once data are broken down by industry and source of funding.

The OECD released additional GERD data in October 2018, during the latter stages of our research. This update extended the availability of data to 41 countries from 1961 to 2017 with varying degrees of completeness. The new dataset includes a large number of additional data points (280) but did not include revisions to the dataset available in June 2018. Of the additional data points, only a third are from the last three decades (1990-2017). Most of the additional data are from the period before 1990. For the UK, there is new data for 14 years—all before 1980. See Appendix 6: OECD data comparison for a more detailed explanation of the differences in data coverage between the two releases.

3.5. Control variables

Within our modelling we need to control for other factors which may influence the level of private R&D investment. Failing to include the right factors in the model could result in misleading conclusions as changes in private R&D could be attributed to public support when they actually result from other factors. This is referred to as "Omitted Variable Bias".

From our literature review, we identified five types of factors which have been used in previous studies of R&D leverage.

1. The **general economic environment** may influence R&D in several closely-related ways. Firstly, the economic "climate" may affect the funds firms have available for R&D, the returns they earn, and their appetite to undertake investments with uncertain returns. Looking at the growth rate of economic variables can control for this. Secondly, the size of an economy can also be an important determinant of R&D, for example because firms may have access to larger markets and better access to finance. It may therefore be helpful to incorporate control variables for the absolute level of GDP or employment, for example, to reflect this. Thirdly, research may be more profitable if incomes are higher, as individuals can better afford products that result from research. Some researchers have therefore included GDP per head within their model specifications.

2. **Workers' skills and knowledge**. Highly-skilled workers may have greater capacity to identify and carry out R&D work. As such, countries or industries

with highly specialised human capital are better placed to use public support to R&D to leverage their own R&D investments to improve productivity and output.

3. A high **degree of competition** in product markets may stimulate firms to innovate new products and services, and develop new processes to reduce costs. On the other hand, in some markets greater competition may reduce incentives to innovate because it reduces the ability of firms to extract returns from their investment.

4. **International trade and investment** may increase the degree of competition faced by domestic firms (see above). It may also enable a firm to benefit from overseas R&D by competing or collaborating firms.

5. **Participation in joint research ventures and linkages with innovation centres** expose firms to knowledge spillovers and create opportunities for collaborating in R&D projects to share costs with other organisations. Becker and Pain (2007) find that little research has been conducted in this area outside the United States, and that it is not clear how robust the positive effects are.

It is important to note that certain influences on private R&D investment may not be easy to observe or measure and in selecting an econometric methodology it is necessary to consider the extent to which different approaches are sensitive to the influence of "omitted variables". This is considered further in Appendix 1: Further details of Econometric techniques. To mitigate the risk of biased estimates due to omitted variables, we tested specifications with a wide range of control variables found in the literature. Where data permitted, we used modelling techniques that allow us to control for unobservable or unmeasurable factors (e.g. institutional factors) that may influence the level of private R&D investment.

Figure 11, below, summarises the most common control variables used in the macro studies included in our literature review.

Figure 11: Control variables identified through the literature review

Variable group	Potential variables	Examples of use previous research
General economic environment	Value added in industry	Falk (2006), Thomson (2013), Economic Insight (2015), OECD (2015), Sussex et al. (2016), Gonzalez and Paxo (2008) and other micro studies.
	GDP	Falk (2006), Wolff (2008), Coccia (2010), Gonzalez and Paxo (2008) and other micro studies.
	Employment (total and in R&D sector)	Toole (2012), Thomson (2013), HMRC (2015) and other micro studies
	Capital stock	Aerts et al. (2008), Yang et al. (2012) and other micro studies
	Gross fixed capital formation	Economic Insight (2015), Toole (2012), Falk (2006), Czarnitzki

		and Lopes-Bento (2012) and other micro studies
	Change in inventory levels[13]	Baghana and Mohnen (2009)
	Cost of R&D capital / interest rates	Thomson (2013), Bloom et al. (2002), Economic Insight (2015)
Workers' skills and knowledge	Compensation of employees	Economic Insight (2015)
	Cost of labour in R&D (Mean wages for "professional occupations")	Thomson (2013), Economic Insight (2015)
	Percentage of population across OECD countries holding different levels of qualifications	Falk (2006), Thomson (2013), Kaiser (2006)
	Quality Adjusted Labour Input	Thomson (2013)
Degree of competition/ concentration in product markets	HHI (Herfindahl Hirschman Index)	Czarnitzki and Licht (2006), Becker and Pain (2007)
	n-firm concentration ratio (where n=3 or 5 typically)	Czarnitzki and Licht (2006), Becker and Pain (2007), Czarnitzki, Hanel and Rosa (2011)
International trade and investment	Exchange rates versus US dollar	Economic Insight (2015)
	Export share of GDP	Falk (2006), Wolff (2008)
	Patent rights, as measured by the "Ginarte-Park" index	Falk (2006)
	Technological opportunity (number of published academic journals)	Thomson (2013)
	Technology Balance of Payments	OECD (2010), Falk (2006)
Joint research ventures and innovation centres	No variables identified	No data sources identified by previous authors

We would ideally like to control for all five types of factors identified above. However, not all of the variables in Figure 11 are available in sufficient detail to enable modelling in a cross-country panel data environment. We were unable to identify suitable sources for the following variables:

- Cost of R&D capital—data required to construct the cost of capital are not available.[14] However, we could use interest rates as a proxy.

[13] The change in inventory levels may be used to test whether fixed investment is being used to fund capital, or inventories

[14] In Thomson (2013), the after-tax cost of R&D investment is measured as 1 – CIT x deductions – credits. This states that a firm's after-tax cost is reduced by allowable deductions ('deductions'("deductions") multiplied by the corporate income tax ('CIT'("CIT") rate and any explicit tax credits. The study identifies the allowable rate of deduction as well as eligibility for additional credits from a range of sources, but does not provide any further detail on the sources or the

- n-firm concentration ratio—not available on an annual basis.
- Cost of labour in R&D—we could not identify a source with data for a sufficient number of countries included in our panel model.
- The "Ginarte-Park" index (to measure the strength of patent rights) and the number of published academic journals (to measure technological opportunity) are not available in cross-country datasets on an annual basis.

3.6. Developing a model specification

For each model, we followed a systematic four-step approach to determine the choice of control variables and our preferred specifications. The steps were as follows:

1. We started by estimating each model with just the lag of private R&D expenditure and public R&D expenditure (we experimented with different lengths of lag). Since a number of other factors are known to influence private R&D, these models are likely to suffer from "omitted variable bias".
2. We added one or two control variable at a time from the first of the groups shown above. For example, we started with a variable to control for the cost of R&D (e.g. interest rates) and one for the size of the economy (e.g. employment or GDP in levels or growth rates). We then added a control variable from another group and compared model specifications using appropriate diagnostic tests. We then added a variable from a third group to the most satisfactory specification, and compare specifications, and so on.
3. Once we had identified a satisfactory model with statistically significant coefficients with the expected signs, we ran diagnostic tests to test the robustness of the model, and further refined the specification if required. The tests included:
   - the AR(2) test to test whether the model is robust to the presence of unit roots;
   - the Hansen test for a situation where the instruments outnumber the coefficients estimated by the model (i.e. overidentifying restrictions); and
   - the test for Nickell bias (i.e. whether the dynamic panel correctly captures the relationship between private R&D investment in the current year and its values in the previous years).
4. We then undertook a further layer of testing by replacing an existing control variable with another control variable from within its own group and comparing the results.

A shortlist of preferred model specifications was determined by identifying the most robust specifications according to diagnostic tests and coefficient analysis of the

calculations. Further, they did not find evidence of a link between the cost of capital and business expenditure on R&D.

control variables. We also took into account the sample size—all else equal, a large sample should produce more robust results than a smaller sample.

Our preferred model specifications are presented in the following chapters.

3.7. The role of time lags

Businesses typically invest in R&D for the same reason that they invest in new equipment, technology or staff training. That is, they expect to earn returns on their investment in the future. These returns could take the form of new products or services, or new processes that improve the efficiency of production. Unexpected changes in the economic environment, including levels of investment in public R&D, may lead businesses to re-evaluate and adjust their investment decisions. However, such adjustments take time, for example as businesses hire new staff or purchase additional equipment to increase the volume of R&D they undertake.

The outcomes of R&D activity also do not manifest themselves instantly. It takes time to innovate, and for results to become publicly available. There is therefore likely to be a lag between public R&D work being undertaken and private businesses responding with their own R&D work to build upon the findings of the public R&D.

Both of these factors imply that the relationship between public R&D and private R&D is likely to materialise over time and our modelling approaches need to incorporate a time dimension to take this into account. Nonetheless, the exact lag between public R&D investments and private R&D investments is unknown. Different lag structures need to be tested to establish the most robust model specification.

To explore this we started by using a one-period lag of public R&D as an explanatory variable. Maintaining the same model specification, we changed the lag structure on public R&D to a two period lag and compared the resulting model to that based on the one-period lag. The more robust model, according to coefficient signs and the significance of control variables and diagnostic tests, was selected. This process was repeated up to a three period lag for time series models and up to a four period lag for panel series models. Thomson (2013) and Economic Insight (2015) use a lag of one year, whereas Guellec and van Pottelsberghe de la Potterie (2003) use lags of up to three years.

3.8. Inflation and currency adjustments

For the analysis based on OECD datasets, R&D expenditure data were deflated into 2010 constant prices[15] and converted into US dollars using the current exchange rate.[16] For our estimates of the UK leverage rate using cross-country data, we

[15] Our models used either CPI or GDP deflators to convert data into real values. Testing suggested that the choice of deflator had little impact on results, reflecting the very high correlation between the two types of deflator.

[16] It is inappropriate to use a fixed exchange rate for this analysis because the degree of complementary in private spending may be a function of the exchange rate. For example, if the UK

estimated our regressions using R&D expenditure data in both US dollars and Sterling. The models which used only UK data from the ONS were estimated in Sterling. Where applicable, adjustments have also been made to control variables (for example, GDP).

3.9. Estimating the short-run and long-run impact

The private sector may not respond immediately to changes in government support for R&D. We examine whether the causal link between public and private R&D investment materialises gradually over time. This involves investigating the relationship between public support in one period and private R&D investment in subsequent periods, with various degrees of time lag.

For example, consider the following model specification:

$$PVT_{GERD\ t} = \alpha + \beta_1 PVT_{GERD_{t-1}} + \beta_2 PUB_{GERD\ t} + control$$

In the above equation, GERD funded by the private sector in year t ($PVT_{GERD\ t}$) is explained by:

- a constant term, α ;
- GERD funded by the private sector in the previous year, t-1, $PVT_{GERD_{t-1}}$multiplied by a coefficient, β_1;
- GERD funded by the public sector in the same year, t, $PVT_{GERD\ t}$ multiplied by a coefficient, β_2; and
- Other control variables.

The coefficient β_2 is an estimate of the average percentage change in GERD funded by the private sector in a certain year due to a one percent change in GERD funded by the public sector in the same year, i.e. the short-run impact.

$$Short - run\ impact = \beta_2$$

The coefficients, β_1 and β_2, can be combined using the following formula to obtain the average percentage change in GERD funded by the private sector due to a one percent change in GERD funded by the public sector in the long run:

government's real expenditure in sterling is unchanged over a number of years, but suddenly falls in dollar terms due to sterling depreciation, to a first approximation we might expect complementary investment to fall in dollar terms too. But it's not clear that it would necessarily be one-for-one. For example, if research in the UK becomes cheaper, multi-national companies might decide to undertake more activity there. So with a fixed exchange rate a depreciation might be followed by an unexplained increase in dollar-denominated complementary activity, and vice versa. Having a variable exchange rate overcomes this problem.

$$Long - run\ impact = \frac{\beta_2}{1 - \beta_1}$$

The coefficient, β_1, could also provide an indication of time for the full impact to manifest. The larger the value of β_1, the longer it takes an increase in public funding to have the full long-run impact on private R&D expenditure.

3.10. Converting elasticities into monetary terms

Our model specifications are set up such that the regression coefficients provide estimates of leverage rates expressed as elasticities. In other words, in the regression specification in Section 3.9 above, the coefficients are an estimate of a percentage change in private R&D corresponding to a one percent change in public R&D. To convert the elasticities into monetary terms, we use the following formula for the change in private R&D corresponding to a one unit change in public R&D:

$$\Delta(Private\ R\&D) = \beta_{Public\ R\&D}\left(\frac{Private\ R\&D}{Public\ R\&D}\right)$$

where $\beta_{Public\ R\&D}$ is the coefficient on Public R&D (e.g. β_2 in the regression in Section 3.9 above), and $\left(\frac{Private\ R\&D}{Public\ R\&D}\right)$ is the ratio of private to public R&D over the sample used in the regression.

The above formula can be modified to convert elasticities into monetary terms for specific types of public support, by using the appropriate coefficient and substituting the denominator in the ratio. For example, the formula to calculate the impact of £1 change in direct public support to businesses for R&D (direct support) on private R&D expenditure is calculated as:

$$\Delta(Private\ R\&D) = \beta_{Direct\ Support}\left(\frac{Private\ R\&D}{Direct\ Support}\right)$$

where $\beta_{Direct\ Support}$ is the coefficient on direct support by governments to businesses for R&D, and $\left(\frac{Private\ R\&D}{Direct\ Support}\right)$ is the ratio of private R&D expenditure to direct support by governments to businesses for R&D over the sample used in the regression.

There are alternative ways of implementing this formula. For example, the median ratio might be used instead of the mean, or the ratio might be calculated using data for only the most recent years instead of the entire sample. Within the specifications presented throughout the report, we have translated the elasticities from our regressions using the mean ratio of private to public R&D spending across the entire sample used for the corresponding regression. This ensures that the leverage rate estimates and the corresponding monetary impacts are calculated for a consistent time period. We have undertaken sensitivity testing to explore the impact of making alternative assumptions in this calculation and the findings are reported in Figure 101 in Appendix 8: Econometric modelling outputs and test results.

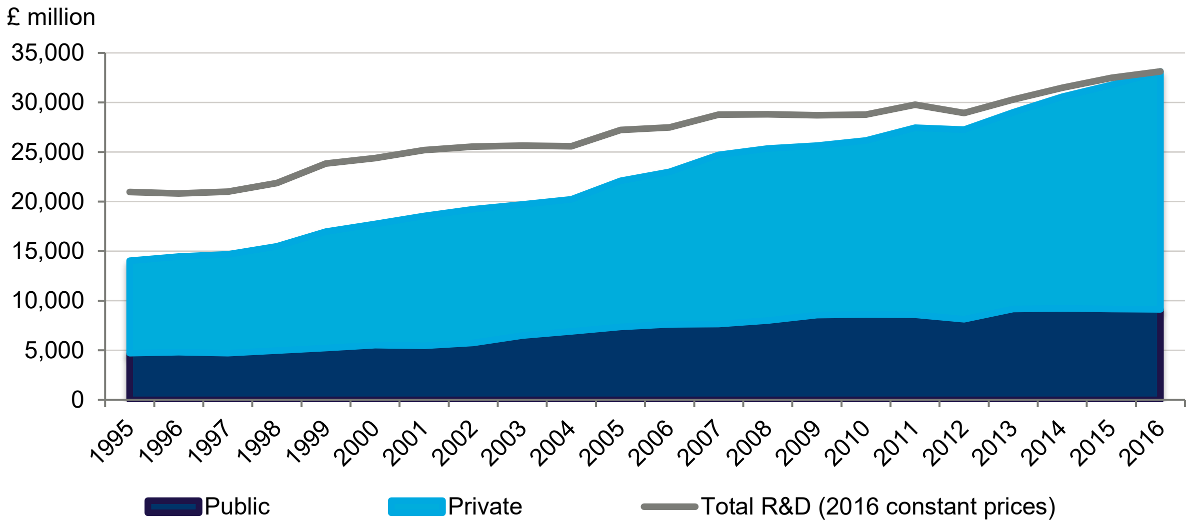
4. What is the best estimate of the leverage rate in the UK?

4.1. The value of public and private sector R&D in the UK

In 2016, the latest year of data available at the time we undertook our analysis, the total value of R&D investment conducted in the UK was £33 billion. The value of UK R&D has been steadily increasing over the past 20 years, growing at an average annual growth rate of 4.2 percent in nominal terms. The growth rate has accelerated since 2013, driven by the acceleration in privately funded R&D, which grew by an average of 6.5 percent between 2013 and 2016. By comparison, public sector R&D has remained constant over this period (Figure 12).

This divergent trend in private and public R&D investment over the past few years has increased the proportion of R&D funded by the private sector to 72 percent, the highest since the current data series began. Of the £33 billion of R&D conducted in the UK in 2016, £24 billion was funded by the private sector.

Figure 12: UK public and private sector R&D 1995-2016



Source: ONS GERD

In this part of the analysis we seek to establish the influence of public R&D support on private R&D investment. That is, the overall UK leverage rate. The matrix below (Figure 13) illustrates the types of R&D included in our definition of public and private sector R&D for this part of the study.

Figure 13: Analysis of the impact of all public R&D on all private R&D

<table>
<tr><th>Performed by

Funded by</th><th>Government</th><th>Research councils</th><th>Higher education</th><th>Business</th><th>Private non-profit</th></tr>
<tr><td>Government</td><td colspan="5" rowspan="4">Public sector R&D</td></tr>
<tr><td>Research councils</td></tr>
<tr><td>Higher education funding councils (HEFC)</td></tr>
<tr><td>Higher education</td></tr>
<tr><td></td><td colspan="5"></td></tr>
<tr><td>Business</td><td colspan="5" rowspan="3">Private sector R&D</td></tr>
<tr><td>Private non-profit</td></tr>
<tr><td>Overseas</td></tr>
</table>

Source: Oxford Economics

4.2. Time series analysis

Our first approach to assessing the overall UK leverage rate was based on time series analysis of ONS data. We applied a range of techniques to analyse the ONS GERD and BERD datasets, but we were unable to overcome the challenge posed by the limited number of data points available to work with. We were therefore unable to obtain any satisfactory specifications through time series approaches. Further details of the time series analysis are presented in Appendix 2: Time series analysis.

4.3. Panel data analysis

Panel data techniques offer a potential way of overcoming the challenges we faced in the time series analysis by enabling us to analyse trends across both time and countries, giving us a larger number of data points to work with. Panel techniques are also better at coping with the influence of unobservable influences on R&D investment.

4.3.1. Data

We used OECD data to enable a panel data approach. This provides significantly more data points than the ONS data, enabling us to more robustly estimate the leverage rate in the UK. The control variables tested in our models were those listed in Figure 11. The discussion below sets out examples of our findings from the most promising specifications tested.

To our knowledge, no data are available that would permit us to adjust private GERD to exclude R&D financed through tax credits across all of the countries in the OECD dataset.[17] As such, all of the results based on OECD panel data must be interpreted acknowledging that private R&D investment is likely to include investment funded through tax credits.

The majority of our modelling was based on the OECD data available as of June 2018. Within this dataset, GERD data were available for 20 consecutive years (1996-2015) for 22 countries and there were a further seven countries with 10 years (2006-2015) of consecutive data. The remaining OECD countries in the sample had less data coverage but, subject to data availability for other variables, could still be incorporated into our modelling.

Correlation analysis can help to highlight potential issues with control variables. For example, GDP is highly correlated with private and public GERD and it is therefore unlikely that a model with GDP would yield statistically significant coefficients (see Figure 14). On the other hand, GDP *growth* and employment *growth*, are not correlated with the R&D variables. Further, these two variables themselves have a correlation coefficient of 0.40, and therefore, it is worth testing both these variables in the same model.

Figure 14: Correlation analysis of key variables

Variable	Private GERD	Public GERD	Emplo-yment growth	Interest rate	GDP	GDP growth
Private GERD (US $, mn)	1.00	0.95	0.01	-0.07	0.89	0.01
Public GERD (US $, mn)	0.95	1.00	0.02	0.01	0.94	0.01
Employment growth	0.01	0.02	1.00	-0.07	0.04	0.40
Interest rate	-0.07	0.01	-0.07	1.00	0.04	0.05
GDP (US $, mn)	0.89	0.94	0.04	0.04	1.00	0.01
GDP growth	0.01	0.01	0.40	0.05	0.01	1.00

Source: Oxford Economics

4.3.2. Model selection

The models presented in the remainder of this chapter have been constructed to establish the best estimate of the leverage rate in the UK. To do so we estimated the relationship between private GERD and public GERD across OECD countries. We then applied econometric techniques to estimate a UK-specific leverage rate within this framework.

As described in Section 3.4.2, we first determined whether a static or dynamic panel approach was needed by running the Wooldridge test. This suggested that a

[17] Data recently published by the OECD do permit such an adjustment to be made for a subset of the countries in the dataset. We tested specifications which incorporate this but were unable to achieve satisfactory results. The findings are presented in Appendix 3: Leverage rates for indirect support (tax credits).

dynamic panel specification was preferable. In cases where dynamic panel approaches have not been successful, there is insufficient data to develop multi-level models and so we were not able to explore that approach.

4.3.3. Control variables

The control variables were selected following the systematic approach outlined in Section 3.6. Failing to include the right factors in the model could lead to misleading conclusions as changes in private R&D could be attributed to public support when they actually result from other factors. The results of various model specifications using different combinations of control variables are presented in Figure 15. This is not an exhaustive list and discussion of the specifications tested, but the descriptions below provide insights into the process undertaken to determine which control variables to include in our modelling.

Firstly, the **economic climate** may affect the funds firms have available for R&D, the returns they earn, and their appetite to undertake investments with uncertain returns. To explore this we tested the GDP growth rate, employment growth rate and investment (GFCF) growth rates in our specification. We also explored using the interest rate, a measure of the cost of access finance to fund R&D. (see models 1 to 5 in Figure 15).

For a model specification to be satisfactory, it must pass the relevant diagnostic tests, and the coefficients on the control variables should be significant, have the expected sign and be of a plausible magnitude. For example, in a model with interest rates and employment growth rates (model 5 in Figure 15), the coefficient on the employment growth rate is positive and statistically significant (this appears intuitively reasonable since faster economic growth, as reflected in employment growth, would be expected to lead to more R&D). On the other hand, the coefficient on interest rates would be expected to be negative, reflecting that higher borrowing costs push up the cost of undertaking R&D for companies who fund their R&D investment through borrowing. This is the case in model 5, and the interest rate coefficient is also significant and of a plausible magnitude.

Model 1 only includes interest rates as a control variable. The coefficients on all variables in this model have the expected sign and are statistically significant at the five percent level.

We then proceeded to add other control variables and re-tested the model specification. Models 2 and 3 also include the level of GDP and level of employment, respectively, but coefficients become insignificant, so we instead tried GDP growth and employment growth in models 4 and 5. Analysis of coefficient signs and significance indicated that Model 5 provided the best specification. We found, for example, that the coefficient on interest rates in Model 4 is insignificant and positive, which is the opposite sign to that suggested by economic theory.

The other variables to control for the general economic environment in our specifications include the stock of capital and the change in inventory levels. The stock of capital provides an indication of the cumulative level of historic investment: countries with higher stock of capital may be inclined to spend more on R&D. On the other hand, the change in inventory levels may be used to test whether fixed investment is being used to fund capital or inventories. Volatile inventory levels may indicate volatile demand for products in the economy and may deter R&D. Model specifications with these control variables did not satisfy the various criteria described above (see model 10, for example). In the model which includes the change in inventory levels, the coefficient on employment growth is negative, and the sample size drops by more than a third.

The second group of control variables included factors relating to **workers' skills and knowledge**. Highly-skilled workers may have greater capacity to identify and carry out R&D work. As such, countries or industries with highly specialised human capital are better placed to use public support to R&D to leverage their own R&D investments to improve productivity and output. We used variables such as the quality-adjusted labour input (QALI) and found that the coefficient on this variable was not significant. Further, the availability of data on QALI is limited, which reduces the sample size for our analysis by more than half (Model 11 in Figure 15).

A **high degree of competition in product markets** may stimulate firms to innovate new products and services, and to develop new processes to reduce costs. We tested whether competition has an effect on private R&D using the Herfindahl Hirschman Index (HHI) in our specification (Model 7 in Figure 15). We found that the coefficient on HHI was negative and not statistically significant.

We also explored specifications which included variables relating to **international trade**, based on the export share of GDP (e.g. model 8 in Figure 15). In countries which are more open to trade, companies may face greater competition as they sell their products, which would be expected to encourage innovation and R&D. Exporting companies may also get greater exposure to the international exchange of knowledge and ideas, which might again be expected to contribute positively to R&D. We found that the coefficient on exports as a proportion of GDP was negative but not statistically significant (model 8).

Figure 15: Panel results using different control variables based on the June 2018 dataset

Dependent variable: Private GERD (log).

Monetary variables specified in US Dollars and deflated using CPI.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
Lag private GERD (log) - lag of dependent variable	0.6988***	0.6561***	0.6454***	1.0878***	0.6865***	0.7575***	0.6870***	0.6873***	0.7681***	0.7542***	0.7575***
	(0.0911)	(0.2296)	(0.1622)	(0.0755)	(0.0846)	(0.1157)	(0.0855)	(0.0809)	(0.0745)	(0.1432)	(0.1157)
Public GERD (log)	0.2267**	-1.4290	0.1437	-0.1072	0.3052***	0.2864**	0.3050***	0.2792***	0.2277**	0.1662	0.2864**
	(0.1049)	(1.2443)	(0.2292)	(0.0772)	(0.0912)	(0.1416)	(0.0918)	(0.0789)	(0.0916)	(0.1703)	(0.1416)
GDP (log)		1.9618									
		(1.2582)									
Interest rates	-0.0234***	-0.0332	-0.0253*	0.0065	-0.0162**	0.0136	-0.0164**	-0.0199*	-0.0106**	-0.0136*	0.0136
	(0.0085)	(0.0260)	(0.0140)	(0.0069)	(0.0065)	(0.0140)	(0.0067)	(0.0103)	(0.0047)	(0.0082)	(0.0140)
Employment (log)			0.3507								
			(0.3417)								
GDP growth rate				1.0332***							
				(0.1280)							
Employment growth rate					1.3367**	1.1991	1.3007**	1.1059*	1.3726***	-2.3093**	1.1991
					(0.5815)	(1.4388)	(0.5951)	(0.5768)	(0.5086)	(1.1535)	(1.4388)
Quality adjusted labour input (log)						1.3364					
						(1.1002)					
Herfindahl Hirschman Index							-0.0317	-0.0357			
							(0.0508)	(0.0580)			
Exports (% of GDP)								-0.0011			
								(0.0022)			
Exchange rates									0.0074		
									(0.0098)		
Change in inventory levels										0.0669**	
										(0.0299)	
QALI (log)											1.3364
											(1.1002)
Constant	0.9063*	-11.2529	-1.1445	0.1100	0.3313	-0.2495	0.3325	0.6053	0.2238	-0.5665	-0.2495
	(0.4955)	(7.5840)	(1.4009)	(0.4367)	(0.2680)	(0.2878)	(0.2699)	(0.5762)	(0.2387)	(0.4665)	(0.2878)
Observations	586	558	542	558	538	203	538	538	538	371	203
Number of countries	31	30	30	30	30	20	30	30	30	28	20
number of instruments	8	11	11	11	19	12	20	21	10	10	12
AR2 p-value	0.818	0.375	0.754	0.216	0.851	0.441	0.856	0.947	0.879	0.361	0.441
Hansen p-value	0.00681	0.172	0.0326	0.277	0.0871	0.148	0.0860	0.0466	0.2238	0.268	0.148

Source: Oxford Economics. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Lag private GERD, Public GERD, GDP, employment, GDP growth, and change in inventory levels are treated as endogenous and instrumented whereas interest rates, QALI, the Herfindahl-Hirschman Index, exports share of GDP, exchange rates are treated as exogenous

The results above provide estimates of the average leverage rate across the panel of OECD countries in the sample. To identify whether the UK leverage rate differs from that of other countries, we introduced an “interaction term”, which identifies the coefficient for the UK separately from that of other OECD countries in the dataset. This is discussed further in the box below.

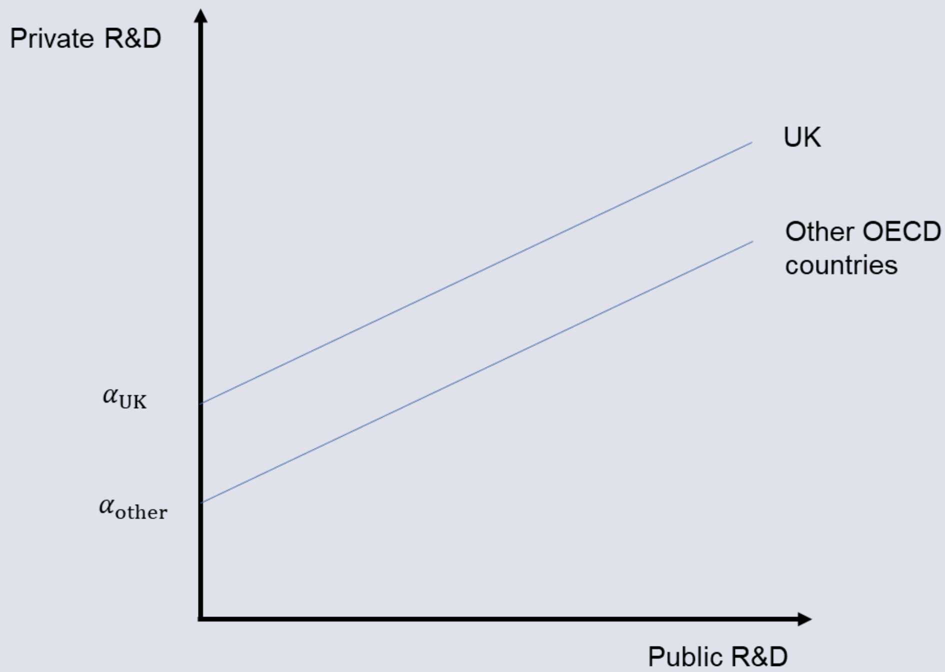
DUMMY VARIABLES AND INTERACTION TERMS

Dummy variables are variables that have been assigned values of either 0 or 1 to indicate that an observation falls into a certain category. They are also sometimes called indicator variables. Dummy variables are used to test whether the coefficients for a certain category are different from the rest of the sample.

Interaction terms, also sometimes referred to as “partitioning”, are used widely in the econometric literature. For example, Rajan and Zingales (2003) use interaction terms in a panel data setting to examine if the number of firms listed in a country is affected by the openness and the historical level of industrialisation; Splimbergo (2009) studies if countries that send large number of students abroad have better democracies.

Within the context of our study, suppose that the level of private R&D investment in the UK is higher than for other OECD countries. This is illustrated through the stylised example shown Figure 16 overleaf, where the UK average, α_{UK}, is higher than the average for other OECD countries, α_{other}. However, the relationship between public R&D and private R&D is the same. In other words, the leverage rate, given by the slope of the line, is the same for the UK and other OECD countries.

Figure 16: Illustration of dummy variables



By including a dummy variable, it is possible to estimate the different coefficients separately, as shown in the equation below, which includes a UK dummy (which takes the value of 1 for UK observations and 0 elsewhere), and an "other OECD country" dummy (which takes the value of 0 for the UK observations and 1 elsewhere).

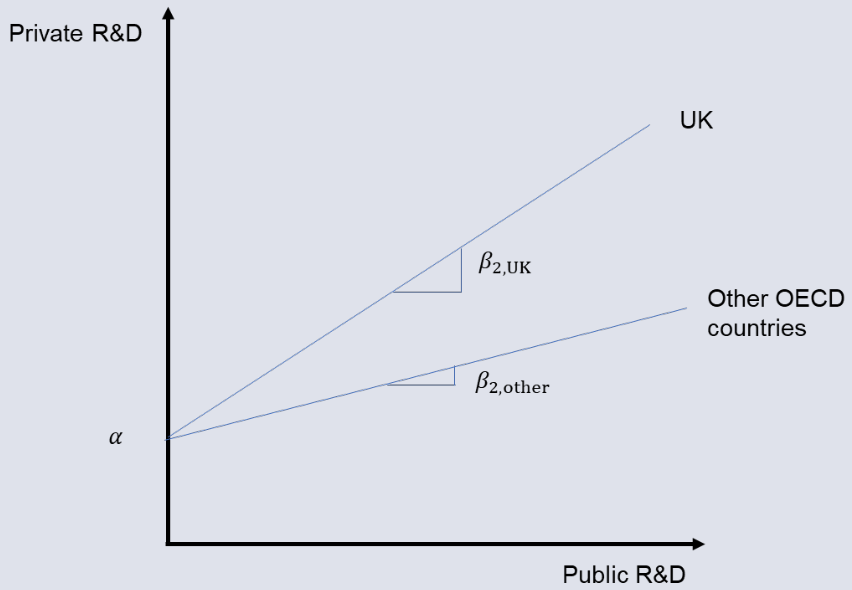
$$PVT_{GERD_{c,t}} = \alpha_{\mathrm{UK}} + \alpha_{\mathrm{other}} + \beta_1 PVT_{GERD_{c,t-1}} + \beta_2 PUB_{GERD_t} + control\ variable$$

In the above equation, GERD funded by the private sector in year t and country c ($PVT_{GERD_{c,t}}$) is explained by:

- a constant term, α_{UK} and α_{other} for the UK and other OECD countries respectively
- GERD funded by the private sector in the previous year, t-1, and country, c ($PVT_{GERD_{c,t-1}}$) multiplied by a coefficient, β_1
- GERD funded by the public sector in the same year, t, multiplied by a coefficient, $\beta_{2,}$, which is the OECD average leverage rate
- control variables.

It is also possible that the leverage rate may vary by country. In Figure 17 overleaf, the leverage rate, given by the slope of the line, is higher for the UK ($\beta_{2,UK}$) compared to other OECD countries ($\beta_{2,other}$).

Figure 17: Illustration of interaction terms



This can be tested by multiplying the dummy variable by the public R&D variable (the "interaction term") and estimating the equation below. Note that only the explanatory variable is multiplied by country to estimate whether different countries have different slopes. A separate constant term for each country is not introduced. We expect this would be captured as "fixed effects" by the panel modelling techniques.

$$PVT_{GERD_{c,t}} = \alpha + \beta_1 PVT_{GERD_{c,t-1}} + \beta_{2,\text{UK}} PUB_{GERD_{UK,t}} + \beta_{2,\text{other}} PUB_{GERD_{other,t}} + control\ variables$$

In the above equation, GERD funded by the private sector in year t and country c ($PVT_{GERD_{c,t}}$) is explained by:

- a constant term, α
- GERD funded by the private sector in the previous year, t-1, and country, c (〖PVT_GERD〗 $\_(c, t-1)$) multiplied by a coefficient, β_1
- GERD funded by the public sector in the same year, t, in the UK ($PUB_{GERD_{UK,t}}$) multiplied by a coefficient, $\beta_{2,UK}$, which is the UK-specific leverage rate
- GERD funded by the public sector in the same year, t, in the other countries ($PUB_{GERD_{other,t}}$) multiplied by a coefficient, $\beta_{2,other}$
- control variables.

The $\boldsymbol{\beta_{2,\text{other}} PUB_{GERD_{other,t}}}$ term can be split further for other countries, e.g. the US, Japan, France, Germany and so on.

4.3.4. Results

Our four preferred model specifications are presented in Figure 18. All models use employment growth and interest rates as control variables but use different lags as instruments.[18] Model 2 uses the same specification as Model 1 but uses additional instruments to account for endogeneity. Model 3 also has the same specification as Model 2 but uses decade-specific dummies as additional instruments. The coefficient on public R&D remains stable across the four model specifications, suggesting the results are robust.

To estimate a specific UK leverage rate, we expressed public and private R&D in GBP terms in Models 1 to 3. Model 4 uses public and private R&D expressed in USD terms (this enables comparison with findings for other countries which were estimated in USD terms).

Note that in Models 1 to 3, we have excluded the constant term. Where similar models were run with the constant term included, we were not able to find a satisfactory specification where the coefficients on the other control variables (e.g. employment growth and interest rates) were significant. While excluding the constant term is a restrictive assumption,[19] we have chosen to include these regressions as a part of our preferred specifications as they provide model specifications which satisfy the relevant diagnostic tests.

These models have been selected as our preferred models because they pass the relevant diagnostic tests, and the coefficients on the control variables are significant and of a plausible magnitude. In each of these models, the AR(2) test for autocorrelation and the Hansen test for overidentified restrictions are satisfied at least at the five percent level of significance, indicating that the models are robust to serial correlation and that the instruments used are suitable for our analysis. The coefficients on employment growth and interest rates have the expected sign, are statistically significant at least at the 10 percent level and most are significant at the five percent level. The coefficients are also of a plausible magnitude.

Across all four models, we treat interest rates as exogenous as they are largely determined by central bank policy. We treat the other variables, i.e. the lag of private

[18] Using lags as instruments is not the same as using lags as explanatory variables. The explanatory variables are used to estimate a causal relationship whereas instruments help mitigate the risk that these causal relationships are biased. The causal relationship is *not* between the dependent variable and the instruments. Dynamic panel models allow us to use various lags of various explanatory variables as instruments. We use the ”xtabond2” command in Stata and test various lags as instruments.

[19] A model specification without a constant term implies that the average level of private R&D in a particular year remains unchanged from its level in the previous year if all the other control variables (i.e. the employment growth rate and interest rate) are zero. While the “fixed effects” term may lead to some changes over time for each individual country, these changes balance out across countries. In other words, the fixed effects term averages out to zero across countries. Therefore, without a constant and if all other control variables are set to zero, there is no change in the average level of R&D across the sample.

R&D spending, public R&D spending and employment growth rate, as endogenous as they are likely to be influenced by private R&D in current or future periods.[20]

We tested a large number of other specifications which either did not satisfy these criteria or, where they did, the sample size was significantly reduced due to a lack of data for certain control variables. Therefore, the models presented in Figure 18 are our preferred specifications.

The coefficient on UK public GERD, the short-run UK leverage rate, ranges from 0.26 to 0.38 and is significant at the one percent level. This is similar to the short-run leverage rate for the rest of the OECD, which ranges from 0.28 to 0.37. Expressed in a different way, each £1 of public R&D expenditure stimulates between £0.50 and £0.74 of private R&D expenditure in the short run (within the same year).[21,22]

The coefficient on lagged private GERD reflects the degree of inertia in private R&D investment and enables us to determine the long-run impact of public R&D on private R&D. A one percent change in private GERD last year is, all else equal, associated with a 0.64 to 0.75 percent change in private GERD this year. Therefore, a 0.26 to 0.38 percent increase in private GERD today (due to a one percent increase in public GERD) leads to 0.19 to 0.24 percent increase in private GERD in the following period. This momentum continues into the future, albeit by smaller amounts in each year. Our analysis suggests that the long-run impact of public R&D on private R&D is around four times the short-run impact: we estimate the long-run UK leverage rate to be between 1.01 and 1.06. This suggests that £1 of public R&D investment stimulates between £1.96 and £2.06 of private R&D in the long run. The impact is most substantial in the first year and fades over time.

[20] In the System GMM approach, variables can be either endogenous or partially exogenous (i.e. pre-determined). We treat the employment growth rate and public R&D spending as partially exogenous (i.e. pre-determined) as they may be determined by factors beyond private R&D spending and other variables in the model. We treat private R&D spending as endogenous in Model 1 and Model 4 in Fig. 18 and as partially exogenous (i.e. pre-determined) in the other models. We discuss our approach and the sensitivity of our results to our choices in detail in Section 9.10.

[21] The impact of an additional £1 of public R&D expenditure is calculated using the average ratio of public to private support over the period covered by each model. The average ratio of public to private R&D used is 1.94 for the models using the June 2018 dataset and 1.77 for the models using the October 2018 dataset.

[22] These results reflect the impact of R&D support by the UK government on private R&D in the UK. They do not factor in the effects of cross-border linkages (e.g. the impact of public R&D support in France on business R&D in the UK). For example, government R&D support to domestic businesses in one country might result in increased R&D activity in another country, perhaps due to supply chain linkages or if a multi-national company has some of its operations in another country.

Figure 18: Results of panel data regression methods based on the June 2018 dataset
Dependent variable: Private GERD (log).
Monetary variables specified in GBP (Model1, 2 and 3) and USD (Model 4) and deflated using GDP deflator.
See Figure 90 – Figure 103 in Appendix 8: Econometric modelling outputs and test results for other model specifications estimated

VARIABLES	Model 1	Model 2	Model 3	Model 4
Lag private GERD (log) – Lag of dependent variable	0.7177***	0.7025***	0.7458***	0.6414***
	(0.0960)	(0.0744)	(0.0812)	(0.0996)
Public GERD (log) – UNITED KINGDOM	0.2949***	0.3125***	0.2568***	0.3798***
	(0.1015)	(0.0758)	(0.0885)	(0.1105)
Public GERD (log) - OTHERS	0.3155***	0.3303***	0.2845***	0.3697***
	(0.1035)	(0.0810)	(0.0892)	(0.1129)
Employment growth rates	0.9153**	0.8581**	0.7657**	1.3811**
	(0.4264)	(0.4248)	(0.3648)	(0.6404)
Interest rates	-0.0125**	-0.0119**	-0.0103*	-0.0179**
	(0.0056)	(0.0054)	(0.0057)	(0.0070)
Constant	-	-	-	0.1967
				(0.2893)
Observations	538	538	538	538
Number of countries	30	30	30	30
Number of instruments	14	15	17	19
AR2 p-value	0.462	0.453	0.442	0.799
Hansen p-value	0.0553	0.0596	0.173	0.13

Source: Oxford Economics
Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD, employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

4.3.5. Lag structure

As discussed above, the leveraging effects of public R&D support may occur gradually over time, i.e. with a "lag". To explore this we undertook analysis to determine the most appropriate lag structure for our model. To do so we compared the robustness of models 1 to 3 in Section 4.3.4 using lags of between one and three years on the public R&D variables. Figure 19, overleaf, shows the regression results using different lag structures for the first three specifications presented in Figure 18. The first three columns of Figure 19 are the same as the first three columns in Figure

18. The next three columns present the results with the first lag of public R&D used instead of the in-year value of R&D. The next three columns present the specification with the second lag, and so on.

The coefficient on the employment growth rate is not significant when lags of public R&D are used except in one case (i.e. Model 3 with the first lag of public R&D). The coefficient on interest rates has the wrong sign when lags of public R&D are used and is not significant when the first lag of public R&D is used. The coefficient on the lag of public R&D is not statistically significant for lag lengths of one or three. When the second lag is used, the coefficient on lag public R&D is significant but negative in two out of three specifications. Therefore, it is not possible to draw conclusions on the impact of public R&D using lag terms.

Figure 19: Results of panel data regressions methods based on the June 2018 dataset
Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using GDP deflator.
See Figure 90 – Figure 103 in Appendix 8: Econometric modelling outputs and test results for other specifications.

VARIABLES	Model 1	Model 2	Model 3	Model 1 (1st lag)	Model 2 (1st lag)	Model 3 (1st lag)	Model 1 (2nd lag)	Model 2 (2nd lag)	Model 3 (2nd lag)	Model 1 (3rd lag)	Model 2 (3rd lag)	Model 3 (3rd lag)
Lag private GERD (log) - lag of dependent variable	0.7177***	0.7025***	0.7458***	0.9972***	0.9782***	0.9696***	1.1619***	1.0781***	1.1545***	1.0701***	1.0500***	1.0690***
	(0.0960)	(0.0744)	(0.0812)	(0.0747)	(0.0769)	(0.0516)	(0.0795)	(0.0927)	(0.0734)	(0.0482)	(0.0881)	(0.0461)
Public GERD (log) - United Kingdom (various lags)	0.2949***	0.3125***	0.2568***	-0.0137	0.0053	0.0072	-0.1893**	-0.1122	-0.1997**	-0.1337	-0.1225	-0.1420
	(0.1015)	(0.0758)	(0.0885)	(0.0875)	(0.0913)	(0.0694)	(0.0905)	(0.1053)	(0.0925)	(0.0834)	(0.1089)	(0.0871)
Public GERD (log) - other OECD (various lags)	0.3155***	0.3303***	0.2845***	0.0101	0.0302	0.0376	-0.1723**	-0.0839	-0.1667**	-0.0714	-0.0504	-0.0711
	(0.1035)	(0.0810)	(0.0892)	(0.0810)	(0.0834)	(0.0577)	(0.0869)	(0.1008)	(0.0810)	(0.0528)	(0.0956)	(0.0509)
Employment growth rate	0.9153**	0.8581**	0.7657**	0.4270	0.4261	0.6621*	0.0335	0.0420	0.3932	0.0716	0.0720	0.5612
	(0.4264)	(0.4248)	(0.3648)	(0.4129)	(0.4340)	(0.3825)	(0.3719)	(0.4171)	(0.3692)	(0.7197)	(0.6139)	(0.6234)
Interest rates	-0.0125**	-0.0119**	-0.0103*	0.0024	0.0022	0.0039	0.0111**	0.0110**	0.0138***	0.0095**	0.0104**	0.0106***
	(0.0056)	(0.0054)	(0.0057)	(0.0039)	(0.0040)	(0.0036)	(0.0047)	(0.0047)	(0.0046)	(0.0039)	(0.0041)	(0.0030)
Observations	538	538	538	538	538	538	519	519	519	508	508	508
Number of countries	30	30	30	30	30	30	30	30	30	29	29	29
Number of instruments	14	15	17	14	15	17	14	15	17	14	15	17
AR2 p-value	0.462	0.453	0.442	0.406	0.362	0.404	0.330	0.313	0.318	0.356	0.396	0.364
Hansen p-value	0.0553	0.0596	0.173	0.854	0.733	0.330	0.953	0.391	0.863	0.923	0.708	0.629

Source: Oxford Economics

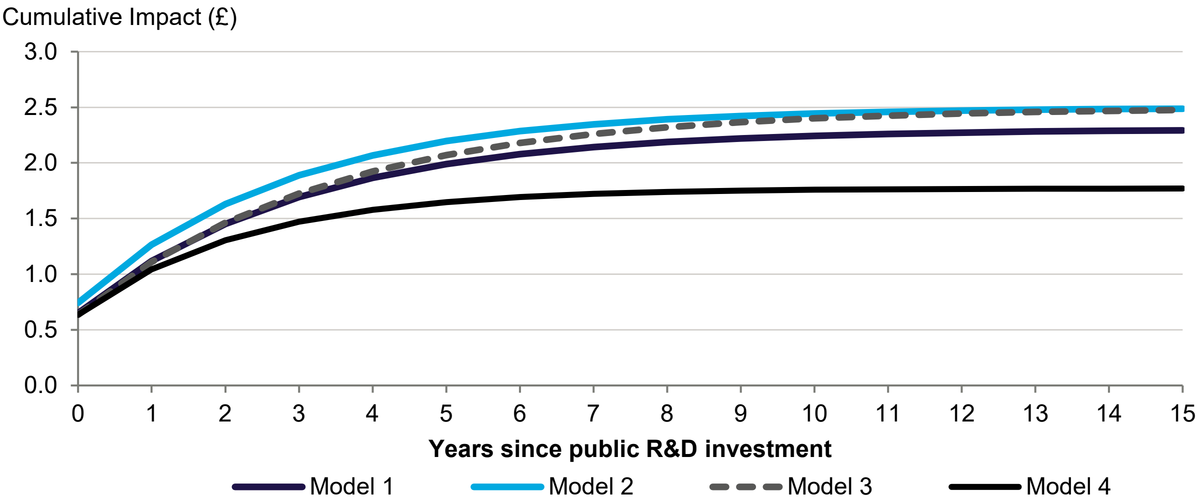
Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD, employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

4.3.6. Over what time period do results materialise?

The dynamic panel specification enables us to estimate the long-run impact of public R&D on private R&D. In addition, we are able to calculate the time period over which the full long-run impact materialises and the profile of the impact over that period. In our analysis, we define the long-run period as the period over which at least 99 percent of the total impact materialises. Figure 20, below, illustrates the time profile of the impact on private GERD from a £1 investment in public GERD for the four models detailed in Figure 18.

The short-run contemporaneous impact is given by the value at zero years since public R&D investment. In the years following the public R&D investment, the additional impact on private GERD decreases in each year until the additional impact is zero and the cumulative impact remains constant. Figure 20 illustrates that the full long-run impact materialises over a period of 10 to 15 years for the four models. Around 80 percent of the cumulative long-run impact in each model manifests in the first three years, and the remaining 20 percent takes a further seven to 12 years to materialise.

Figure 20: Time profile of the impact on private GERD from a £1 investment in public GERD based on the June 2018 dataset



Source: Oxford Economics

4.3.7. Extension to incorporate OECD data released in October 2018

The OECD released additional GERD data in October 2018, during the latter stages of our research. This update extended the availability of data to 41 countries from 1961 to 2017 with varying degrees of completeness. The new dataset includes a large number of additional data points (280) but did not include revisions to the dataset available in June 2018. Of the additional data points, only a third are from the last three decades (1990-2017). Most of the additional data are from the period before 1990. For the UK, there is new data for 14 years—all before 1980. See Appendix 6: OECD data comparison for a more detailed explanation of the differences in data coverage between the two releases.

We tested a number of model specifications based on the October dataset to explore whether the inclusion of additional data points affected our results. Our four preferred model specifications are presented in Figure 21. All models use employment growth and interest rates as control variables, as with the versions based on the June dataset, but use different lags as instruments.[23] Model 2 in Figure 21 uses the same specification as Model 1 but uses time dummies (by decade) as instruments to account for any correlation across countries. Model 3 also has the same specification as Model 1 but uses fewer lags as instruments. The coefficient on public R&D remains stable across the first three model specifications, suggesting the results are robust.

Model 4 is the same as Model 3 but is based on a sample where all values are expressed in USD instead of GBP, to enable comparison with the other countries in our study (the choice of currency has little impact on the results in this case).

In Model 2 in Figure 21 the lag private R&D term is treated as endogenous instead of pre-determined. We discuss the sensitivity of our results to treating the lag term as pre-determined instead of endogenous in Section 9.10.

[23] Using lags as instruments is not the same as using lags as explanatory variables. The explanatory variables are used to estimate a causal relationship whereas instruments help mitigate the risk that these causal relationships are biased. The causal relationship is *not* between the dependent variable and the instruments. Dynamic panel models allow us to use various lags of various explanatory variables as instruments. We used the ”xtabond2” command in Stata and tested various lags as instruments.

Figure 21: Results of panel data regression methods based on October 2018 OECD dataset

Dependent variable: Private GERD (log).
Monetary variables specified in GBP and deflated using GDP deflator.
See Figure 90 – Figure 103 in Appendix 8: Econometric modelling outputs and test results for other model specifications estimated

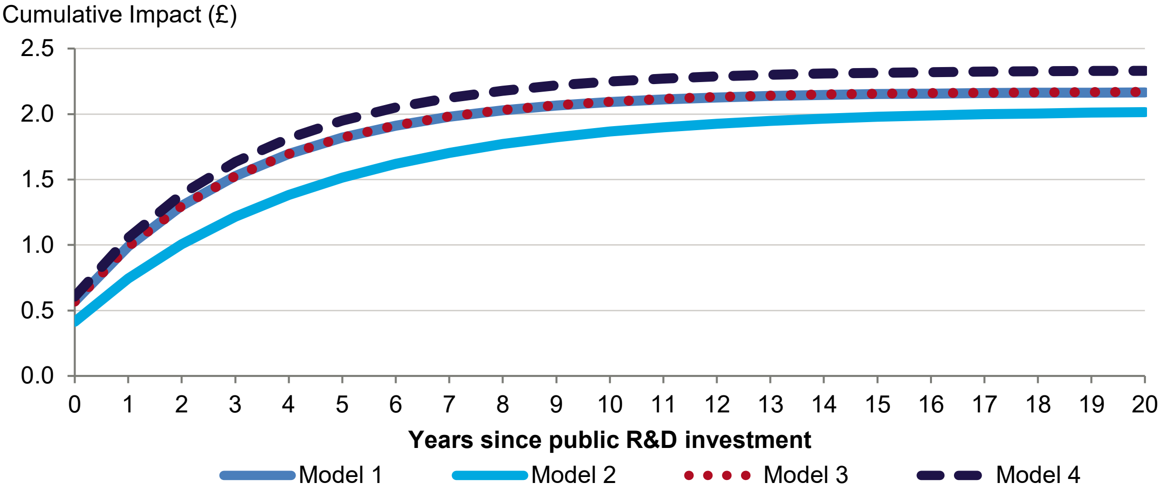
VARIABLES	Model 1	Model 2	Model 3	Model 4
Lag private GERD (log) – Lag of dependent variable	0.7375***	0.7962***	0.7385***	0.7402***
	(0.0303)	(0.0410)	(0.0305)	(0.0424)
Public GERD (log) – UNITED KINGDOM	0.3216***	0.2339***	0.3210***	0.3426***
	(0.0507)	(0.0589)	(0.0502)	(0.0282)
Public GERD (log) - OTHERS	0.3755***	0.2992***	0.3753***	0.3510***
	(0.0384)	(0.0308)	(0.0382)	(0.0384)
Employment growth rates	0.8381*	0.9068*	0.8581*	1.7056***
	(0.5007)	(0.5254)	(0.5123)	(0.4863)
Interest rates	-0.0061***	-0.0053**	-0.0061***	-0.0066***
	(0.0022)	(0.0022)	(0.0022)	(0.0024)
Constant	-0.6729	-0.5602*	-0.6796	-0.5849
	(0.4755)	(0.3080)	(0.4753)	(0.6169)
Observations	751	751	751	751
Number of countries	35	35	35	35
Number of instruments	21	22	13	13
AR2 p-value	0.907	0.632	0.909	0.655
Hansen p-value	0.747	0.0928	0.150	0.0776

Source: Oxford Economics

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD, employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

Fig. 22, below, illustrates the time profile of the impact on private GERD from a £1 investment in public GERD for the four models detailed in Fig. 21. The short-run contemporaneous impact is given by the value at zero years since public R&D investment. In the years following the public R&D investment, the additional impact on private GERD decreases in each year until the additional impact is zero and the cumulative impact remains constant. Fig. 22 illustrates that the full long-run impact materialises over a period of 13 to 16 years for the four models. Around 80 percent of the cumulative long-run impact in each model manifests in the first three years, and the remaining 20 percent takes a further 10 to 13 years to materialise.

Figure 22: Time profile of the impact on private GERD from a £1 investment in public GERD using the October 2018 dataset



Source: Oxford Economics

Fig. 23 compares the range of results from models based on the June 2018 dataset to those obtained using the October 2018 dataset.

Figure 23: Comparison of leverage rates

	June 2018 dataset	October 2018 dataset
Leverage rates (elasticities)		
Short run	0.26 to 0.38	0.23 to 0.34
Long run	1.01 to 1.06	1.15 to 1.32
Leverage rates (Monetary impact)		
Short run	£0.50 to £0.74	£0.41 to £0.61
Long run	£1.96 to £2.06	£2.03 to £2.34

Source: Oxford Economics
Note: The conversion from elasticities to monetary terms is made using the same ratio of private to public R&D to enable comparison across specifications. As discussed previously, choosing an alternate method to calculate the ratio of private to public R&D spending by using additional or fewer years or using the median instead of the mean may influence the uplift in monetary terms.

Extending the underlying dataset has not substantially influenced our findings in relation to the UK leverage rate. However, not all of these additional findings fall within the range estimated from the June dataset, suggesting that the results may have some degree of sensitivity to the period considered. At the same time, there are a number of gaps in the earlier years of the updated dataset, particularly for the UK, so we cannot be certain that incorporating the additional data points results in an unambiguous improvement in our findings.

We therefore propose to use the sensitivity test results to widen the range for our original estimates of the UK leverage rate to include the full range of findings obtained from our models based on both the June and October datasets.

4.3.8. Unit roots

The panel data approach that we have used is less susceptible to bias caused by unit roots than time series methods (as discussed in Section 3.3). However, it is still necessary to check whether the panel data approach adequately controls for any possible bias which could arise due to unit roots. We used the following approaches to check whether our findings are robust in the presence of unit roots.

- Non-stationary series in System GMM approaches can weaken the instruments making the leverage estimates inconsistent. In other words, the validity of the instruments depends on stationarity. In the System GMM setting, the assumption holds if the coefficient on the lag term is less than one. In the regressions in Figure 18 and Figure 21, the coefficient on the lag of private R&D is always less than one, indicating that this assumption of stationarity is valid.

- R&D spending in most countries grows over time as the economies grow, and therefore most countries will have a trending series. If the underlying trend is not accounted for (using a time trend variable), then the results are likely to be biased. However, in our datasets the likelihood of bias is less severe as the number of panels (i.e. countries) exceeds the number of time periods. Nevertheless, we tested our regressions by including a trend variable and found that the results are similar (see Figure 93 in Appendix 8).

To work around the issue of gaps and unbalanced datasets, we could restrict the sample such that the dataset is balanced and without gaps. However, specifications using the trimmed dataset do not pass our diagnostic tests. Therefore, our approach has been to favour sample size using the larger dataset and use other strategies to test for bias due to unit roots (e.g. checking whether the coefficient on the lag term is less than unity).

4.3.9. Final estimates

Bringing together our preferred results from the June and October datasets suggests that in the short run each £1 of public support is estimated to lead to £0.41 to £0.74 of private spending, and in the long run to £1.96 to £2.34.[24]

Figure 24: Preferred estimates of the UK leverage rate

	Leverage rate		**Impact of £1 of public support**	
	Short run	Long run	Short run	Long run
UK leverage rate	0.23 to 0.38	1.01 to 1.32	£0.41 to £0.74	£1.96 to £2.34

Source: Oxford Economics

[24] Models 1 to 3 in Fig. 18 do not include the constant term. While this is a restrictive assumption, we were not able to obtain satisfactory specifications using the June dataset when a constant was included. We have chosen to include the results from the models without a constant in our final estimates as they enable us to present the full uncertainty range based on both the June and October datasets.

COMPARISON OF RESULTS TO THOSE FROM PREVIOUS RESEARCH

As discussed in the literature review, a number of studies have been undertaken across a range of countries to estimate the relationship between public and private R&D based on macroeconomic approaches. Amongst those studies which are most directly comparable with our own, the estimated short run leverage rate varies between 0.07 and 0.58, as shown in Figure 25.

Figure 25: Leverage rates from previous macroeconomic studies

Research Paper	Short-run leverage rate	Long-run leverage rate	Short-run impact (£)	Long-run impact (£)
Economic Insight (2015)	0.29-0.58	0.67	0.70-1.40	1.61
Guellec and van Pottelsberghe (2003) (See note 1)	0.07	0.08	0.77	0.88
Diamond (1998)	n.a.	1.04	n.a.	2.51
Oxford Economics	0.23-0.38	1.01-1.32	0.41-0.74	1.96-2.34

Source: Various studies, Oxford Economics.

Notes: (1) Guellec and van Pottelsberghe (2001) estimate the elasticity with respect to the ratio of private R&D funded by businesses to private R&D funded by the government. The impact in GBP terms is calculated as the product of the elasticities with the ratio of private R&D investment funded by businesses to private R&D funded by the government.

From the previous research summarised in the table above, the Economic Insight study is the most directly comparable to our work due to its UK focus and analysis covering a similar time period. We have built on this work by adopting slightly different techniques which better account for endogeneity which may arise due to omitted variables and a failure to account for two-way causality between public and private R&D. It is therefore worth analysing the difference in findings between our work and the Economic Insight study in a little more detail (see Figure 26, overleaf).

The table shows the model coefficients corresponding to the headline results from the Economic Insight study. Only one of the models (model 3, on page 41 of their paper) includes a lagged private R&D term, which allows us to estimate the impact in the short run and the long run. The other models (model 3 on page 42, and models 2 and 3 on page 44) do not include a lagged private R&D term, and therefore the elasticity on the public R&D coefficient only corresponds to the short run impact (i.e. within the same year). We present the coefficients from the model with the lagged private R&D term (model 3 on page 42 of the Economic Insight study) in Figure 26. Figure 26 uses 2012 values of private and public GERD, as used in the Economic Insight (2015) study, with the corresponding coefficients from the models in Figure 25 to enable comparison with our findings.

Our short-run coefficients are similar to those obtained by Economic Insight, but our long-run coefficients suggest that the long-run impact is around 1.5 times higher than estimated in the earlier study.

We believe our coefficients present a more accurate picture as the model upon which the Economic Insight estimates are based may be susceptible to unit roots and endogeneity (due to omitted variables and a failure to account for two-way causality between public and private R&D), which would bias both the short-run and long-run coefficients.

With respect to the long run coefficients, none of the other models in the Economic Insight study corresponding to the headline results include a lagged private R&D term, which means that the comparison of long-run impact is based on a single model.

While the long-run impact in our model takes around one to six years longer to materialise than in the Economic Insight model, the length of time period does not materially impact the findings, since only an additional three pence of impact arises in the final five years of our estimates.

Figure 26: Comparison to Economic Insight research

	Economic Insight (Model with lag term)	**Oxford Economics leverage rates adapted for comparison with Economic Insight**
Coefficient on lagged private R&D	0.57	0.64 to 0.80
Short-run leverage rate	0.29	0.23 to 0.38
Long-run leverage rate	0.67	1.01 to 1.32
Private GERD (£m, 2012)	18,952	18,952
Public GERD (£m, 2012)	8,054	8,054
Short-run impact of a £1 increase in public R&D	0.68	0.55 to 0.89
Long-run impact of a £1 increase in public R&D	1.58	2.38 to 3.10

Source: Economic Insight (2015), Oxford Economics.

Note: Fig. 26 uses 2012 values of private and public GERD, as used in the Economic Insight (2015) study, with the corresponding coefficients from the models in Fig. 18 to enable direct comparison with our findings. Note that in the rest of our study, including Fig. 25, we have used the average values of private and public R&D across the sample period used in each regression. We have taken this approach to avoid our results being biased by recent changes in public or private R&D expenditure.

5. Does the leverage rate depend on the type of support?

The government supports R&D in various ways, most notably through its funding of universities and research councils, by providing direct support to businesses who undertake R&D, and through tax credits, which provide indirect support to businesses engaged in R&D. The government must decide how much funding to allocate through each of these mechanisms and an important factor in making this decision is the extent to which leverage rates may vary across different types of support.

This section of the study investigates leverage rates across the three main types of support identified above.

5.1. Recent trends in public funding and direct support

5.1.1. Public funding of universities and research councils

The first part of this question considers the impact of publicly funded R&D conducted by universities and research councils on total private sector R&D. This is illustrated in Figure 27, below.

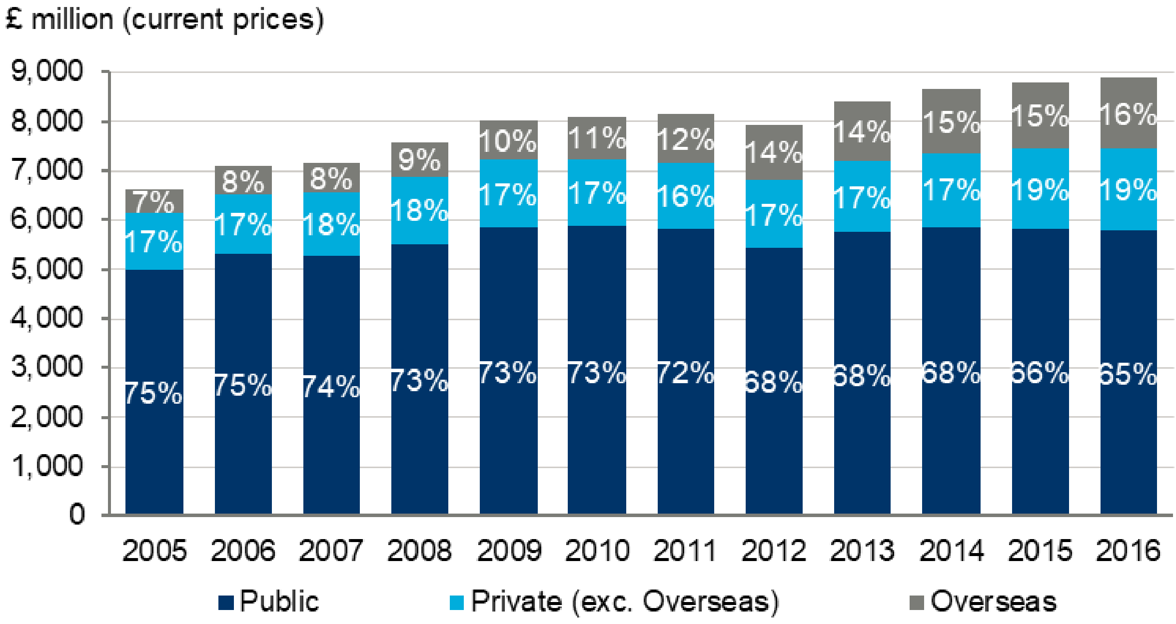
Figure 27: Analysis of the impact of publicly funded R&D in universities and research councils on all private R&D

<table>
<tr><th>Performed by
Funded by</th><th>Government</th><th>Research councils</th><th>Higher education</th><th>Business</th><th>Private non-profit</th></tr>
<tr><td>Government</td><td rowspan="4"></td><td colspan="2" rowspan="4">Publicly funded R&D in universities and research institutions</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Research councils</td></tr>
<tr><td>Higher education funding councils (HEFC)</td></tr>
<tr><td>Higher education</td></tr>
<tr><td></td><td colspan="5"></td></tr>
<tr><td>Business</td><td colspan="5" rowspan="3">Private sector R&D</td></tr>
<tr><td>Private non-profit</td></tr>
<tr><td>Overseas</td></tr>
</table>

Source: ONS GERD

The public sector funded 65 percent of R&D performed by universities and research councils in 2016 (Figure 28), amounting to £5.8 billion. However, the share of university and research council funding provided by private sources has been increasing over time: in 2005, the private sector proportion of higher education and research council R&D funding stood at 25 percent, but has since increased to 35 percent in response to an acceleration in the funding provided by foreign businesses for R&D conducted by UK universities.

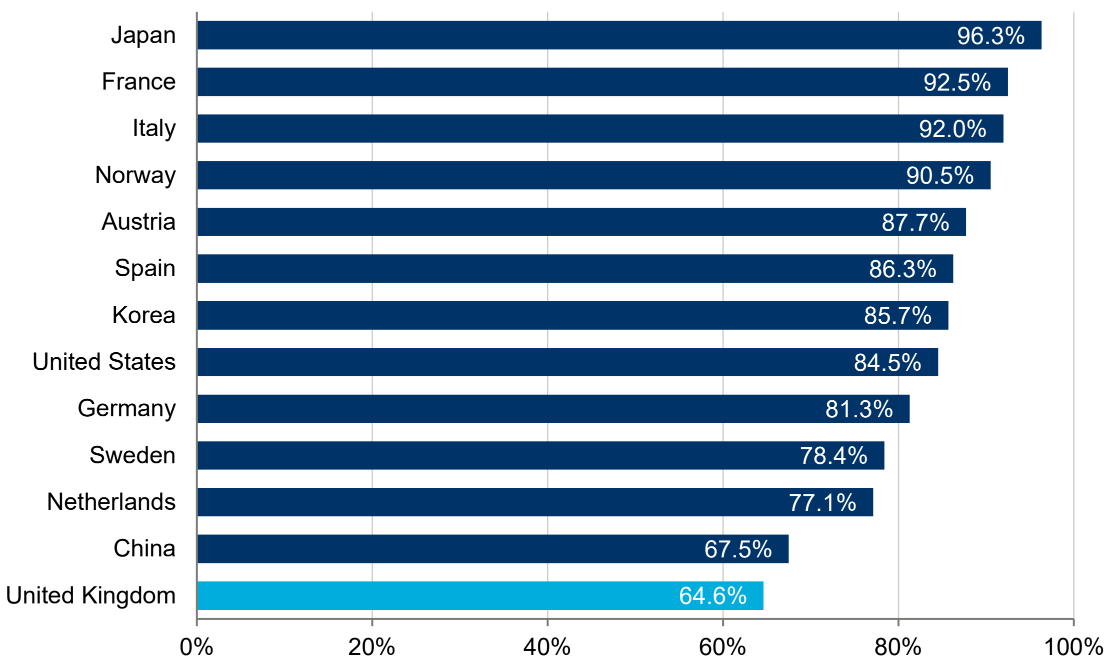
Figure 28: R&D in universities and research councils, by source of funding



Source: ONS

Relative to its global peers, a much larger proportion of the R&D undertaken in UK higher education institutions is privately funded. In Japan, France, Italy and Norway the proportion of university R&D that is funded by the public sector is greater than 90 percent (Figure 29). Other European countries publicly fund more than three quarters of R&D conducted by universities.

Figure 29: Proportion of higher education R&D funded by the public sector 2015



Source: OECD

5.1.2. Direct support for R&D in businesses

In this section of the report we also consider the leverage rate generated by direct government support to businesses. This is illustrated in Figure 30, below.

Figure 30: Analysis of the impact of direct government support to businesses on all private R&D

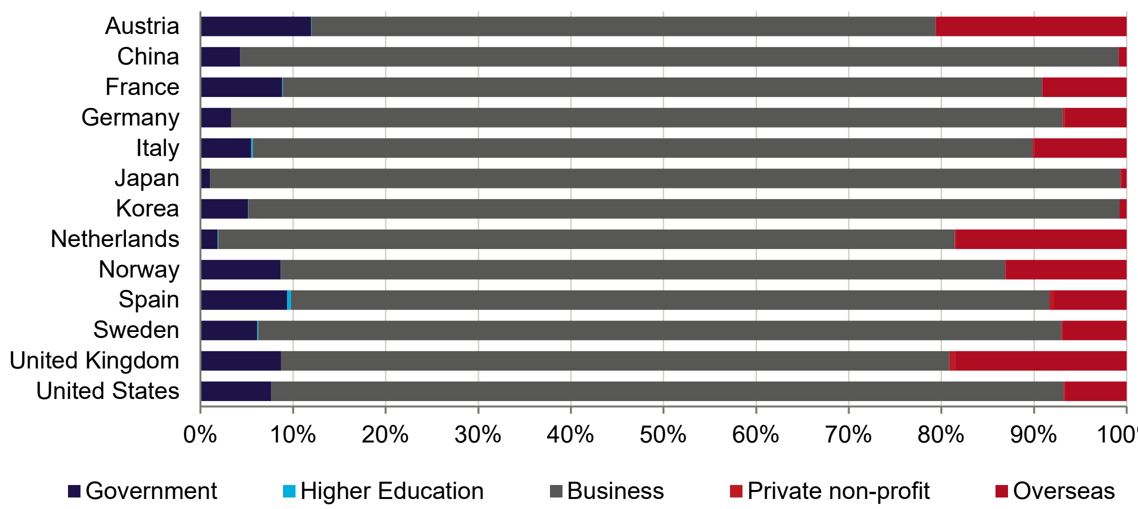
<table>
<tr><th>Performed by
Funded by</th><th>Government</th><th>Research councils</th><th>Higher education</th><th>Business</th><th>Private non-profit</th></tr>
<tr><td>Government</td><td rowspan="4" colspan="3"></td><td rowspan="4">Publicly funded R&D in business</td><td rowspan="4"></td></tr>
<tr><td>Research councils</td></tr>
<tr><td>Higher education funding councils (HEFC)</td></tr>
<tr><td>Higher education</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Business</td><td rowspan="3" colspan="5">Private sector R&D</td></tr>
<tr><td>Private non-profit</td></tr>
<tr><td>Overseas</td></tr>
</table>

Source: Oxford Economics

In 2016, eight percent of R&D performed by UK businesses was funded by the public sector, totalling £1.7 billion. In contrast, self-funded business R&D totalled £16.7 billion, with a further £3.6 billion funded by foreign businesses.

The proportion of publicly funded support for R&D in business in the UK is high relative to many of its global peers. According to the OECD, in 2015, 8.7 percent of R&D performed by UK business was funded by the public sector, a larger share than in countries such as the United States, South Korea and Germany (Figure 31). In Western Europe, the share of business R&D funded by the government is highest in Austria, where it accounts for 12 percent of the total.

Figure 31: Proportion of business R&D by source of funding (2015)



Source: OECD

In the next section we investigate the leverage rate achieved through this direct public support of R&D in higher education and businesses.

5.2. Modelling approach

The model specifications presented in section 5.3 have been developed to determine whether the type of public investment in R&D affects the leverage rate. Specifically, the models are designed to establish whether the OECD average historic leverage rate for public funding of universities and research councils is different to that for direct public support for R&D in business.

We have explored the leverage rate associated with both types of direct public funding using data on R&D investment by source of funding and sector of performance from the OECD.

Before starting the modelling, we calculated the correlation between publicly funded R&D in higher education and research councils and publicly funded R&D in business. In current US dollars, the correlation between these two series is 0.73 across all countries included in our regression (see Figure 32). Using highly correlated variables in the model could "confound" the leverage estimates. That is, the model may attribute the causal effect of one type of public investment to the other, leading to biased leverage estimates. In addition, including both in the same regression could lead to large standard errors such that the variables are not individually significant.

On the other hand, omitting one type of public R&D investment to estimate the leverage rate corresponding to the other may lead to omitted variable bias. Omitted variables have the same effect as two-way causality, i.e. they lead to endogeneity in the model. However, within the System GMM approach we can mitigate the impact of omitted variables using lags of the different types of public funding as instrumental variables. In other words, we used past values of public R&D funding as instruments to control for the exclusion of present values of other sources of R&D funding.

To test whether collinearity is likely to be of concern, we estimated versions of our regressions which included both variables in the same regression, and other versions which included only one of the variables. We found the coefficients from the different models to be similar and also statistically significant where both variables are included in the model. This indicates that the collinearity is not large enough to bias the coefficients estimated from the model.

Figure 32: Correlation analysis of key variables in the analysis

Variable	Private GERD	Public HERD	Public BERD	Other public R&D	Interest rate	Employment (000s)	Employment growth	GDP	GDP growth
Private GERD	1.00	0.98	0.76	0.96	-0.07	0.95	0.01	0.89	0.01
Public HERD	0.98	1.00	0.73	0.94	-0.08	0.95	0.00	0.87	0.01
Public BERD	0.76	0.73	1.00	0.90	0.11	0.82	0.05	0.87	0.02
Other public R&D	0.96	0.94	0.90	1.00	0.01	0.95	0.02	0.95	0.01
Interest rate	-0.07	-0.08	0.11	0.01	1.00	-0.02	-0.07	0.04	0.05
Employment	0.95	0.95	0.82	0.95	-0.02	1.00	0.02	0.88	0.00
Employment growth	0.01	0.00	0.05	0.02	-0.07	0.02	1.00	0.04	0.39
GDP	0.89	0.87	0.87	0.95	0.04	0.88	0.04	1.00	0.01
GDP growth	0.01	0.01	0.02	0.01	0.05	0.00	0.39	0.01	1.00

Source: Oxford Economics analysis of OECD data available as of June 2018

As with our estimates of the overall leverage rate, a Wooldridge test suggested that a dynamic panel specification was preferable to a static one.

From our earlier analysis we had identified that the most satisfactory model specification for estimating leverage rates used employment growth and interest rates as control variables. For consistency with that analysis we took a similar specification as the starting point for this part of the analysis. Nonetheless, we also tested more than 20 other model specifications to verify that it was not possible to improve upon our preferred specification. Instrumental variables were also used to account for potential endogeneity.

In the following regressions, the values of public and private R&D expenditures for different countries are converted in US Dollars using market exchange rates and using CPI to account for inflation. As explained in the previous chapter, the OECD data include private R&D funded through tax credits.

5.3. Results for direct support to higher education and businesses

5.3.1. Results based on June 2018 OECD panel datasets

The results from the most promising model specifications are presented in Figure 33, below. Our preferred models are models 1, 2 and 4 because they pass the relevant diagnostic tests, and the coefficients on the control variables are significant and are of plausible magnitudes. In each of these models, the AR(2) test for autocorrelation and the Hansen test for overidentifying restrictions are satisfied indicating that the models are robust to serial correlation and that the instruments used are suitable for our analysis. The coefficients on employment growth have the expected sign and are statistically significant at the one percent level. The coefficient on interest rates is significant at the 10 percent level in all three models.

Other specifications were tested but either did not satisfy these criteria or, where they did, the sample size was significantly reduced due to availability of data for certain control variables. The other models shown in the table help inform the range and check the sensitivity of our results to changes in control variables. However, in these models, key control variables are not significant (e.g. interest rates in model 3 and model 6). Models 5 and 6 present the results when only one of the two types of public funding is included.

Figure 33: Results of panel data regressions methods
Dependent variable: Private GERD (log).
Monetary variables specified in USD and deflated using CPI.
See Figure 105 – Figure 108 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Lag private GERD (log) - lag of dependent variable	0.7448***	0.7418***	0.7739***	0.7651***	0.8334***	0.8643***
	(0.0737)	(0.0756)	(0.0660)	(0.0723)	(0.0584)	(0.0674)
Employment growth rate	1.4795***	1.5244***	1.5879***	1.6413***	1.1907**	2.1984***
	(0.5419)	(0.5298)	(0.4805)	(0.4176)	(0.6054)	(0.3413)
Interest rates	-0.0121*	-0.0113*	-0.0101	-0.0095*	-0.0155*	0.0020
	(0.0072)	(0.0068)	(0.0065)	(0.0057)	(0.0081)	(0.0020)
Public GERD (log) – Universities and research councils	0.1406**	0.1525**	0.1139**	0.1293**		0.1474**
	(0.0586)	(0.0597)	(0.0490)	(0.0547)		(0.0750)
Public GERD (log) – Direct support to business	0.0962**	0.0894**	0.0944**	0.0962**	0.1046**	
	(0.0417)	(0.0351)	(0.0388)	(0.0382)	(0.0440)	
Herfindahl-Hirschman Index[25]			0.2452***	0.2458***		
			(0.0681)	(0.0712)		
Constant	0.6717**	0.6449**	0.5958**	0.5639**	0.9328**	0.0791
	(0.3137)	(0.3042)	(0.2584)	(0.2520)	(0.3709)	(0.0613)
Observations	499	499	499	499	499	499
Number of countries	28	28	28	28	28	28
Number of instruments	17	18	24	25	15	17
AR2 p-value (See note 2)	0.729	0.721	0.718	0.693	0.868	0.711
Hansen p-value (See note 3)	0.166	0.218	0.230	0.269	0.165	0.154

Source: Oxford Economics

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD (universities and research councils), Public BERD (Direct support to businesses) and employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

The central leverage rate estimates, based on models 1, 2 and 4 in Figure 33, are summarised in Figure 34 below.

Figure 34: Leverage rates for direct support

	Leverage rate (OECD average)		**Impact of £1 of public support for the UK**[26]	
	Short run	Long run	Short run	Long run
Direct support to universities and research councils	0.13 to 0.15	0.55 to 0.59	£0.54 to £0.64	£2.29 to £2.46
Direct support to businesses	0.09 to 0.10	0. 35 to 0.41	£0.79 to £0.85	£3.07 to £3.63

Source: Oxford Economics

These models (models 1, 2 and 4 in Figure 33) suggest that the leverage rate is between 0.1293 and 0.1525 for public funding of R&D in universities and research institutions in the short run. Interpreting these coefficients for the UK, we can say that £1 of public R&D funding allocated to universities and research institutions is associated with £0.54-£0.64 in private R&D expenditure in the short term. In the long run, we find that a £1 increase in public R&D investment allocated to universities and research institutions in the UK in one year leads to £2.29 to £2.46 in private R&D investment in the long term.

Using the same specifications, we found a leverage rate of between 0.0894 and 0.0962 for direct support to businesses in the short run. This suggests that £1 of public expenditure to support business R&D is associated with an average of £0.79-£0.85 in private R&D expenditure in the short term. In the long run, £1 of public investment to support business R&D in the UK in one year leads to £3.07 to £3.63 in private R&D investment in the long term.

This suggests that the central estimates for leverage rates are higher for direct support to universities and research institutions. However, the UK provides considerably more support to universities and research councils than to businesses. As such, a £1 increase in public support to businesses represents a proportionately greater uplift than a £1 increase in support to universities and research councils. For this reason we find that £1 of direct support to businesses has a greater impact in monetary terms than £1 of direct support to universities.

However, it is important to note that the 95 percent confidence intervals for the leverage rates (based on models 1, 2 and 4 in Figure 33) for the two types of public support overlap, and therefore, we cannot reliably conclude that one kind of public funding has more of an impact than the other.

We introduced interaction terms into the model used for this part of the study to test whether there is a statistically significant difference between the UK and OECD average leverage rates. No such difference was found, suggesting that leverage

[25] A measure of market concentration, calculated as the sum of squared market shares of all firms in the market. A large value indicates the market is dominated by a few large firms.
[26] While the models are estimated for the OECD, our interest here is on the UK leverage rate for each type of support. The impact of £1 of spending is therefore calculated based on the UK ratio of public and private R&D expenditure.

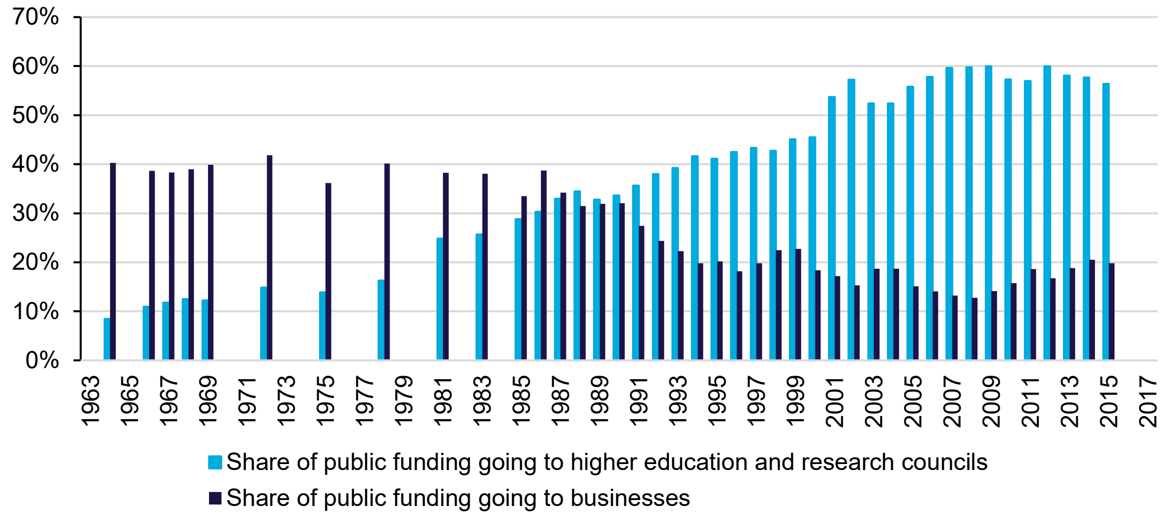
rates for direct support to universities and to businesses in the UK are similar to the respective OECD averages.

5.3.2. Extension to incorporate OECD data released in October 2018

The OECD released additional GERD data October 2018, during the latter stages of our research. This extended the availability of data to cover the period from 1961 to 2017, with varying degrees of completeness. The new dataset includes a large number of additional data points which were not in the June dataset, (165) but does not revise the existing data. However, there are only five additional observations in the dataset for the post-1980 years, suggesting that the main change relates to the incorporation of information for earlier years than were available previously (see Appendix 6: OECD data comparison for more details of the data coverage in the two releases of OECD data).

Figure 35 below shows the share of each type of public support within overall public GERD. This reveals that the share of government R&D support going to higher education and research councils was much lower before 1981. Conversely, direct support to businesses was a much higher share of public support than it is today. Further, data for the UK are only available for every other year, at most, in the 1960s and 1970s. Due to the gaps in the data and the differences and the changing pattern of support, it is not clear whether reliable results can be obtained from including the entire dataset from 1960.

Figure 35: Ratio of public funding to private R&D funding to public R&D funding by type of funding



Source: OECD (October 2018 dataset)

As such, we have tested the effect of including the October 2018 dataset in two ways. Model 1 in the table below includes the entire dataset, whereas Models 2 and 3 only include the additional data points for the post-1980 years.

The results are presented in Figure 36. The model specifications include variables for public funding to universities, public funding to businesses, as well as employment growth and interest rates as control variables. The coefficients on employment growth have the expected sign and are statistically significant at least at the 10 percent level. The coefficient on interest rates is significant at least at the 10 percent level in Models 2 and 3. In each of these models, the AR(2) test for autocorrelation and the Hansen test for overidentifying restrictions are satisfied indicating that the models are robust to serial correlation and that the instruments used are suitable for our analysis.

Figure 36: Results of panel data regressions methods
Dependent variable: Private GERD (log).
Monetary variables specified in USD and deflated using CPI.
See Figure 105 – Figure 108 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	**Model 1**	**Model 2**	**Model 3**
Lag private GERD (log) - lag of dependent variable	0.5479***	0.5393***	0.7162***
	(0.0884)	(0.0884)	(0.0822)
Employment growth rate	1.9431***	1.0337*	1.1975**
	(0.3756)	(0.5966)	(0.5039)
Interest rates	-0.0026	-0.0146*	-0.0136*
	(0.0040)	(0.0081)	(0.0074)
Public GERD (log) – Universities and research councils	0.4376***	0.3163***	0.1494**
	(0.0866)	(0.0709)	(0.0592)
Public GERD (log) – Direct support to business	0.1129	0.1155**	0.1098**
	(0.0780)	(0.0558)	(0.0484)
Constant	-0.0229	1.0311***	0.7830***
	(0.2513)	(0.2830)	(0.2280)
Observations	691	504	504
Number of countries	32	29	29
Number of instruments	14	18	20
AR2 p-value (See note 2)	0.642	0.647	0.662
Hansen p-value (See note 3)	0.642	0.632	0.276

Source: Oxford Economics

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD (universities and research councils), Public BERD (Direct support to businesses) and employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

The models based on the June 2018 dataset suggest that £1 of direct support to businesses has a greater impact in monetary terms than £1 of direct support to universities. However, as we noted above, the overlapping confidence intervals for these findings imply that this conclusion is subject to a high degree of uncertainty.

This view is reinforced by our findings based on the October 2018 dataset, under which certain specifications suggest the opposite may be true. That is, that leverage rates per £1 of investment could be higher for direct support to universities and research institutions (see second and third columns of results in Figure 37).

Figure 37: Comparison of leverage rates

	Sample covered	June 2018 (Preferred specifications in Figure 33)	Full October 2018 dataset (Model 1 in Figure 36)	October 2018 dataset using data from 1980 (Model 2 in Figure 36)	October 2018 dataset using data from 1980 (Model 3 in Figure 36)
Leverage rates (elasticities)	Short run				
	Universities and research councils	0.13 to 0.15	0.44	0.32	0.15
	Direct support to business	0.09 to 0.10	0.11	0.12	0.11
	Long run				
	Universities and research councils	0.55 to 0.59	0.97	0.69	0.53
	Direct support to business	0.35 to 0.41	0.25	0.25	0.39
Leverage rates (monetary impact)	Short run				
	Universities and research councils	£0.54 to £0.64	£1.84	£1.33	£0.63
	Direct support to business	£0.79 to £0.85	£0.97	£1.00	£0.95
	Long run				
	Universities and research councils	£2.29 to £2.46	£4.07	£2.88	£2.21
	Direct support to business	£3.07 to £3.63	£2.16	£2.16	£3.34

Source: Oxford Economics

Note: The conversion from elasticities to monetary terms is made using the same ratio of private to public R&D to enable comparison across specifications. As discussed previously, choosing an alternate method to calculate the ratio of private to public R&D spending by using additional or fewer years or using the median instead of the mean may influence the uplift in monetary terms.

In our view, the findings which include the full history of the new dataset should be treated with caution, as there are many missing values in the period before 1980 and the UK R&D funding landscape was significantly different in that period. Nonetheless, models 2 and 3 in Figure 36, provide opposite conclusions concerning the impact of each £1 invested in higher education or direct support.

As such, we believe these two sets of updated results should be used to expand the range of the estimates for the leverage delivered by each type of support.

5.3.3. Final estimates

Expanding our uncertainty range to incorporate the findings from the preferred specifications in the models based on both the June 2018 and October 2018 datasets widens the range of long-run impacts per £1 of spending to £2.29 to £2.88 for higher education and £2.16 to £3.63 for direct support to business. This means that the range of estimates for each type of support overlaps, reinforcing our conclusion that we cannot reliably determine which type of support is likely to leverage a greater amount of private R&D expenditure.

Figure 38: Preferred estimates of the leverage rates for support to universities and research councils and direct support to businesses

	Leverage rate		**Impact of £1 of public support**	
	Short run	Long run	Short run	Long run
Direct support to universities and research councils	0.13 to 0.32	0.53 to 0.69	£0.54 to £1.33	£2.21 to £2.88
Direct support to businesses	0.09 to 0.12	0.25 to 0.41	£0.79 to £1.00	£2.16 to £3.63

Source: Oxford Economics

5.4. Public funding of other types of R&D

The analysis above estimated leverage rates for support to the higher education and business sectors. We would expect the overall UK leverage rate to be an average of these findings, plus the equivalent finding for government funded R&D undertaken by government and private non-profit organisations (see Figure 39).

Figure 39: Analysis of the impact of different forms of public R&D on all private R&D

<table>
<tr><th>Performed by
Funded by</th><th>Government</th><th>Research councils</th><th>Higher education</th><th>Business</th><th>Private non-profit</th></tr>
<tr><td>Government</td><td rowspan="4">Publicly funded R&D in government and private non-profit</td><td colspan="2" rowspan="4">Publicly funded R&D in government and private non-profit</td><td rowspan="4">Publicly funded R&D in government and private non-profit</td><td rowspan="4">Publicly funded R&D in government and private non-profit</td></tr>
<tr><td>Research councils</td></tr>
<tr><td>Higher education funding councils (HEFC)</td></tr>
<tr><td>Higher education</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>Business</td><td colspan="5" rowspan="3">Private sector R&D</td></tr>
<tr><td>Private non-profit</td></tr>
<tr><td>Overseas</td></tr>
</table>

Source: Oxford Economics

We have undertaken two types of analysis to check whether this is the case. Firstly, we adopted a “weighted-means” approach using the leverage rates from the analysis above. Secondly, we undertook further econometric modelling using similar models to those deployed above to test whether the results implied by the weighted-means estimation are plausible.

5.4.1. Weighted-means analysis

In our preferred specification for estimating the UK leverage rate, the impact on private R&D for each £1 spent on public R&D is between £0.41 and £0.74 in the short run and between £1.96 and £2.34 in the long run. Using the range of results from Figure 37, the impact of public funding to universities and research councils is £2.21 to £2.88 in the long run, while the impact of direct public funding to businesses is £2.16 to £3.63 in the long run (see Figure 37 above).

Assuming that the leverage rate for all types of public funding is a weighted average of that for individual types of public funding and using the mean of the estimates from the preferred models (i.e. the models in Figure 18, Figure 21, Figure 33 and Figure 36), the implied leverage rate for other kinds of public funding is (-) £0.39 in the short run and (-) £0.18 in the long run.

Figure 40: Implied impact from a £1 injection of different types of public R&D, using weighted-means analysis

	UK Expenditure (2016, constant prices), GBP mn	Short-run impact (£)	Long-run impact (£)
Total public R&D expenditure	9,150	0.57	2.10
R&D support to universities and research institutions	5,804	0.74	2.43
Direct R&D support to businesses	1,735	0.89	3.11
Other public R&D expenditure	1,611	**-0.39**	**-0.18**

Source: Oxford Economics

The results for the “other public R&D expenditure” category under this approach appear to indicate some crowding out in the short run which reduces in the long run.

The fact that the findings from this approach are not of a similar magnitude to the leverage rates estimated for the other types of leverage means that they are open to challenge. At the same time, the nature of the data for other types of public R&D expenditure is such that it is hard to develop a robust model specification for this category on its own (see Section 5.4.2, below), preventing us from testing whether the implied short-run and long-run findings are correct, or an anomaly caused by the nature of the underlying data.

5.4.2. Econometric analysis

We re-ran models 1 and 2 from Figure 33, but this time included other types of public funding as an additional variable. Public R&D spending on universities and research councils and direct support to businesses are highly correlated with other kinds of public R&D funding, with correlation coefficients of more than 0.90. As discussed above, including highly correlated variables in the same equation is likely to lead to confounding, where the coefficients vary significantly and are not statistically significant.

As shown in Figure 41 overleaf, the coefficients on other types of public funding are not significant, indicating that collinearity is likely to be of concern. It is difficult to draw conclusions about the impact of other kinds of public funding based on this analysis and more detailed interrogation of the underlying micro data may be required to better understand the factors at work for this category of R&D support.

Figure 41: Results of panel data regressions methods
Dependent variable: Private GERD (log).
Monetary variables specified in USD and deflated using CPI.

Variables	**Model 1**	**Model 2**
Lag private GERD (log) - lag of dependent variable	0.7216***	0.5567***
	(0.0706)	(0.0750)
Employment growth rate	1.3978**	1.2948**
	(0.5768)	(0.6414)
Interest rates	-0.0148	-0.0162
	(0.0090)	(0.0100)
Public GERD (log) – Universities and research councils	0.1278*	0.3348***
	(0.0687)	(0.0883)
Public GERD (log) – Direct support	0.1085***	0.1282***
	(0.0414)	(0.0468)
Public GERD (log) – other	0.0380	-0.0318
	(0.0515)	(0.0783)
Constant	0.6438**	0.8959***
	(0.2876)	(0.3074)
Observations	499	499
Number of countries	28	28
Number of instruments	20	22
Hansen p-value (See note 3)	0.243	0.553

Source: Oxford Economics

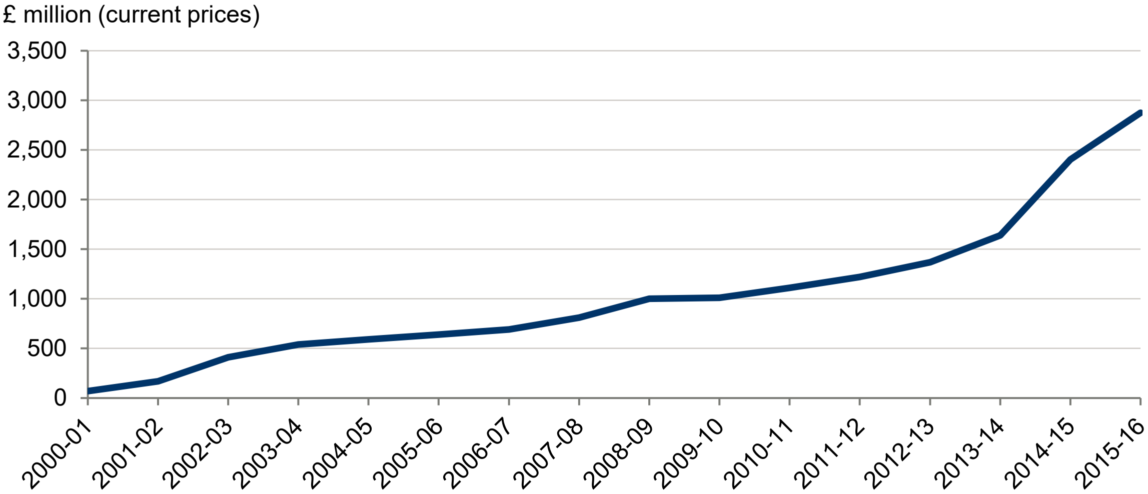
Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. A high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private GERD, Public GERD (universities and research councils), Public BERD (Direct support to businesses), Public (Other) and employment are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

5.5. Indirect support for R&D in businesses

5.5.1. Recent trends

Tax credits represent a form of indirect support to businesses engaging in R&D. In the 2015-16 financial year, the total value of tax credits claimed by UK businesses was £2.9 billion. There has been a noticeable acceleration in the uptake of tax credits in recent years: the value has increased by more than 75 percent since 2013-14 (Figure 42). This trend coincides with the introduction of The Research and Development Expenditure Credits (RDEC) scheme for large companies in 2013.

Figure 42: Tax credits claimed by UK businesses for R&D investments, 2000-01 to 2015-16



Source: HMRC

HMRC R&D TAX CREDITS DATA

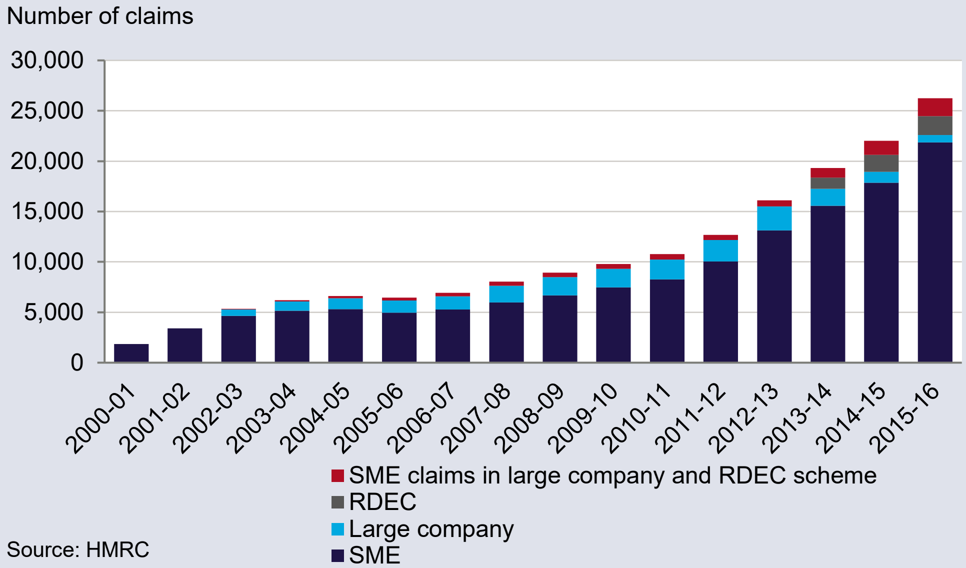
HMRC publishes data on R&D tax credits claimed by UK businesses since the introduction of R&D tax credit schemes in 2000. The data identifies the value of R&D tax credits split by the region and industrial sector that the business operates in and is available on an annual basis from the tax year 2000-01 to 2015-16.

R&D tax credits are a tax relief scheme designed to encourage greater R&D spending by reducing a company's corporation tax bill by an amount equal to a percentage of the company's allowable R&D expenditure or by making a payment to the company. The UK government introduced its first R&D tax credit scheme, the Small or Medium-sized Enterprise (SME) scheme, in 2000, which was followed by another scheme, the Large Company Scheme, introduced in 2002. Under these schemes, SMEs were able to claim a higher rate of relief and, unlike larger companies, were able to claim a cash payment if they had no tax bill to reduce.

In April 2013 the Research and Development Expenditure Credits (RDEC) scheme (also known as "above-the-line") was introduced for large companies. Eligible companies could choose between the new RDEC scheme and Large Company Scheme from April 2013 to April 2016, after which the Large Company Scheme was no longer available.

Figure 43 below shows the number of claims received for R&D tax credits by scheme. In the financial year 2015-16, more than 26,000 claims for R&D tax credits were made. There has been a recent acceleration in the number of claims made by SMEs which is likely to reflect recent changes to the SME scheme which have made the scheme more attractive. For example, from April 2012, the £10,000 minimum R&D expenditure requirement was removed meaning that more companies were eligible for tax relief. Additionally, there was an increase in the SME payable tax credit rate from 11 percent in 2012-13 to 14.5 percent in 2014-15.

Figure 43: Number of R&D tax credit claims received by scheme

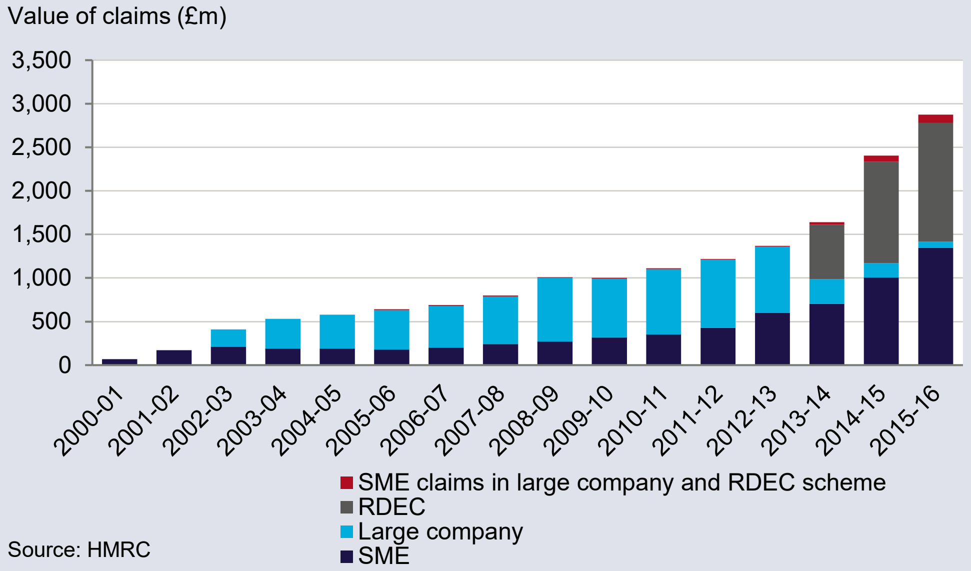


Source: HMRC

Viewed according to the value of claims, it is large companies that receive the greatest proportion of support (Figure 44). This is because larger companies typically claim a much larger amount than SMEs. The value of all R&D tax relief provided in 2015-16 was almost £2.9m. £1.4m of which was claimed through the RDEC scheme, a further £1.3m through the SME scheme and the remainder through the Large Company scheme and SMEs making claims through the Large Company or RDEC schemes.

The growth in the cost of R&D tax relief reflects both the increase in number of claims, illustrated in Figure 43 above and also the greater degree of support provided to each claimant. For large companies, there has been an acceleration in the value of tax relief claimed since the introduction of the RDEC scheme in 2013-14 which has a higher rate of support compared to the Large Company scheme.

Figure 44: Value of R&D tax credits claimed by scheme



Source: HMRC

5.5.2. HMRC time series data approach to estimating the leverage rate from tax credits

We explored a range of models to establish a best estimate of the leverage rate for R&D tax credits in the UK.

Our first approach was based on analysis of time series data from the ONS and HMRC. We sourced data for the value of tax credits claimed for the period from 2000-01 to 2015-16, with no industry or regional breakdown. Prior to this, there was no R&D tax credits scheme in place and therefore the value of tax credit support was zero.

The correlation analysis for this dataset is presented in Figure 45. This informed our model specification, and for consistency we included those control variables which gave us the best model specifications elsewhere in the study (although we did also test other control variables to see whether we could obtain preferable specifications).

The correlation matrix identifies a strong negative correlation between workforce jobs and interest rates which could potentially lead to multicollinearity, and so we tested these variables separately in the model.

Figure 45: Correlation analysis of key variables in the analysis

Variable	Private GERD	Tax Credits	Interest rate	Workforce jobs
Private GERD	1.00	-0.36	-0.43	0.47
Tax credits	-0.36	1.00	-0.85	0.93
Interest rate	-0.43	-0.85	1.00	-0.90
Workforce jobs	0.47	0.93	-0.90	1.00

Source: Oxford Economics

Similar to our approach for the UK leverage rate, we started by determining the most appropriate type of model specification given the nature of the data. The time series for tax credits and private R&D were both found to suffer from unit roots, which could lead to spurious regression results (as suggested by the Augumented Dickey Fuller, the Zivot Andrews and the Clement Reyes Montanes tests). We therefore chose to specify our model in the first difference of the logs (i.e. we used growth rates instead of levels).

Various modelling specifications and combinations of control variables were tested but we were unable to establish a robust statistically significant relationship. This included testing different lag structures, although since businesses are likely to claim tax credits at the end of the financial year in which they invested in R&D, there is less reason to believe higher order lags would be appropriate in this case. The most likely explanation for why we were unable to establish a robust relationship is the limited sample size: we had only 21 years of data to work with (which effectively reduces to 20 since the model uses the change in the variables instead of their levels).

This short time series limits our ability to add a large number of control variables (including lags) because the degrees of freedom would become very low. This makes it difficult to robustly determine which are the key factors associated with private R&D. We present the results from various specifications in Figure 123 – Figure 125 in Appendix 8: Econometric modelling outputs and test results.

5.5.3. HMRC regional panel data

We have also attempted to we estimate the average relationship between regional private GERD and regional R&D tax credits across UK regions over the period 2013-14 to 2015-16 (i.e. the analysis is based on a panel dataset). Using panel data techniques provides a larger number of data points, albeit with a relatively short time series.

We therefore ran both static and dynamic models with instrumental variables to estimate the leverage rate. The results are shown in Fig. 68 of Appendix 3: Leverage rates for indirect support (tax credits). Once again, we found that the small dataset limited the degrees of freedom, and therefore our ability to add a large number of control variables (including lags). Additionally, due to the regional nature of the tax credits data any control variables needed to have a regional dimension, which greatly reduced the number of variables which could be tested.

As such, we did not obtain statistically significant results for the impact of tax credits using either type of model.

5.5.4. OECD cross sectional data

Our third approach to estimating the leverage rate from indirect support was to use data from the OECD, which indicated the value of tax credit support provided as a proportion of GDP. The June 2018 OECD dataset on tax incentives provided a single year of information, limiting us to a cross-section approach. The limited nature of the dataset once again limited our ability to add a large number of control variables (including lags) and we were unable to find a working specification using cross-section data. The unsuccessful regression results are presented in Figure 71 in Appendix 3: Leverage rates for indirect support (tax credits).

5.5.5. OECD panel data

We undertook a final set of testing using updated tax credits data released by the OECD in October 2018. This added a time series dimension, giving us a panel dataset covering 31 countries (a total of around 281 observations). The number of years per country varies from more than 15 (Belgium, Japan, UK, US) to two (Finland). The number of data points appeared sufficient to attempt dynamic panel modelling techniques. However, we were still unable to obtain significant results.

Figure 127 in Appendix 8: Econometric modelling outputs and test results provides a sample of the regression outputs using an adjusted private R&D series (with the tax credits adjustment) using tax credits individually as an explanatory variable, but also alongside other types of public R&D (and with other control variables). Again, we were unable to obtain a satisfactory model.

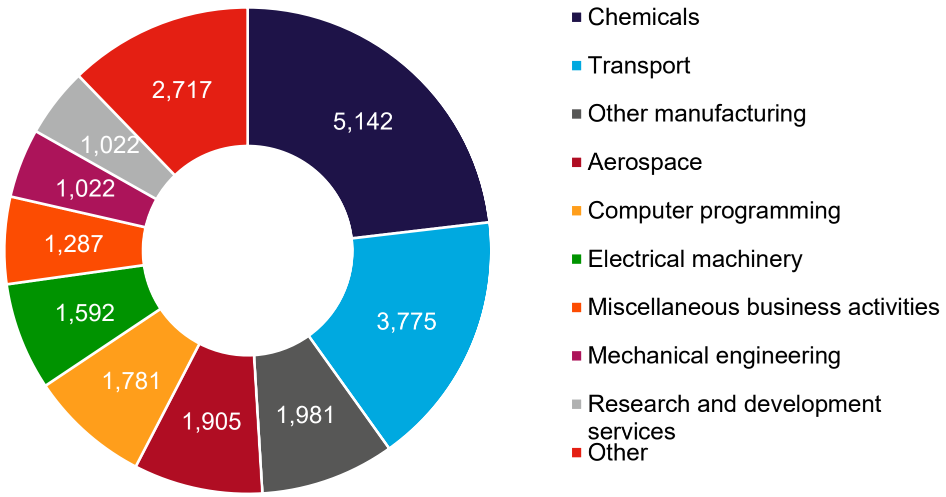
6. How do leverage rates differ across sectors in the UK?

6.1. Analysis using ONS data on R&D by product group

The ONS BERD dataset categorises R&D expenditures according to either the industrial sector of the company undertaking the research, or the product group that the research corresponds to. However, it is only possible to analyse the breakdown by product group by source of funding, and so we focus on this categorisation within our analysis.

The bulk of R&D investment relates to chemicals, transport, other manufacturing and aerospace. Chemicals and transport alone account for more than one-third of R&D investment in 2016 (Figure 46).

Figure 46: UK BERD by product group (2016, £m)



Source: ONS

We used this dataset to explore whether the UK leverage rate might vary across product groups over the period from 2000 to 2015.

One complication when undertaking this analysis is that product groups relate to the subject matter of the R&D, whereas most economic data, such as that we wish to use as control variables in our modelling, is categorised according to the industrial sector classification of the firm undertaking it.[27] For the purposes of our analysis we therefore had to treat product groups as equivalent to industry sectors.

We deployed panel data techniques to assess leverage rates by product groups. These should enable unobservable sector specific-effects to be accounted for within the modelling, for example those relating to institutional factors in particular sectors. Omitting such factors from the modelling framework could lead to biased estimates of the relationship between public and private R&D.

Nonetheless, we were unable to find evidence of any statistically significant differences in the leverage rate across sectors. The few models which did indicate that there may be differences across sectors contained coefficients with implausible magnitudes and tended to fail diagnostic tests (see Figure 135 – Figure 139 in Appendix 8: Econometric modelling outputs and test results). As such we did not deem those findings to be robust.

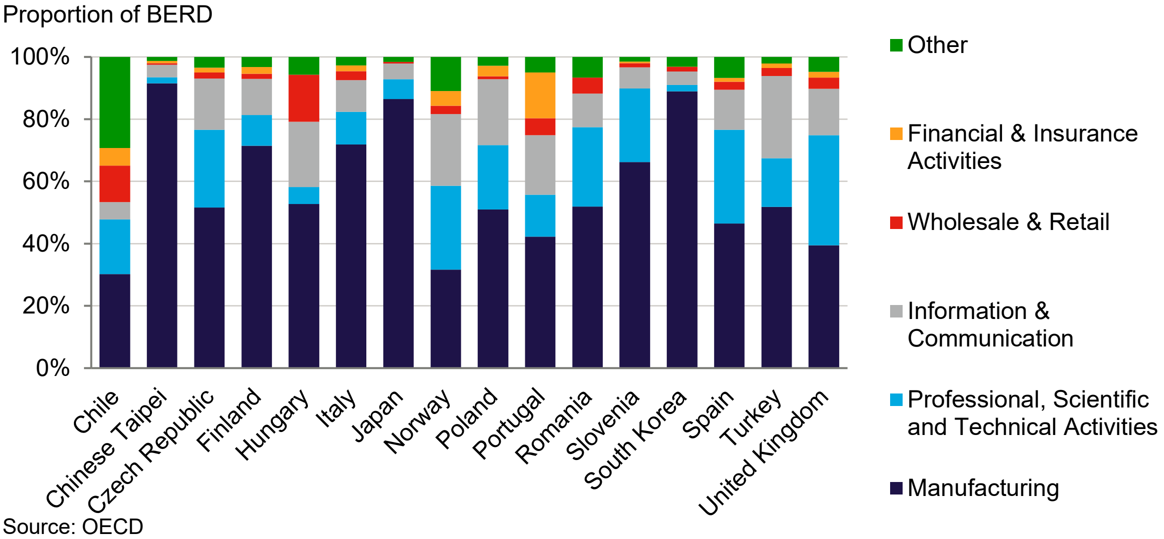
More details on the modelling approach and results from this part of the analysis are presented in Appendix 4: Do leverage rates differ across sectors in the UK.

6.2. Analysis using OECD data

The OECD provides a breakdown of R&D expenditure by industrial sector of the company undertaking the research. Comparing across countries from the OECD dataset with available data, the UK had the largest proportion of BERD conducted by the industry “professional, scientific and technical activities” in 2014 (Figure 47). The other countries in the sample, with the exception of Chile and Norway, allocate a greater share of BERD to manufacturing, especially in Chinese Taipei, Japan and South Korea where more than 80 percent of BERD in 2014 was conducted in manufacturing.

[27] We would expect a reasonable degree of overlap between the two concepts, for example because we would expect most R&D relating to chemicals to be undertaken by companies in the chemicals sector. This will not always be the case, however. It is not difficult to imagine, for example, that a company classified within other manufacturing sectors might undertake R&D relating to chemicals.

Figure 47: Cross-country comparison of BERD by industry (2014)



Source: OECD

Our second approach to estimating leverage rates across sectors was to use panel data from the OECD BERD dataset for the period 2007 to 2015. This dataset details the value of R&D conducted across 26 OECD countries and 14 industries.

The use of panel data in this case enabled unobservable sector and country specific-effects to be accounted for within the modelling. Such effects might relate to institutional factors relating to particular sectors in certain countries, for example. Omitting such factors from the modelling framework could lead to biased estimates of the relationship between public and private R&D.

Once again, we were unable to obtain a satisfactory model in this part of the study. A more detailed discussion of the modelling approach and the results are presented in Appendix 4.

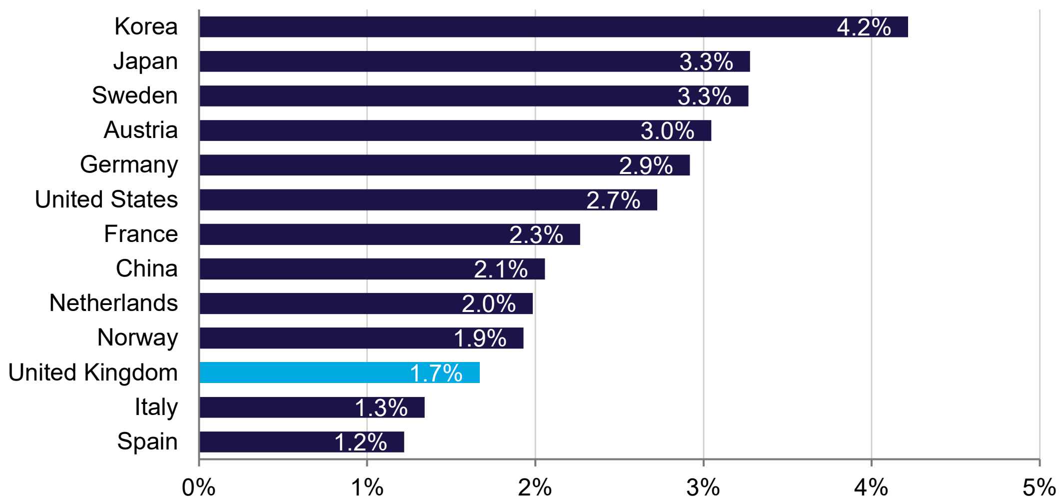
One potential issue could be the way that the OECD data have been compiled. Although they purport to show R&D investment by sector, the accompanying notes suggest that the data may have been compiled in slightly different ways by national statistical offices, and this may make it difficult to estimate robust relationships within a panel framework.

7. How does the leverage rate differ across countries?

7.1. International comparison of R&D investment

The UK invested 1.7 percent of GDP in R&D in 2016 and this proportion has been broadly stable for over 20 years. In a global context the UK invests less in R&D than many other developed economies. South Korea invests more than twice as much in R&D as a proportion of GDP (4.2 percent) and the UK is behind many European and international counterparts who invest between two and three percent of GDP. Spain and Italy are the laggards in our sample, investing 1.2 percent and 1.3 percent of GDP on R&D respectively (Figure 48).

Figure 48: R&D as a proportion of GDP (2016)



Source: OECD, Oxford Economics

While the OECD data presented above demonstrate that countries dedicate varying amounts of resources to R&D, they do not tell us anything about the impact of that spending. Of interest in the context of this study is whether leverage rates differ across countries.

7.2. Panel data analysis

7.2.1. Approach

The models presented in this chapter have been developed to determine whether the leverage rate differs across countries. Subject to data availability, the models estimate the relationship between private GERD and public GERD across OECD countries over the period 1981-2016. Using econometric techniques, we are able to estimate country-specific leverage rates within this framework and test whether they are different to those for the group as a whole.

The panel data approach enables us to estimate leverage rates for individual countries in the OECD dataset and to test whether there are statistically significant differences in these leverage rates. For this part of the analysis we use the same OECD R&D dataset, panel of countries and control variables as was used to determine the UK leverage rate in Section 4.3.4. This part of the modelling was carried out in US dollars, and so we use Model 4 in Figure 18 to compare the UK results to those for other countries.

To determine the UK leverage rate in Section 4.3.4, we used a UK interaction term to separately estimate the impact of public R&D on private R&D in the UK from that in the rest of the OECD. We employ the same technique in this part of our modelling. As each interaction term counts as a separate explanatory variable, we estimate the country-specific leverage rate for each country separately using one model with one interaction term for each country. This enables estimation of country-specific leverage rates, which can be tested to determine whether they are significantly different to the rest of the sample. We retain the same control variables to maximise the consistency and comparability of results across countries. Note that only the explanatory variable (public R&D) is multiplied by country to estimate whether different countries have different leverage rates. A separate constant term for each country is not introduced as we expect this would be captured as “fixed effects” by the panel modelling techniques.

7.2.2. Results

The estimated short-run UK leverage rate from our model specified in US dollars was 0.3798, compared to the OECD average of 0.3052. Incorporating interaction terms for other countries generated leverage rates ranging from 0.3203 for Spain to 0.3862 for Finland.

In the longer term, we estimated a UK leverage rate of 1.06, and the range for other countries was between 0.95 for Spain and 1.11 for Finland (the OECD average was 0.95). The country-specific leverage rates presented in Figure 49 are all significant at the one percent level.

This model specification has been selected as our preferred specification because it passes the relevant diagnostic tests, the coefficients on the control variables are significant and are of a plausible magnitude. In each of these models, the AR(2) test for autocorrelation and the Hansen test for overidentifying restrictions are satisfied indicating that the models are robust to serial correlation and that the instruments used are suitable for our analysis. Across all 11 specifications presented in Figure 49, the coefficients on employment growth and interest rates have the expected sign, are statistically significant at the five percent level, and their magnitude remains stable. This suggests the model is robust.

Figure 49: Results of panel data regressions methods

Dependent variable: Lag private GERD (log). Monetary variables specified in USD and deflated using CPI.
See Figure 109 – Figure 110 in Appendix 8: Econometric modelling outputs and test results for other countries and specifications.

Variables	Dynamic Panel OECD	Dynamic Panel - ES	Dynamic Panel - UK	Dynamic Panel - FR	Dynamic Panel - DE	Dynamic Panel - US	Dynamic Panel – IT	Dynamic Panel – JP	Dynamic Panel – NO	Dynamic Panel – FI	Dynamic Panel - CA
Lag private GERD (log) - lag of dependent variable	0.6865***	0.6641***	0.6414***	0.6361***	0.6432***	0.6499***	0.6513***	0.6450***	0.6458***	0.6536***	0.6456***
	(0.0846)	(0.0929)	(0.0996)	(0.0982)	(0.1012)	(0.0975)	(0.0973)	(0.1002)	(0.1005)	(0.0975)	(0.1016)
Public GERD (log) – country specific		0.3203***	0.3798***	0.3793***	0.3755***	0.3630***	0.3563***	0.3634***	0.3820***	0.3862***	0.3560***
		(0.0885)	(0.1105)	(0.1062)	(0.1117)	(0.1079)	(0.1082)	(0.1062)	(0.1159)	(0.1160)	(0.1123)
Public GERD (log) – Total/Other	0.3052***	0.3359***	0.3697***	0.3794***	0.3635***	0.3681***	0.3761***	0.3376***	0.3658***	0.3551***	0.3715***
	(0.0912)	(0.0943)	(0.1129)	(0.1121)	(0.1156)	(0.1147)	(0.1121)	(0.1054)	(0.1143)	(0.1099)	(0.1172)
Employment growth rate	1.3367**	1.4286**	1.3811**	1.3685**	1.3165**	1.4505**	1.4522**	1.1931**	1.3707**	1.4924**	1.4223**
	(0.5815)	(0.5981)	(0.6404)	(0.6484)	(0.6409)	(0.6512)	(0.6394)	(0.6026)	(0.6309)	(0.5932)	(0.6364)
Interest rates	-0.0162**	-0.0161**	-0.0179**	-0.0178**	-0.0175**	-0.0166**	-0.0157**	-0.0168**	-0.0175**	-0.0160**	-0.0169**
	(0.0065)	(0.0071)	(0.0070)	(0.0069)	(0.0070)	(0.0069)	(0.0064)	(0.0071)	(0.0070)	(0.0067)	(0.0071)
Constant	0.3313	0.2808	0.1968	0.1687	0.2305	0.1386	0.0574	0.4145	0.1945	0.1974	0.1552
	(0.3794)	(0.2148)	(0.2893)	(0.2840)	(0.3010)	(0.3212)	(0.2838)	(0.2810)	(0.2760)	(0.2614)	(0.2886)
Observations	538	538	538	538	538	538	538	538	538	538	538
Number of countries	30	30	30	30	30	30	30	30	30	30	30
Number of instruments	19	19	19	19	19	19	19	19	14	19	19
AR2 p-value (See note 2)	0.851	0.807	0.799	0.789	0.8	0.785	0.767	0.816	0.799	0.785	0.785
Hansen p-value (See note 3)	0.087	0.106	0.13	0.137	0.127	0.13	0.164	0.151	0.022	0.209	0.134
Ratio of public to private investment in sample	1.71	1.11	1.95	1.39	2.10	1.77	1.11	2.97	1.17	2.62	1.35

Source: Oxford Economics

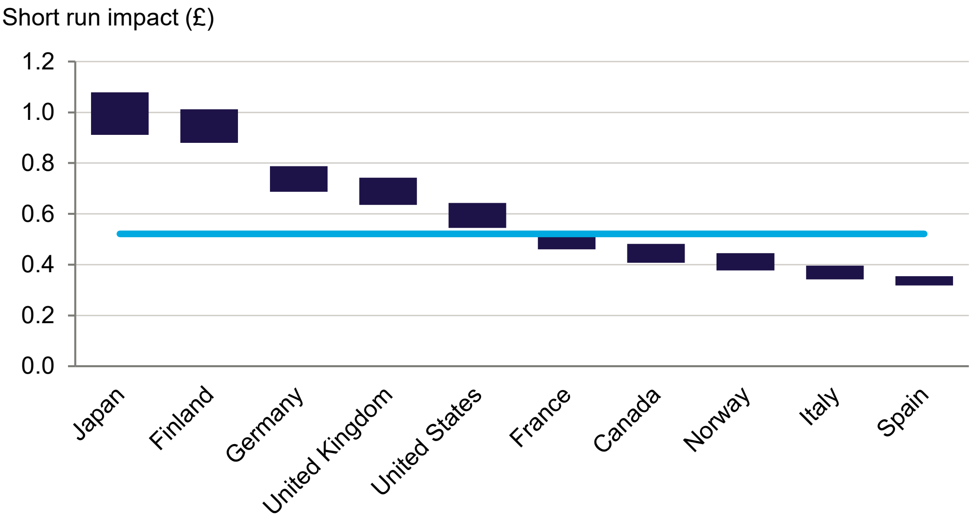
Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The “AR2 p-value” reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. Put simply, a high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying. restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private BERD, Public BERD and GVA growth rate are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

Interpreting these coefficients, we can say that £1 of public R&D expenditure in the UK stimulates an average of £0.74 in private R&D investment in the UK in the short term. The comparable average OECD short-term impact, estimated using a model without interaction terms, is £0.52.

We find that the difference in the impact of £1 of spending across countries is noticeably greater than differences in the estimated leverage rates. This arises because small differences in short-run leverage rates are magnified when considering the impact of an additional £1 of public R&D expenditure due to differences in the ratio of private to public R&D expenditure. We find that the smallest short-run impact is in Spain at £0.34 compared to the largest short-run impact at £1.00 in Japan.

Our findings are summarised in Figure 50. To reflect that leverage rates can vary depending on the precise model specification used, we have estimated a range for each country using different model specifications but the same underlying dataset.

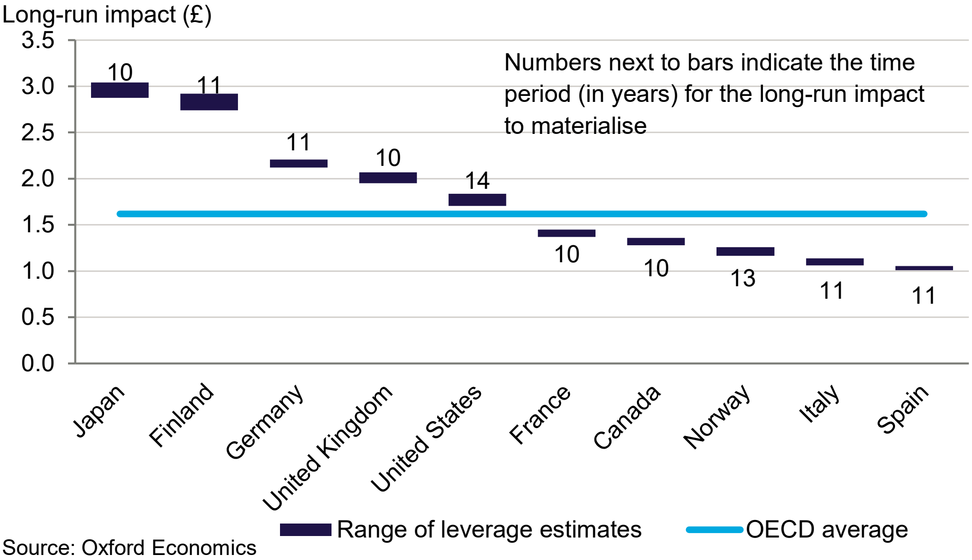
Figure 50: Cross-country comparison of short-run impacts from £1 of public R&D support using the June 2018 dataset



Source: Oxford Economics

In the long run, £1 of public R&D investment in the UK in one year leads to a total increase of £2.06 in private R&D investment. The impact in the UK is above the average OECD long-term impact, which stands at £1.62. The impact of the same £1 in public R&D investment is smallest in Spain at £1.03 and largest in Japan at £2.96 (Figure 51 shows a range of long-run estimates for each country, based on different model specifications estimated using the same dataset).

Figure 51: Cross-country comparison of long-run impacts from £1 of public R&D support using the June 2018 dataset



Source: Oxford Economics

7.2.3. Sensitivity tests

While we would prefer to keep the same specification across countries to maximise the comparability of results, we did test other specifications to see whether alternative combinations of control variables might improve upon the results. The other specifications tested either did not satisfy the criteria above or, where they did, the sample size was significantly reduced due to a lack of data for certain control variables.

We also tested whether the model outputs are robust to the exclusion of any particular country. We did this by running the same regression specification as under the "Dynamic Panel – OECD" column in Figure 49, but by dropping one country at a time. The median of coefficients suggested by the sensitivity tests is very similar to the coefficients presented in Figure 49, which indicates that the panel is not biased due to a single country. These sensitivity tests are summarised in Figure 52, below, and further details presented in Figure 109 and Figure 110 in Appendix 8.

Figure 52: Results of sensitivity tests to check for bias due to a single country using the June 2018 dataset
See Figure 109 – Figure 110 in Appendix 8: Econometric modelling outputs and test results *for other countries and specifications.*

Variables	Full sample	Median of values from sensitivity tests	Range of values from sensitivity tests
Lag private GERD (log) - lag of dependent variable	0.6865	0.6882	0.6403 to 0.7202
Public GERD (log) – Total/Other	0.3052	0.3030	0.2724 to 0.3561
Employment growth rate	1.3367	1.3429	0.9925 to 1.6368
Interest rates	-0.0162	-0.0160	-0.014 to -0.019

Source: Oxford Economics

7.2.4. Extension to incorporate OECD data released in October 2018

As mentioned in previous sections, the OECD released additional GERD data in October 2018, during the latter stages of our research. We have run additional specifications to test the impact of incorporating the additional data into our cross-country analysis.

Using the same specification as Model 4 in Figure 18 (which is based on values in US dollars) but with the additional years of data, we find the short run monetary impact to be generally within the range of estimates obtained from the June dataset, but the long run impacts are higher for all countries. With these specifications, it typically takes around 15 years for long-run impacts to materialise across the countries in our sample.

Figure 53: Results of sensitivity tests with additional data: impact per £1 of public support

	Short run		Long Run	
	June 2018 dataset (£)	**October 2018 dataset (£)**	**June 2018 dataset (£)**	**October 2018 dataset (£)**
Japan	0.91 to 1.08	1.01	2.88 to 3.04	3.43
Finland	0.88 to 1.01	0.89	2.74 to 2.92	3.39
Germany	0.69 to 0.79	0.72	2.12 to 2.21	2.78
United Kingdom	0.64 to 0.74	0.61	1.95 to 2.07	2.34
United States	0.55 to 0.64	0.60	1.71 to 1.84	2.35
France	0.46 to 0.53	0.45	1.37 to 1.45	1.50
Canada	0.41 to 0.48	0.45	1.28 to 1.36	1.76
Norway	0.38 to 0.45	0.38	1.17 to 1.26	1.42
Italy	0.34 to 0.4	0.39	1.06 to 1.14	1.44
Spain	0.32 to 0.35	0.37	1.01 to 1.06	1.41

Source: Oxford Economics

We were not able to obtain a specification that passed all diagnostics for the OECD average, and had to change the instruments used to obtain a satisfactory model. With the adjusted specification, the OECD average with the new specification is similar in the short run to the June results at £0.42 (compared to £0.52 previously) and £1.61 in the long run (compared to £1.62 previously).

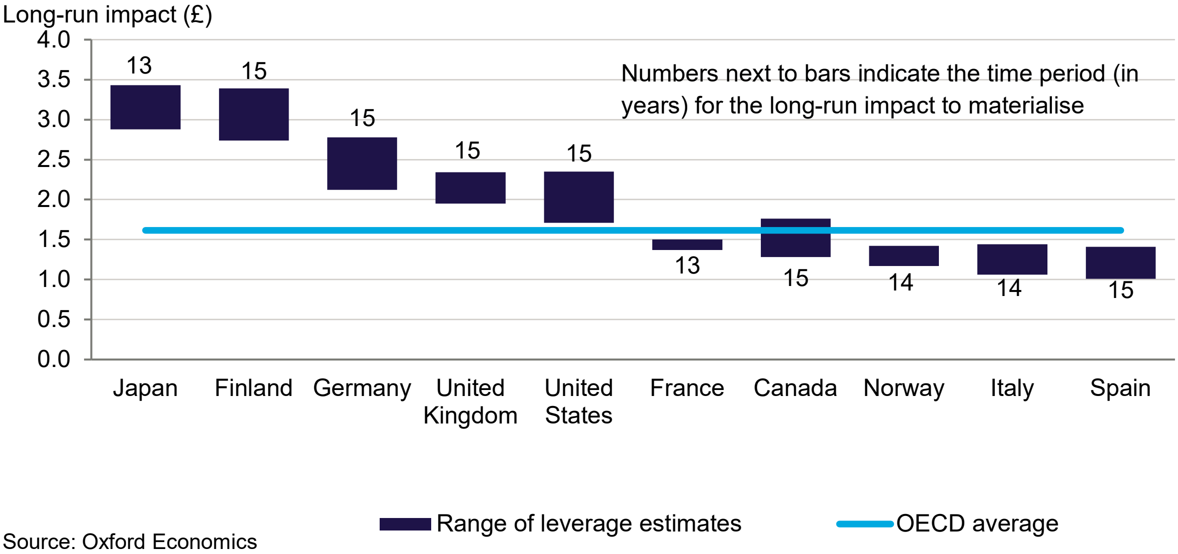
7.2.5. Final results

As before, given the additional uncertainty introduced by extending the time period, we would suggest extending the ranges around our findings for each country to incorporate the results based on both the June and October datasets. The short run leverage rate ranges from 0.3203 for Spain to 0.3862 for Finland. In the longer term, we estimate the leverage rates to range between 0.95 and 1.38.

The chart below shows the long-run impact of £1 of public R&D investment. We find the highest long-term impact for Japan, where £1 of public support is estimated to stimulate £3.16 of private investment in the long term. The monetary impact is lower in Finland, despite having the highest leverage rates. In that case, £1 of public support stimulates an estimated £3.07 in private investment. In contrast, the same £1 of public support in Spain would encourage just £1.21 of private investment.

The numbers shown indicate how long the long-run impact takes to materialise and are the larger of the estimates obtained from the June and October datasets. While the range has been extended for each country, the ranking of mid-points is the same as that obtained from the June dataset.

Figure 54: Preferred estimates of long-run impact of £1 of R&D support across countries based on models using the June 2018 and October 2018 datasets



Source: Oxford Economics

8. What are the drivers of leverage rates?

8.1. Evidence from the literature

In the previous chapter we estimated leverage rates for a range of OECD countries. Understanding how the UK compares to its international peers is likely to be of interest to policymakers, and naturally leads to the question of how leverage rates could be increased to match those of the best performing countries. To do so requires a better understanding of the drivers of the differences in leverage rates across countries.

Much less research has been conducted into the drivers of leverage rates than to estimating their magnitude. This might largely be on account of the lack of data given that many of the potential drivers might be institutional or cultural factors which are difficult to observe and quantify. During the course of our research we have identified a number of, largely unobservable, factors which might influence leverage rates across countries:[28]

1. **Intellectual Property (IP) rights—**stronger intellectual property rights might improve the ability of those undertaking research to capture returns on their investments.

2. **Spillover effects from clusters of R&D expertise—**the presence of major innovators may be sufficient to influence national leverage rates in certain countries.

3. **Quality of research institutions—**higher quality research institutions might produce better quality research which may have greater benefits to private businesses.

4. **Absorptive capacity—**leverage rates might be greater in countries with higher "absorptive capacity". That is, companies that are able to recognise the value of R&D conducted by others and transfer the findings to their own business needs might be more likely to conduct their own R&D as a result.

5. **Availability of R&D inputs—**the responsiveness of the supply of R&D inputs (particularly labour) will affect the extent to which R&D input costs rise in response to increased demand. This, in turn, could influence businesses' desire to invest in R&D activities in response to public R&D.

[28] Some of these factors may affect private R&D investment directly, as well as influencing leverage rates. However, because these factors are largely unobservable there are data and modelling limitations which mean they are not included as control variables.

6. **The nature of R&D being conducted—**R&D conducted or funded by different institutions may produce research that is more beneficial to businesses considering R&D expenditure.

7. **“High tech” intensity**—more technologically advanced companies may be better equipped to adapt cutting-edge research to their business needs.

8.2. Assessing the drivers of leverage rates

To test which of the factors identified above may influence leverage rates, we have identified a set of proxy variables which are as closely related as possible to each of the factors. We identified proxies published by international data sources such as the OECD and the World Economic Forum’s Global Competitiveness Index (GCI). These have been grouped according to the factors identified in the previous section and are presented in Figure 55 below.

Figure 55: Potential drivers of leverage rates

Category of drivers	Proxy Variable	Source
Intellectual property rights	Property rights, 1-7 (best)	WEF GCI
Intellectual property rights	Intellectual property protection, 1-7 (best)	WEF GCI
Intellectual property rights	International patents[29], applications/million pop	WEF GCI
Spillover effects from clusters of R&D expertise	Number of the world’s top 2000 R&D investors with headquarters in the country	OECD
Quality of research institutions	Quality of scientific research institutions, 1-7 (best)	WEF GCI
Absorptive capacity	Firm-level technology absorption, 1-7 (best)	WEF GCI
Absorptive capacity	University-industry collaboration in R&D, 1-7 (best)	WEF GCI
Absorptive capacity	Capacity for innovation	WEF GCI
Availability of R&D inputs	Ease of access to loans, 1-7 (best)	WEF GCI
Availability of R&D inputs	Availability of scientists and engineers, 1-7 (best)	WEF GCI
Nature of R&D	Share of GERD funded by government	OECD
Nature of R&D	Share of GERD funded by higher education	OECD
Nature of R&D	Share of GERD funded by business	OECD
Nature of R&D	Share of GERD performed by higher education	OECD
Nature of R&D	Share of GERD performed by business	OECD

[29] Patents filed with the Patent Cooperation Treaty

“High tech” intensity	Share of manufacturing defined as “high tech”	Oxford Economics
“High tech” intensity	Share of manufacturing defined as “high tech” or “medium-high tech”	Oxford Economics
“High tech” intensity	Availability of latest technologies, 1-7 (best)	WEF GCI

Source: Oxford Economics

To gain a better understanding of which factors might influence leverage rates across countries we have undertaken correlation analysis to look at the relationships between the country leverage rates estimated from our econometric modelling, and the variables presented in Figure 55. While this type of correlation analysis can identify associations between two data series, it does not provide insights into the degree of causality between them. The sample size is also very small, since we only have leverage rate estimates for 10 countries. **The analysis should therefore be regarded as indicative, rather than definitive.** It does, nonetheless, provide a basis for identifying potential areas for further research.

In Figure 56, overleaf, we present the findings from our correlation analysis. Our estimated leverage rates represent the average leverage rate (for each country) across the time period over which the regression was undertaken.[30] The potential drivers are available for a shorter time period than the modelling is conducted over, therefore they have been averaged across as many years as possible that overlap with the modelling period.[31] Outliers that appear to be distorting the results have been removed from the calculation to ensure data from one country alone are not driving our conclusions.

Our analysis finds that the availability of latest technologies is the most strongly correlated with leverage rates with a correlation of 0.88. We find that “intellectual property protection”, with a correlation of 0.78, is very positively correlated with our estimated country leverage rates. Another variable within the same category, “property rights”, has the third largest correlation with leverage rates.

Two of the three proxy variables relating to absorptive capacity also have a correlation that exceeds 0.5, suggesting that further research might look into this as a potential driver of leverage rates. “Ease of access to loans” is the other remaining variable which has a correlation coefficient greater than 0.5.

At the other end of the spectrum, we find no strong evidence of a correlation between sources of funding or sectors of performance and leverage rates. We also do not find strong evidence of an association between the “high tech intensity” of the manufacturing sector and leverage rates across countries. The correlation between leverage rates and the share of manufacturing defined as high tech or medium high tech is only 0.29. However, the high-tech intensity indicator from the WEF provides the strongest correlation amongst those calculated.

[30] This section of the analysis is based on the country leverage rates estimated in section 7.2.2.
[31] We have excluded a small number of countries from some of the correlation estimates where they appeared to be significant outliers which had a disproportionate impact on the overall findings.

Figure 56: Correlation analysis between country leverage rates and potential drivers of leverage

Proxy variable	Category of driver	Correlation coefficient
Availability of latest technologies, 1-7 (best)	“High tech” intensity	0.88
Intellectual property protection, 1-7 (best)	Intellectual Property rights	0.78
Property rights, 1-7 (best)	Intellectual Property rights	0.68
International patents, applications/million pop	Intellectual Property rights	0.67
Ease of access to loans, 1-7 (best)	Availability of R&D inputs	0.63
University-industry collaboration in R&D, 1-7 (best)	Absorptive capacity	0.57
Firm-level technology absorption, 1-7 (best)	Absorptive capacity	0.54
Capacity for innovation, 1-7 (best)	Absorptive capacity	0.43
Share of GERD performed by business	Nature of R&D	0.42
Share of manufacturing defined as “high tech”	“High tech” intensity	0.41
Quality of scientific research institutions, 1-7 (best)	Quality of research institutions	0.31
Availability of scientists and engineers, 1-7 (best)	Availability of R&D inputs	0.29
Share of manufacturing defined as “high tech” or “medium-high tech”	“High tech” intensity	0.29
Share of GERD funded by business	Nature of R&D	0.26
Number of the world’s top 2000 R&D investors with headquarters in the country	Spillover effects from clusters of R&D expertise	0.00
Share of GERD performed by higher education	Nature of R&D	-0.30
Share of GERD funded by government	Nature of R&D	-0.30
Share of GERD funded by higher education	Nature of R&D	-0.56

Source: Oxford Economics

9. Sensitivity testing

In this chapter, we summarise the various sensitivity tests we undertook to test the robustness of our findings to alternate assumptions and modelling approaches. We do not present any new results in this section but provide cross-references to the rest of the report and the annexes where applicable.

9.1 Static panel and pooled regression methods

Our preferred modelling approach has been to use dynamic panel methods. We discuss the limitations of pooled regressions and static panel methods in Section 3.4.2.

According to Hsiao (1986), the OLS coefficient of the lagged dependent variable is expected to suffer from an upward bias due to its ignorance of individual specific effects, whereas Nickel (1981) argues that the within estimator of the fixed effects model is expected to be downward biased.

Hence, Blundell and Bond (1998) argue that a plausible parameter estimate should therefore lie between the fixed effect and the OLS estimates.

We present the OLS and static panel (fixed effects) estimates in Figure 90 and Figure 91 in Appendix 8. This confirms that our findings from the dynamic panel approach do, indeed, fall between the estimates obtained from a fixed effect and OLS model specification.

9.2. Alternative control variables

We have run a large number of specifications for various models using alternative control variables. We discuss our approach to testing different control variables in Section 3.5. We present the results of sensitivity tests to different specifications in Appendix 8 (for example, see Figure 92, Figure 93, and Figure 101).

9.3. Time as a control variable

Only one of our main specifications includes decade-specific dummies (Model 3 in Fig. 18 and Model 2 in Fig. 21). However, Roodman (2006) recommends the use of time dummies in all specifications as this makes the assumptions underlying the diagnostics tests more likely to hold, and therefore makes the diagnostic tests more reliable.

Figure 92 presents the results of models with time dummies included in the regression in various ways. We find that the inclusion of time dummies does not result in satisfactory model specifications.

Time trends can also be included as a continuous variable (instead of dummies). Running a sensitivity with time trend included as a control variable will help us test if the underlying trend in R&D spending is likely to lead to bias our findings, either due to unit roots or omitted variables. We tested our regressions by including a trend variable and found that the results are similar (see Figure 93 in Appendix 8).

9.4. Restricting the sample

Given the gaps in our dataset, we have explored restricting our data such that we have a more balanced dataset without gaps. Figure 94 and Figure 95 in Appendix 8: Econometric modelling outputs and test results presents the results of models estimated using various subsets of the dataset. We found that "trimming" the data in this way does not result in satisfactory model specifications. For example, the coefficient on the lag term and, in one model, the coefficient on employment, are not significant.

9.5. Testing for bias driven by specific countries

9.5.1. Bias due to individual countries skewing the results

We have tested whether our results are biased by a single country that has a significant influence on the results. To do this, we re-ran one of our preferred specifications (i.e. Model 5 from Fig. 15), dropping a single country each time (see Figure 96-Figure 98). We did not find any single country to have a significant influence on our results.

9.5.2. Weighted regressions

We tested weighted regression models using GDP and various R&D levels as weights (see Figure 99). We found that the results are not significantly different from those of our preferred models.

9.5.3. Adjusting for inflation using CPI and the GDP deflator

Our models used either CPI or GDP deflators to convert data into real values. Testing (as shown in Figure 100) suggested that the choice of deflator had little impact on results, reflecting the very high correlation between the two types of deflator.

9.5.4. Using the R&D to GDP ratio instead of levels

Our preferred specifications model the log of private R&D expenditure with the log of public R&D expenditure and other control variables. An alternate approach would have been to use the ratios of public R&D and private R&D spending to GDP. Figure 106 in Appendix 8 shows the results of model specifications using the private R&D to GDP ratio as the dependent variable and the public R&D to GDP ratio as the independent variable, along with other controls in a dynamic panel setting. We were unable to find a specification that satisfies our diagnostic tests when taking this approach.

9.5.5. Adjusting private and public R&D for tax credits

The BERD and GERD data record R&D funded through tax credits as privately-funded R&D, even though it has been funded by an offsetting tax reduction (a form of indirect support to R&D). In our preferred specifications, we have not incorporated an adjustment into the data to exclude the estimated value of tax-credit-funded R&D. However, we have run alternate models based on an dataset which incorporates the adjustment for offsetting tax reduction. Our approach to adjust the data is described in Section 3.3. Figure 108 in Appendix 8: Econometric modelling outputs and test results compare the regression models based on the unadjusted and adjusted series respectively, and show that the adjustment for tax credits does not have a significant impact on our estimates of leverage.

9.5.6. System GMM and Difference GMM

We selected the System GMM approach over the Difference GMM approach as the former allows for a wider choice of potential instruments, in turn allowing for a more efficient model. We have also tested whether the models using the Difference GMM approach produce very different results (see Figure 103 in Appendix 8). However, we were unable to find any satisfactory model specifications and therefore, were not able to draw inferences on the leverage rate using the Difference GMM approach.

9.5.7. Instrumentation approach: predetermined variables and endogenous variables

The System GMM approach allows for variables to be treated as exogenous, endogenous or pre-determined.

Exogenous variables are those whose values are not influenced by the relationship we are trying to estimate. In other words, the relationship between public and private R&D does not affect how interest rates are set. In technical terms, exogenous variables are those which are not correlated with the error term. In our regressions, interest rates are treated as exogenous as they are determined by central bank policy. Technically speaking, exogenous variables are those that are independent of current disturbances (i.e. the variable is not correlated with the error term).

Pre-determined variables are those that are not strictly exogenous. A idiosyncratic shock to private R&D today may not affect public R&D spending or employment today, but may have an influence on future public R&D spending or employment. The government may choose to adjust its spending depending on current levels of private R&D spending. Similarly, firms may choose to increase employment directly related to R&D spending or may choose to adjust their labour force based on the outcome of their R&D efforts. In technical terms, pre-determined variables are those that are not strictly endogenous even if independent of current disturbances, they are still influenced by past ones.

Endogenous variables are those which are determined within the equation we are trying to estimate. For example, in a demand equation with quantity as the dependent variable, there is a two way relationship between price and quantity. Price is considered an endogenous variable.

Including endogenous or pre-determined variables in a regression will lead to biased estimates. We account for this using “instruments”, i.e. proxy variables, that break the reverse link between private R&D spending and the endogenous/pre-determined variables. In technical terms, endogenous variables are not independent of the error term (i.e. correlated with the error term).

Figure 57 shows the instrumentation approach followed in our preferred specifications in Figure 18 and Figure 21. Specifically, in three out of the eight models (Model 1 and Model 4 in Figure 18 and Model 2 in Figure 21), the lag private R&D term is treated as endogenous instead of pre-determined.

Figure 57: Instrumentation approach

Control variables	Lag private R&D	Public R&D	Employment growth	Interest rates
Figure 18 – Model 1	Strictly endogenous	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 18 – Model 2	Not strictly endogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 18 – Model 3	Not strictly endogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 18 – Model 4	Strictly endogenous	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 21 - Model 1	Not strictly endogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 21 - Model 2	Strictly endogenous	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 21 - Model 3	Pre-determined	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous
Figure 21 - Model 4	Pre-determined	Not strictly exogenous (Pre-determined)	Not strictly exogenous (Pre-determined)	Exogenous

Source: Oxford Economics

We have tested whether the choice of treating the lag private R&D term as pre-determined instead of endogenous has a significant effect on the coefficient. In these three specifications, treating the lag dependent variable as pre-determined (instead of endogenous) does not change the results significantly (see Figure 102 in Appendix 8).

10. Conclusion

Below we present our main findings for each of the key research questions.

10.1. What is the best estimate of the leverage rate in the UK?

Our preferred models suggest that the short run leverage rate in the UK is between 0.23 and 0.38. Expressed another way, each £1 of public R&D expenditure stimulates between £0.41 and £0.74 of private R&D in the same year.

Our analysis suggests that the long-run impact of public R&D on private R&D is more than three times the short-run impact: we estimate the long-run UK leverage rate to be between 1.01 and 1.32. This suggests that £1 of public R&D investment stimulates between £1.96 and £2.34 of private R&D in the long run. The impact is most substantial in the first year and fades over time. For the UK, almost all benefits are realised within 15 years.

Figure 58: Estimates of UK leverage rates

	Leverage rate		**Impact of £1 of public support**	
	Short run	Long run	Short run	Long run
UK leverage rate	0.23 to 0.38	1.01 to 1.32	£0.41 to £0.74	£1.96 to £2.34

Notes: This table is identical to Figure 24 in Section 4.3.9.
Source: Oxford Economics

10.2. How does the leverage rate differ across the different types of public support?

Using a similar model to the overall leverage results we estimated separate leverage rates for direct public support to universities and research councils, and to businesses. Our findings are summarised in the table below.

Figure 59: Leverage rates for direct support

	Leverage rate		**Impact of £1 of public support**	
	Short run	Long run	Short run	Long run
Direct support to universities and research councils	0.13 to 0.32	0.53 to 0.69	£0.54 to £1.33	£2.21 to £2.88
Direct support to businesses	0.09 to 0.12	0.25 to 0.41	£0.79 to £1.00	£2.16 to £3.63

Notes: This table is identical to Figure 38 in Section 5.3.3.
Source: Oxford Economics

This suggests that leverage *rates* are higher for direct support to universities and research councils. However, the government provides considerably more direct support to universities and research councils than to businesses. As such, a £1 increase in public support to businesses represents a larger proportional increase than if that same £1 were allocated to universities and research councils. Therefore, a £1 increase in public support to businesses *may* stimulate a greater value of private R&D than £1 in public support to universities and research councils. However, the uncertainty ranges for the impact of £1 of public support to universities and research councils and to businesses overlap, and so we are unable to draw firm conclusions concerning which type of support may lead to the largest impact on private R&D.

These findings are based on analysis of data for a group of OECD countries. We did not find any evidence that UK leverage rates for direct support to each sector are substantively different to the OECD average rates.

We also investigated the impact of indirect support through R&D tax credits using a range of different models based on data from HMRC, ONS and the OECD. However, we were unable to obtain robust results in this part of the analysis, most likely because relatively few data points are available to identify the impact of tax credits on private R&D and isolate this impact from that of other influences. In light of the data limitations at the macro level, micro analysis may represent a better option for investigating the impact of indirect support.

10.3. How does the UK leverage rate differ across sectors?

Our study investigated whether leverage rates vary across industrial sectors. Despite testing a range of models, approaches and datasets, we were unable to obtain robust evidence of differences in leverage rates across sectors. Data availability is limited when disaggregating R&D expenditure at this level of granularity, and we would recommend that this question is revisited when longer time series of data are available.

It may also be the case that the need to transpose product groups to the equivalent sector introduces a degree of inaccuracy into the sectoral analysis. This question could be explored further if ONS were able to make available BERD data split by sector and source of funding.

How does the leverage rate differ across countries?

Alongside our analysis of the UK, we have estimated leverage rates for nine other OECD countries. The short run leverage rate ranges from 0.3203 for Spain to 0.3862 for Finland. In the longer term, we estimate the leverage rates to range between 0.95 and 1.38.

To enable comparison we need to convert leverage rates into monetary terms. When we do this we find that the highest long-term impact was found for Japan, where £1 of public support is estimated to stimulate £3.16 of private investment in the long term. The monetary impact is lower in Finland, despite having the highest leverage rates, where £1 of public support is stimulates an estimated £3.07 in private investment. In contrast, the same £1 of public support in Spain would encourage just £1.21 of private investment. It typically takes around 15 years for long-run impacts to materialise across the countries in our sample.

10.4. What are the key drivers of leverage rates?

We have undertaken indicative analysis of the associations between national leverage rates and a range of institutional factors. We find that countries with strong protection for intellectual property and property rights, access to the latest technologies, and ready access to finance tend to have higher leverage rates. These findings should, however, be treated with caution since they do not imply that the presence of such factors *cause* higher leverage rates. We recommend that further research should be undertaken in this area.

10.5. Limitations

The results presented in this study are based on data stretching back over decades (as far back as the 1960s in some cases). Our results reflect the experience and conditions over this period, during which there have been significant changes in the nature of public support to R&D, as well as the way R&D is conducted in the economy. The channels through which public support influences private R&D are likely to have changed over this period, and the dynamism of the R&D sector means that many of the underlying dynamics will continue to change in future. As such, there is no guarantee that the past experience reflected in our results will be repeated in future years. We would therefore advise caution in using our findings to inform future policy choices.

Appendix 1: Further details of Econometric techniques

Fixed and random effects estimators (static models)

These models are useful when analysing the impact of variables that vary over time, while controlling for country- and sector- specific factors. These will help mitigate the risk of omitted variable bias.

Two-way causality between private and public investment can lead to results from ordinary least squares models being biased and inconsistent. Using instrumental, or proxy, variables that break the link between private investment and public investment (the endogenous variable in this instance) allows us to overcome any endogeneity issues arising from simultaneity.

Static panel methods also allow for the use of instrumental variables, which enable us to control for a two-way causal relationship between public and private R&D investment ("simultaneity") or omitted variables which have not been included in the models. However, this increases the volume of data required as it is necessary to find suitable variables to act as instruments. Further, these methods are not suitable in cases where past values of investment have an impact on present values.

Dynamic panel models

Introduction to dynamic panel models

Private R&D investment in the current period might be affected by past trends in private R&D, as well as public support and the control variables. This can create complications within the modelling process.[32] In such cases, dynamic panel methods, such as the Arellano Bond estimator (also known as Difference GMM) and Blundell Bond estimator (System GMM), would allow us to account for the presence of such "dynamic effects". The Arellano–Bond estimation (Difference GMM) starts by transforming all regressors, usually by differencing, and uses the generalized method of moments (GMM). The Arellano–Bover/Blundell–Bond estimator (System GMM) augments Arellano–Bond by making an additional assumption that first differences of instrument variables are uncorrelated with the fixed effects. This allows the introduction of more instruments and can dramatically improve efficiency. It builds a system of two equations—the original equation and the transformed one.

[32] Including past values of private R&D investment will lead to bias in the estimation process as past values will be correlated with the error term due to serial correlation.

The assumption of no correlation between the first differences of instrument variables and fixed effects in System GMM allows for the inclusion of time-invariant regressors, which would disappear in Difference GMM.

Dynamic panel models have become increasingly popular in many areas of economic enquiry, and their use has provided new insights. Using dynamic panel models allows us to find overall (long-run) coefficients for the explanatory variables as well as the contemporaneous (or short-run) ones. Dynamic models were used by Thomson (2013) and Guellec and van Pottelsberghe (2003) to measure the additionality of public R&D investment.

The advantages of dynamic models include:

- accounting and controlling for the impact of past values of private R&D on current values;
- estimation of overall (long-run) and contemporaneous (short-run) effects; and
- use of past values of explanatory variables as instrumental variables to mitigate the bias due to two-way causality between private and public R&D.[33]

The robustness of dynamic panel methods depends on the amount of data used, and the inclusion of suitable controls. In particular, dynamic panel methods can be vulnerable to omitted variable bias. It is sometimes possible to mitigate this risk by using suitable instrumental variables. Dynamic panel methods allow the use of past values of variables as instruments, which reduces the need to find alternative instrumental variables. While past values of variables can also be used as instruments in a static panel model setting, doing so would not necessarily account for serial correlation between past and current values of R&D investment. There is therefore a greater risk of obtaining biased estimates in a static panel setting.

The need for a dynamic model: Wooldridge test for serial correlation

The Wooldridge test allows us to check whether past values of private R&D influence current values, and therefore whether the variables suffer from autocorrelation. If the variables are found to be autocorrelated we may infer that there is a need for a dynamic model.[34] The disadvantage of a dynamic panel model, however, is that it can add considerable complexity to the modelling process. A simpler static model might therefore be a preferable approach if the Wooldridge test does not suggest a dynamic panel is necessary.

[33] To avoid overfitting the model, we would start with a single lag and then add more depending on the sample size and the model diagnostics.
[34] Strictly speaking, the Wooldridge test is a test for autocorrelation and not a definitive test to choose between static and dynamic panel methods. However, it is commonly applied to inform choices between static and dynamic panels.

Multi-level models

Sector-specific factors are likely to be similar across countries, and the country-specific factors are likely to be common across sectors. A multi-level model accounts for such interdependencies in the country- and sector-specific factors, and provides better estimates in a static panel setting. The multi-level model does, however, result in a more complex modelling framework and is typically unable to account for dynamic effects. We did not therefore, recommend its use in this study.

Improving on previous research

The Economic Insight study (2015) is the most recent literature available on UK leverage rates. BEIS has identified that Diamond (1999) and Lichtenberg (1987), in common with Economic Insight (2015) use time series regression analysis to estimate the responsiveness of private R&D investment to a change in public R&D investment.

Below we discuss how the dynamic panel approach improves on issues identified in previous studies.

Limited data points

Our use of panel data techniques, where each panel is defined by country (and sometimes industry), provides a substantial increase in the number of data points available and enables us to overcome the limitations of short time series. The dynamic panel estimators that we have explored are designed for just this kind of situation, where the time series dimension is short but a large amount of cross-sectional information is available.

Model specification issues

The panel data methods used are well suited to controlling for unobservable country- or sector- specific factors. As discussed above, omitted variable bias is one of the causes of endogeneity, which can be mitigated using suitable instruments. Dynamic panel methods allow the use of past values of variables, which reduces the need to find alternate variables for use as instruments. Finally, statistical tests can be used to check whether omitted variables are leading to biased results (for example, the Ramsey Regression Equation Specification Error Test, or RESET test).

Collinearity between different types of public funding

Previous studies analysed whether the elasticity of private funding with respect to public funding varied according to the type of public funding allocated, i.e. Government funding, Higher Education funding, Research Councils (RCs) funding or HEFCs funding. The studies recognised that 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.[35] Figure 60 below shows the correlation between the different types of public funding.

Figure 60: Correlation between different types of public funding

	Grants and loans	Tax credits	Funding through HEI and RCs
Grants and loans	1.00	0.85	0.88
Tax credits	0.85	1.00	0.95
Funding through HEI and RCs	0.88	0.95	1.00

Source: Oxford Economics

Using highly correlated variables in the model could “confound” the leverage estimates, i.e. the model may attribute the causal effect of one type of public investment to the other, leading to biased leverage estimates. Including both in the same regression could lead to large differences in coefficients from small changes in the specification and large standard errors (the variables are not individually significant). On the other hand, omitting one type of public R&D investment to estimate the leverage rate corresponding to the other may lead to lead to omitted variable bias.

Not including other sources of public funding is likely to lead to the additionality estimates being biased upwards due to the positive impact on private R&D of the other type of public funding Statistically, omitted variables have the same effect as two-way causality, i.e. they lead to endogeneity in the model. However, within the System GMM approach, we mitigate the impact of omitted variables using suitable lags of the different types of public funding as instrumental variables. In other words, we used past values of public R&D funding as instruments to control for the exclusion of present values of other sources of R&D funding.

To test whether collinearity is likely to be of concern**,** we estimated separate regressions by including both variables in the same regression, and also individually, i.e. by excluding the other source of public funding from the model. We found that the coefficients from various models are similar and also statistically significant where both variables are included in the model. This indicates that collinearity is not strong enough to bias the coefficients estimated from the model.

Two-way causality between private and public investment can lead to results from ordinary least squares models being biased and inconsistent. Using instrumental, or proxy, variables that break the link between private investment and public investment (the endogenous variable in this instance) allows us to overcome any endogeneity issues arising from simultaneity. The System GMM approach uses “internal” instruments, i.e. lags of the endogenous variable, to account for potential two-way causality. This approach is similar to that taken in the study by Becker and Pain (2003).

[35] For example, see Economic Insight (2015), Annex B, Table A8.

Selection bias

There may be "selection bias", whereby the sectors that receive most support are also those with the highest leverage rates. This may be the case where the scope for leveraging private funding has been considered during the funding allocation process. While this makes sense from a resource allocation perspective, it is important to understand such factors since they may mean that findings do not hold true across all sectors. Several studies, such as Czarnitzki et al. (2011), use variables such as the number of R&D employees and historic expenditure on R&D to control for increased propensity for certain firms to receive more R&D support from the government. At the country level, the propensity for certain countries to spend more on R&D can be accounted for using suitable control variables.

Unit root issues

In time series data when using ordinary least squares techniques, there is a risk of spurious regressions due to an issue known as "unit roots", particularly where R-squared values are extremely high.

Time series data need to be tested for stationarity, i.e. the absence of unit roots. In simple terms, a non-stationary series has no tendency to a long-run path. Anything that influences the series will tend to have a permanent effect on it.

The existence of unit roots may lead to invalid estimates from regression analysis. In dynamic panel models, the "Arellano-Bond (2) test of first differences" allows us to test whether the model is robust to the presence of unit roots.

Weak instruments

The two stage least squares approach is a technique that enables an examination of instruments to check whether they are considered weak. However, this is one based on linear estimation which is not equivalent to the GMM estimator which simplifies to the former only when the errors are homoscedastic. Homoscedasticity is not likely to hold in our case as the variances in idiosyncratic errors may be different in different countries. Therefore, we have not been able to implement the two stage least squares approach.

More generally, the Arellano Bond estimator (Difference GMM) is likely to suffer from the weak instrument problem if the relationship between private R&D and the change in private R&D is weak. However, the estimator we use, i.e. the System GMM estimator designed by Blundell and Bond, which is implemented in Stata using the xtabond2 command, mitigates this risk using an instrument-construction process that does not rely on the assumption about the correlation between private R&D and the change in private R&D.

Model specification

Size effects

In our specifications, we have used both the level of employment and the level of GDP in our regressions, but found that the coefficients on these were not significant. This may be because differences in the size of the economy are captured in through "fixed effects" in the panel set up, or due to the strong correlation between public GERD or the lag of private R&D and the size of the economy (measured either through GDP or employment levels). We have also tried specifications with the intensity of private R&D as the explanatory variable and public R&D intensity as the main explanatory variable, but were not able to find a satisfactory specification.

Based on the above, we believe that the panel effects control for the impact of the size of the economy on private R&D.

Use of instruments

Instruments are used to control for potential endogeneity in a regression. As mentioned above, there is potential two-way causality between private R&D and public R&D. There may also be conceptual reasons to believe that an increase in private R&D investment may increase employment. Therefore we have specified public R&D and employment growth as endogenous variables that will be estimated using instrumental variables. Further we have tested and found that public R&D and employment growth are endogenous, and therefore we have specified them appropriately in the xtabond2 syntax used to implement the System GMM estimator in Stata. We found that the interest rate was not endogenous, and we have therefore treated it as an exogenous variable in our specification.

Another source of potential endogeneity is Nickell bias. This is bias which arises due to the inclusion of the lagged dependent variable which is potentially endogenous. The LSDVC (Least Squared Dummy Variable – Corrected) technique allows us to correct for Nickell bias. However, the LSDVC approach but does not allow for the use of other instruments to account for other endogenous variables (i.e. endogeneity due to public R&D or employment growth). If Nickell bias had been the only concern, we would have used LSDVC approach. In addition to the lag variable, in this case, there are other explanatory variables that are potentially endogenous. The System GMM approach allows us to account for Nickell Bias as well as use other instruments to account for endogeneity due to other variables. Therefore, we use the flexibility of the System GMM approach to account for these concerns.

In building our econometric models, we were concerned to limit the number of instruments used. A large number of instruments, i.e. "instrument proliferation", weakens the estimation process as well as the diagnostic tests. A general rule of thumb is to limit the number of instruments to less than the number of countries.[36]

[36] (Roodman 2006)

We have reported the number of instruments in all our specifications, and have limited it to less than the number of countries in our sample.

We use lagged variables as instruments. To determine the preferable model specification we have tested regressions where we limited the lag on private R&D and public R&D to one, two, three, four and five lags. We found that the results are of a similar magnitude (i.e. 0.3206 to 0.4689 compared to 0.2339-0.3798 in our preferred specifications).

The number of instruments also has implications for testing model diagnostics. Both the Sargan and Hansen tests are tests for overidentifying restrictions. The Sargan test is not robust to heteroscedasticity, but is not weakened by a large number of instruments. On the other hand, the Hansen test is robust to heteroscedasticity but is weakened by a large number of instruments. A general rule of thumb is to limit the number of instruments to less than the number of countries, as noted above.[37] In all our models, we use the Hansen test to account for heteroscedasticity and check whether the number of instruments is below the number of countries. We have reported the number of instruments and the p-values for the Hansen test in all our specifications.

[37] (Roodman 2006)

Appendix 2: Time series analysis

Overall UK leverage rate

Our first approach to assessing the overall UK leverage rate was based on time series analysis of ONS data. This approach was ultimately unsuccessful, but in this appendix we describe the work undertaken and main findings.

Data

As discussed in the box in Section 3.3, within the GERD and BERD databases R&D funded through tax credits is counted within business-funded R&D. That is, business-funded R&D includes some spending which is indirectly supported by the public sector. As outlined in the box in Section 3.3 we adjusted the data series to account for this by adjusting the GERD data to remove the component for business funded R&D which is actually funded through tax credits.

The R&D tax credit schemes in the UK were introduced in 2000 for small and medium sized enterprises and in 2002 for larger firms.[38] The adjustment to GERD data is therefore required post-2000 but no adjustment is made prior to that because the tax credit scheme was not in place. From 1995 to 2000, the unadjusted and adjusted private BERD figures are equal.

We ran our analysis using both the adjusted and unadjusted datasets. We found that the tax credit adjustment makes very little difference to the results and the discussion below is relevant to both the adjusted and unadjusted datasets.

Model selection

The models in this section estimate the impact of public R&D in stimulating additional private R&D in the UK, over the period from 1995 to 2016.

To provide a best estimate of the UK leverage rate we first determined which type of model specification was appropriate given the nature of the data. The time series for public and private R&D both suffer from unit roots (as suggested by the Augumented Dickey Fuller, the Zivot Andrews and the Clement Reyes Montanes tests). The presence of units roots could lead to spurious regression results and so we specified our model in the first difference of the logs (i.e. we used growth rates instead of levels).

A simple Ordinary Least Squares (OLS) regression using various specifications suggested a negative relationship between public R&D and private R&D. However, two-way causality between private and public investment can lead to results from OLS models being biased and inconsistent. To overcome this we used instrumental,

[38] "R&D tax credits", in Institute for Fiscal Studies <https://www.ifs.org.uk/economic_review/fp214.pdf/> [accessed 25 January 2018]

or proxy, variables (using past values of public R&D as instruments) that break the link between private investment and public investment.

THE USE OF LAGS AS INSTRUMENTS

Note that using lags as instruments is not the same as using lags as explanatory variables. The explanatory variables are used to estimate a causal relationship, whereas instruments help mitigate the risk that these causal relationships are biased. The causal relationship is not between the dependent variable and the instruments, so where lags are used as instruments, these lags should not themselves belong to the regression. In other words, if we believe that private R&D investment is influenced by public R&D in the current year and the previous two years, then the instruments for public R&D investment should not include the lag in the two previous years. We used lags of two, three and four years as instruments in our regressions.

As a further check, we experimented with Error Correction Models (ECMs). An ECM is a time-series model commonly used to estimate both short-run and long-run effects of one time series on another.

Control variables

Control variables were selected following the systematic approach outlined in Section 3.6. Failing to include the right factors in the model could lead to misleading conclusions as changes in private R&D could be attributed to public support when they actually result from other factors.

We describe the process we have followed below, along with a few examples of the outcomes to illustrate our approach to building and testing a robust model to estimate leverage. Where data permits, we have tested all of the variables listed in Figure 11 in our specifications.

From our literature review, we identified four types of factors which have been used as control variables in previous studies of R&D leverage. Firstly, the **economic climate** may affect the funds firms have available for R&D, the returns they earn, and their appetite to undertake investments with uncertain returns. Looking at the growth rate of economic variables can control for this. To do this, we tested the GDP growth rate, employment growth rate and investment (GFCF) growth rates in our specification.[39]

To decide on our preferred control variables, the models tested using the process described above must pass the relevant diagnostic tests; the coefficients on the control variables should be significant; with an economically sensible sign; and be of a plausible magnitude. For example, in a model with employment growth, the coefficients on the employment variable was negative and not statistically

[39] See specifications IVREG B, IVREG C and IVREG D in Figure 115

significant.[40] Similarly, in models with GFCF growth or GDP growth, the coefficients were not found to be statistically significant in most specifications, and where they are significant, the magnitude is implausibly large and not economically meaningful.[41]

The size of an economy may also influence the value of R&D undertaken. However, the GDP and employment time series are likely to suffer from unit roots, and therefore including these in a model is likely to lead to spurious regression results. To mitigate the bias arising from unit roots, we express the model in first differences of the logs, which is mathematically equivalent to the growth rate of these variables.

The other variables to control for the general economic environment in our specifications included the FTSE-350 Index and the AIM All Share Index, and also the stock of capital and the change in inventory levels. The various share indices offer an alternate way of measuring the general economic climate and provide an indication of the ability of firms to raise capital through equity. Model specifications with these control variables did not satisfy the various criteria described above. For example, specifications that included capital stock changes, the coefficient on capital stock was not significant. [42]

The second group of control variables identified from previous research related to **workers' skills and knowledge**, including the cost of researchers' wages. The latter might be expected to be negatively related to the amount of R&D undertaken since higher wage costs make R&D more costly. We explored this by including variables for R&D wages or compensation of employees.[43]

As well as being negative, the coefficient on R&D wages should be significant and of a plausible magnitude. We found that the coefficient is statistically insignificant.[44]

The third group of control variables related to the degree of competition in an economy since a high **degree of competition** in product markets may stimulate firms to innovate new products and services, and develop new processes to reduce costs. We used the Herfindahl-Hirschman Index (HHI) as an indicator for the degree of competition, but the coefficient on this indicator was not statistically significant.[45]

The final group of variables included factors relating to **international trade and investment**, which may increase the degree of competition faced by domestic firms. It may also enable a firm to benefit from overseas R&D by competing or collaborating firms. To explore this we developed specifications which included exchange rates and the export-share of GDP. A high volume of exports would indicate that the potential size of the market available for newly developed products would be larger, and therefore businesses would have a greater incentive to invest in

[40] The model with specification IVREG B in Figure 115

[41] See the model with specification ECM J in Figure 115 The results indicate that a 1 percentage increase in GDP leads to a 260% decrease in private R&D, where the coefficient is significant at the 10 percent level.

[42] See specifications IVREG L in Figure 116

[43] See specifications IVREG E and IVREG G in Figure 115

[44] See specifications IVREG E and IVREG F in Figure 115

[45] See specification IVREG O in Figure 116

R&D to develop new products. They might also face greater competition and benefit from a greater exposure to new products, technologies and ideas. However, we found that the coefficient on export share of GDP and on exchange rates was not statistically significant. [46]

Results

As outlined above, various modelling specifications were tested, but we were unable to establish a robust statistically significant relationship. The most likely explanation is the limited sample size, since we had only 21 years of data to work with (which reduces to 20 since the model uses the change in the variables instead of their levels, and further to 19 in ECMs and IV regressions due to the use of lag terms).

This short time series limits our ability to add a large number of control variables (including lags) because we have relatively few “degrees of freedom” available to work with.[47] As a result the coefficients will be subject to a high degree of uncertainty, making it difficult to robustly determine the key drivers of private R&D. Summary statistics of the variables used in the modelling are presented in Figure 61 below.

Figure 61: Summary statistics of variables used in UK time series regressions

Variable	Min	Max	Mean
Private BERD (£, mn)	0.0	18,278.7	10,040.3
Private BERD adj (£, mn)	0.0	18,278.7	9,722.6
Public GERD (£, mn)	5,962.4	8,770.1	7,223.9
Employment growth	-3%	4%	1%
Interest rate	0%	15%	7%

Source: Oxford Economics analysis of ONS and OECD data as of June 2018

Figure 62 shows the results from our Error Correction Model (ECM), Instrumental Variables (IV) and OLS regressions with and without the adjustment for tax credits. Each of these used the first difference in the log of employment (approximately the employment growth rate) as a control variable. We have selected specifications with employment growth rate as an example for our discussion in this section as we have found specifications with employment growth rate to have a statistically significant results elsewhere in our analysis. We tested a large number of specifications including other control variables individually and jointly, but we were not able to establish a satisfactory model.

The results presented here are largely similar to those from other model specifications using other control variables, which are presented in Figure 111 – Figure 122 in Appendix 8: Econometric modelling outputs and test results.

[46] See specifications IVREG P, IVREG Q in Figure 116

[47] Degrees of freedom are the number of observations/values in the data that are free to vary when estimating a regression. It is typically calculated as n-k-1 where n is the number of observations and k is the number of independent variables in the regression.

The first row in Figure 62 is the coefficient on the public GERD variable—the estimated leverage rate. In the ECM and OLS specifications, the leverage rate is negative, suggesting that public R&D crowds-out private R&D, although these coefficients are not statistically significant. The coefficient on the employment variable is also statistically insignificant in the ECM specification. Given that neither of the explanatory variables are statistically significant, the ECM cannot be regarded as an appropriately specified model.

By comparison, the coefficient on employment growth is statistically significant in one of the IV and both OLS specifications, but the magnitude appears implausibly high. For example, in the IV model, a one percent change in employment growth is, all else equal, associated with a 3.52 percent change in private GERD. We therefore conclude that neither the IV nor OLS specifications provide an appropriate basis for estimating the overall leverage rate.

Figure 62: Results of time series regressions methods using only one control variable

Dependent variable: Private GERD (first difference of logs)[48]

Monetary variables specified in GBP and deflated using CPI

See Figure 111 – Figure 122 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	**ECM (not adjusted for tax credits)**	**ECM (adjusted for tax credits)**	**IV REG (not adjusted for tax credits)**	**IV REG (adjusted for tax credits)**	**OLS (not adjusted for tax credits)**	**OLS (adjusted for tax credits)**
Public GERD (first differences of logs)	-0.0769	-0.0605	0.3787	-0.8748	-0.1864	-0.2827
	(0.1813)	(0.2263)	(4.7110)	(4.3946)	(0.2261)	(0.2739)
Employment (first differences of logs)	0.5010	0.0539	3.5226**	3.4531	2.2794***	2.6445***
	(0.8713)	(1.1493)	(1.4120)	(2.0268)	(0.4851)	(0.6985)
Constant	0.0237*	0.0252	-0.0123	0.0090	0.0060	0.0038
	(0.0119)	(0.0151)	(0.0875)	(0.0849)	(0.0095)	(0.0109)
Observations	19	19	19	19	20	20
R-squared	0.4878	0.4620	n.a.	.1785	0.3128	0.2846
F-test	4.76	4.29	4.25	1.74	13.46	7.68
Prob > F	0.0159	0.0225	0.0331	0.2067	0.0003	0.0042

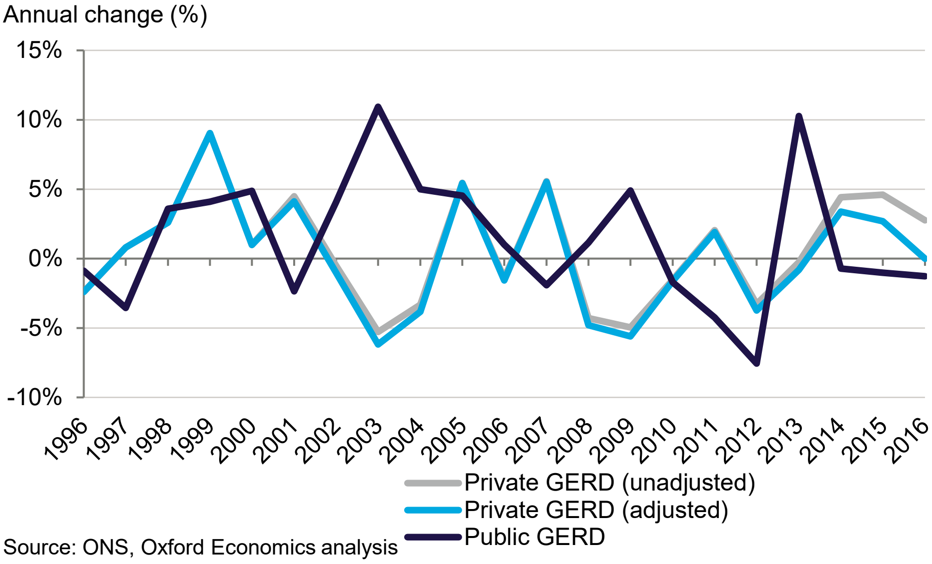
Source: Oxford Economics

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Stata suppresses the R-squared result when R-squared is negative as a negative R-squared is not a statistically meaningful result.

[48] The R-squared indicates how well the model predicts the dependent variable, whereas the F-test tests whether the coefficients in the model are significant. A p-value of greater than 0.05 indicates that the null hypothesis of joint significance of control variables cannot be rejected. In other words, we cannot confidently say that the coefficients are all not zero.

Figure 63 below illustrates the historic growth in private GERD (unadjusted and adjusted for government tax credits), our dependent variable, and public GERD, the independent variable of interest. The unadjusted and adjusted private GERD series are identical for 1996 to 2000 as there was no tax credit scheme during this period. The chart illustrates that the growth rate of private GERD fluctuates from year to year, which may explain why it is difficult to establish a clear association with public GERD.

Figure 63: Growth in public GERD and private GERD

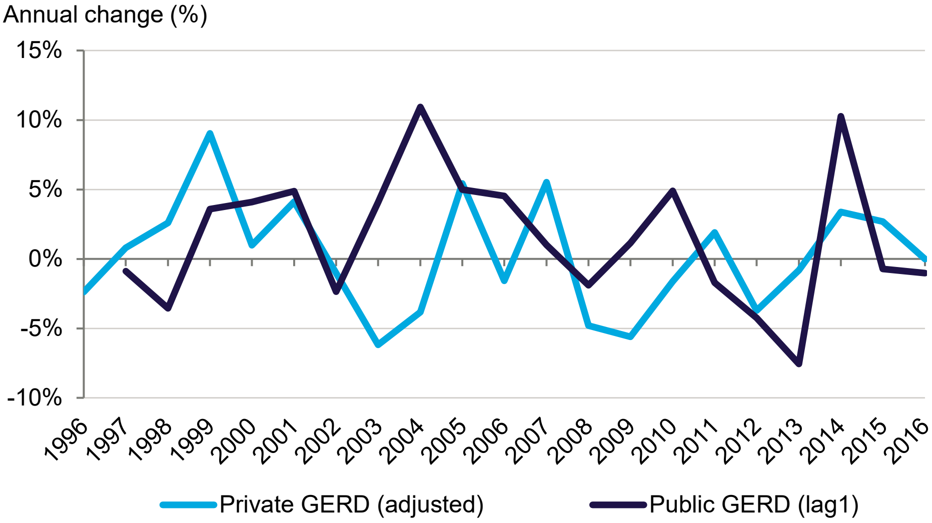


Source: ONS, Oxford Economics analysis

Lag structure

As mentioned in Section 3, it is expected that the level of private R&D will respond to public R&D with a lag. In Figure 64 and Figure 65 below we present the growth in adjusted GERD alongside the one-year and two-year lag of public GERD respectively. Figure 64 does not reveal any clear association between the growth in (adjusted) private GERD and the growth in public GERD, lagged by one year.

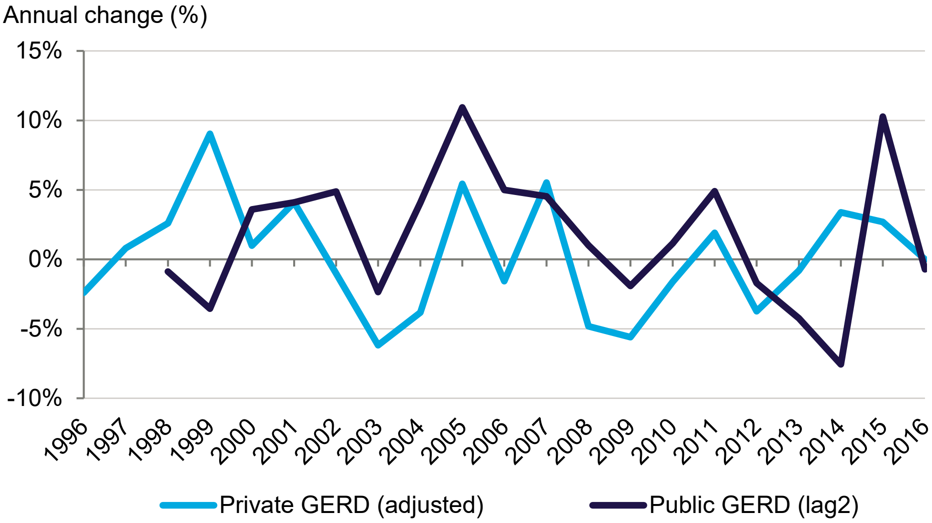
Figure 64: Growth in public GERD (one-year lag) and private GERD



Source: ONS, Oxford Economics analysis

The association becomes more apparent when using the two-year lag of growth in public GERD (Figure 65). This does not necessarily imply there is a statistically significant causal relationship between the two variables because it omits all other variables that may influence private GERD. To establish this we need to refer to our econometric models.

Figure 65: Growth in public GERD (two year lag) and private GERD



Source: ONS, Oxford Economics analysis

To determine the lag structure we followed the approach described in Section 3, comparing the robustness of models using one, two and three period lags of public R&D as explanatory variables. The tables below illustrate the regression results using different lag structures for the IV and ECM specifications respectively. As shown in the tables, the coefficients on various lags of public R&D investment are not significant even at the five percent level of significance. Once again, we present results based on employment growth as a control variable, but similar results were found when testing other control variables.

For both the IV and ECM specifications, the coefficient on employment growth is insignificant at the 10 percent level. In the IV specifications, the coefficients on this variable are also implausibly large in magnitude. For example when using a three period lag of public R&D, a one percent change in employment growth is, all else equal, associated with a 23 percent reduction in private GERD. Further, the F-test results reject the null hypothesis that the variables are jointly significant. Once again, therefore, we are unable to establish a satisfactory model for estimating the leverage rate using a time series approach. The failure to establish a satisfactory model is likely to be due to the small sample size, and not because of the lack of a meaningful economic relationship between the variables.

Figure 66: Results of time series Instrumental Variable (IV) regressions methods using only one control variable and various lags[49]
Dependent variable: Private GERD (first difference of logs)
Monetary variables specified in GBP and deflated using CPI

Variables	IV Reg – no lags (adjusted for tax credits)	IV Reg – 1 lag (adjusted for tax credits)	IV Reg – 2 lags (adjusted for tax credits)	IV Reg – 3 lags (adjusted for tax credits)
Public GERD (first differences of logs)	-0.8748			
	(4.3946)			
Public GERD (first differences of logs) - first lag		-1.9856		
		(3.3424)		
Public GERD (first differences of logs) - second lag			2.7238	
			(8.0435)	
Public GERD (first differences of logs) - third lag				-20.2115
				(353.6688)
Employment (first differences of logs)	3.4531	5.2249	0.5092	-23.1295
	(2.0268)	(5.5179)	(13.6359)	(477.4133)
Constant	0.0090	0.0082	-0.0196	0.5655
	(0.0849)	(0.0453)	(0.0498)	(10.1424)
Observations	19	19	19	19
R-squared	0.1785	n.a.	n.a.	n.a.
F-test	1.74	0.45	0.32	0.00
Prob. > F	0.2067	0.6451	0.7278	0.9956

Source: Oxford Economics

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; In general, R-squared measures are not informative in IV regressions. Stata suppresses the R-squared result when R-squared is negative as a negative R-squared is not a statistically. meaningful result. Both the public GERD variables (various lags) and employment, both expressed as the first differences of their logs, are instrumented using their first lags.

[49] The R-squared indicates how well the model predicts the dependent variable, whereas the F-test tests whether the coefficients in the model are significant. A p-value of greater than 0.05 indicates that the null hypothesis of joint significance of control variables cannot be rejected. In other words, we cannot confidently say that the coefficients are all not zero.

Figure 67: Results of time series Error Correction Model (ECM) regressions methods using only one control variable and various lags
Dependent variable: Private GERD (first difference of logs)
Monetary variables specified in GBP and deflated using CPI

Variables	ECM - 1st lag (adjusted for tax credits)	ECM - 2nd lag (adjusted for tax credits)	ECM – 3rd lag (adjusted for tax credits)	ECM – 4th lag (adjusted for tax credits)
Public GERD (first differences of logs)	-0.0605			
	(0.2263)			
Public GERD (first differences of logs) - first lag		0.0769		
		(0.2310)		
Public GERD (first differences of logs) - second lag			0.3551	
			(0.2227)	
Public GERD (first differences of logs) - third lag				-0.4295*
				(0.2410)
Employment (first differences of logs)	0.0539	0.3018	0.6158	0.1231
	(1.1493)	(1.1441)	(1.0558)	(1.0393)
Constant	0.0252	0.0204	0.0127	0.0291*
	(0.0151)	(0.0151)	(0.0146)	(0.0141)
Observations	19	19	19	19
R-squared	0.4620	0.4390	0.5040	0.5406
F-test	4.29	3.91	5.08	5.88
Prob. > F	0.0225	0.0301	0.1026	0.0073

Source: Oxford Economics

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix 3: Leverage rates for indirect support (tax credits)

Time series analysis

Various modelling specifications and combinations of control variables were tested to investigate the leverage rate achieved through indirect support, but we were unable to establish a robust statistically significant relationship. This included testing different lag structures, although since businesses are likely to claim tax credits at the end of the financial year in which they invested in R&D, there is less reason to believe higher order lags would be appropriate in this case. The most likely explanation for our inability to identify a robust model is, once again, the limited sample size: we had only 21 years of data to work with (which effectively reduces to 20 since the model uses the change in the variables instead of their levels).

This short time series limits the degrees of freedom and therefore our ability to add a large number of control variables (including lags). This makes it difficult to robustly determine which are the key factors associated with private R&D. Summary statistics of the variables used in this section of the modelling are presented in Figure 68 below.

Figure 68: Summary statistics of variables used in time series regressions

Variable	**Min**	**Max**	**Mean**
Private GERD (£, mn)	17,897	21,505	19,900
Tax credits (£, mn)	79	1,568	654
Interest rate	1.2%	14.9%	7.6%
Workforce jobs (000s)	28,495	35,057	31,573

Source: Oxford Economics analysis of HMRC, ONS and OECD data as of June 2018

Figure 69 shows the results from ECM, IV and OLS regressions.[50] In all three models the coefficient on the tax credits variable is negative and insignificant. Each of these equations used the first difference of the log of employment (approximately the employment growth rate) as a control variable. In both the ECM and IV model, the coefficient on our employment variable was insignificant, and therefore neither of the two independent variables in these models were able to explain changes in private GERD. The results presented here are similar to those from model specifications using other control variables, which are presented in Figure 123 – Figure 125 in Appendix 8.

[50] For simplicity we have selected model specifications based on a single control variable. While this may lead to omitted variable bias, we also developed specifications with more variables and obtained similar results.

Figure 69: Results of time series regression methods using only one control variable

Dependent variable: Private GERD (first differences of logs)
Monetary variables specified in GBP and deflated using CPI
See section Figure 123 – Figure 125 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	ECM	IV REG	OLS
Tax credits (first differences of logs)	-0.0403	-0.2843	-0.0333
	(0.0352)	(0.3750)	(0.0399)
Employment (first differences of logs)	1.1751	16.0930	1.6465**
	(0.7883)	(22.1307)	(0.5408)
Constant	0.0003	-0.0960	-0.0089
	(0.0121)	(0.1243)	(0.0121)
Observations	14	14	14
R-squared	0.6055	n.a.	0.2672
F-test	5.12	0.29	4.86
Prob > F	0.212	0.7561	0.0308

Source: Oxford Economics
Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

HMRC regional panel data

As with the previous section, the models presented in this section have been developed to establish a best estimate of the leverage rate for R&D tax credits in the UK. However, in this section we estimate the average relationship between regional private GERD and regional R&D tax credits across UK regions over the period 2013-14 to 2015-16 (i.e. the analysis is based on a panel dataset). Using panel data techniques provides a larger number of data points, albeit with a relatively short time series.

We developed a correlation matrix using employment and GVA variables as potential controls, as these are some of the few variables available at regional level. The correlation matrix suggests a strong positive correlation between workforce jobs and GVA which could potentially lead to multicollinearity, and so we have tested these variables separately in the model.

Figure 70: Correlation analysis of key variables in the analysis

Variable	Private BERD	Tax Credits	Workforce jobs	Growth in workforce jobs	GVA	GVA growth
Private BERD	1.00	0.23	0.44	0.10	0.37	0.02
Tax credits	0.23	1.00	0.30	0.18	0.36	0.17
Workforce jobs	0.44	0.30	1.00	0.17	0.86	0.13
Growth in workforce jobs	0.10	0.18	0.17	1.00	0.10	0.46
GVA	0.37	0.36	0.86	0.10	1.00	0.13
GVA growth	0.02	0.17	0.13	0.46	0.13	1.00

Source: Oxford Economics

To test whether a dynamic panel specification is needed, we ran the Wooldridge test which determines whether variables suffer from autocorrelation. If variables are found to be autocorrelated we may infer the need for a dynamic model to account for this. The Wooldridge test did not indicate any evidence of autocorrelation in the dataset. However, the reliability of the Wooldridge test is reduced when working with small samples and this result should not be regarded definitive.

We therefore ran both static and dynamic models with instrumental variables to estimate the leverage rate. The results are shown in Figure 71 and we did not obtain statistically significant results for the impact of tax credits using either type of model. We did obtain a significant and large coefficient for GVA growth in both models, but the coefficients on employment growth are insignificant. In the dynamic panel specifications, the coefficient on lagged private GERD is high, and where it is above one this implies that historic investments in private GERD will have an ever-increasing impact on private GERD today as time progresses. This type of "explosive" series appears implausible suggesting these models should not be relied upon.

The small dataset limits the degrees of freedom and therefore our ability to add a large number of control variables (including lags). Additionally, due to the regional nature of the tax credits data any control variables we are able to include in the specification need to have a regional dimension, which greatly reduces the number of control variables which can be tested.

Figure 71: Results of panel regression methods using only one control variable
Dependent variable: Private GERD (log)
Monetary variables specified in GBP and deflated using CPI
See Figure 126 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	Dynamic panel with GVA growth	Dynamic panel with employment growth	Static panel with GVA growth (first differences)	Static panel with employment growth (first differences)
Lag of Private GERD (logs)	0.9828***	1.0919***	n.a.	n.a.
	(0.0442)	(0.1172)		

Tax credits (logs)	0.0991	0.1177	0.1770	0.5079
	(0.0671)	(0.1219)	(0.1987)	(0.3236)
GVA growth rate	2.9887**		2.2943*	
	(1.4043)		(1.2718)	
Employment growth rate		0.3926		1.0977
		(3.1869)		(2.3008)
Constant	-0.3852	-1.1753	0.0133	-0.0903
	(0.4965)	(0.9197)	(0.0645)	(0.1021)
Observations (See Note 2)	33	33	11	11
Number of regions	11	11	11	11
Wald Chi (dynamic) / F-test (static)	510.22	98.81	1.93	1.28
Prob > chi2/ Prob > F	0.0000	0.0000	0.2065	0.3288

Source: ONS GERD data

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The number of observations in the static panel, specified in first differences, with instrumental variables reduces from 33 to 11 as we use the first lag of tax credits as instruments.

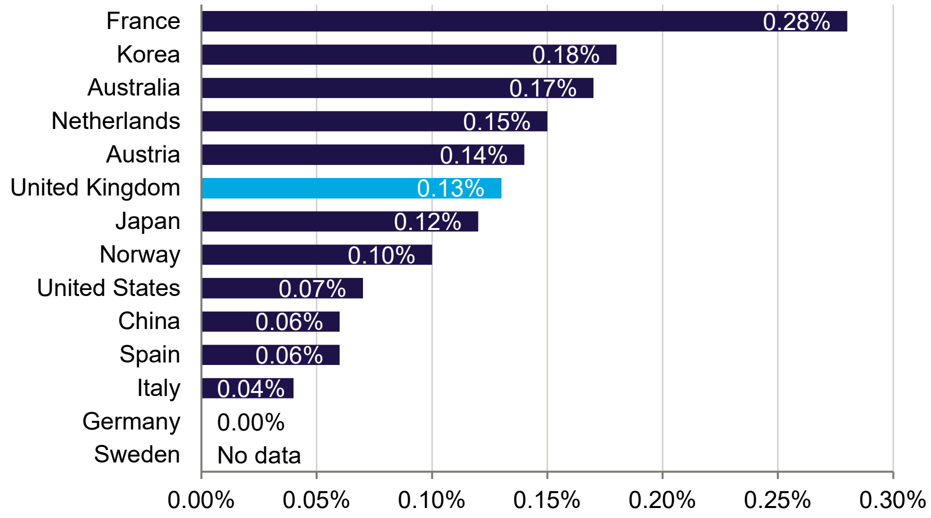
OECD cross sectional data

Our third approach to estimating the leverage rate from indirect support was to use data from the OECD, which indicate the value of tax credit support provided as a proportion of GDP. In the initial dataset downloaded from the OECD in June 2018, data on tax incentives were only available for a single year, and so this part of the analysis is based on a cross-section approach, rather than the panel approach used elsewhere.

In the latest available year, the UK's tax incentive support for business R&D was equivalent to 0.13 percent of GDP, placing the UK in the middle of the ranking, and similar to the value for Austria and Japan (Figure 72). At the upper end of the spectrum is France, which provides tax credit support equivalent to 0.28 percent of GDP, while at the lower end are countries such as Germany, which provide no tax credits to businesses engaging in R&D.[51]

[51] "A Study on R&D Tax Incentives", in European Commission <https://ec.europa.eu/taxation_customs/sites/taxation/files/resources/documents/taxation/gen_info/economic_analysis/tax_papers/country_fiches.pdf> [accessed 26 June 2018]

Figure 72: Tax incentive support for BERD (% of GDP, latest available year)



Source: OECD

To explore the impact of indirect R&D support we estimated simple OLS regressions using tax credits and various combinations of other explanatory variables. The results from just a few of the regressions we attempted are shown in Figure 73.[52] While we obtain statistically significant results for tax credits, the coefficients on other control variables are not statistically significant, and those on employment growth are not of the expected sign. The limited nature of the tax credits data once again appears to offer the most likely explanation for this. In effect, the small dataset limits our ability to add a large number of control variables (including lags).

Figure 73: Results of country cross-section regression methods using only one control variable

Dependent variable: Private GERD (log)

Monetary variables specified in GBP and deflated using CPI

Variables	Country cross-section with GVA growth	Country cross-section with employment growth	Country cross-section with GVA growth and interest rates	Country cross-section with employment growth and interest rates
Tax credits (logs)	0.7153***	0.6911***	0.6623***	0.6777***
	(0.0839)	(0.0878)	(0.0775)	(0.0823)
GDP growth rate	0.0168		1.5732	
	(1.7029)		(1.7919)	
Employment growth rate		-18.1837		-12.8403
		(18.1875)		(17.5842)
Interest rates			-0.1886*	-0.1713**
			(0.0926)	(0.0599)
Constant	1.0097	1.5073	2.0465**	1.9428**
	(0.9029)	(0.9725)	(0.9524)	(0.9111)

[52] The results presented are indicative of the kinds of results we obtained from alternative specifications.

Observations	26	23	26	23
R-squared	0.8267	0.8450	0.8500	0.8685

Source: Oxford Economics
Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The number of observations in the static panel, specified in first differences, with instrumental variables reduces from 33 to 11 as we use the first lag of tax credits as instruments.

OECD panel data

In the analysis in the previous section, we only had one observation per country, limiting our analysis to a cross-section approach. A new dataset became available in October 2018, during the latter stages of our research, and adds a time series dimension. This provided a panel dataset covering 31 countries (a total of around 281 observations). The number of years per country varies from more than 15 (Belgium, Japan, UK, US) to two (Finland).

The number of data points appeared sufficient to attempt dynamic panel modelling techniques. Figure 127 in Appendix 8: Econometric modelling outputs and test results provides a sample of the regression outputs using an adjusted private R&D series (with the tax credits adjustment) on tax credits individually, but also alongside other types of public R&D (and with other control variables).

Unfortunately, we were unable to obtain a suitable econometric model, perhaps due to the limited sample size. For example, in models 11 and 12 in Figure 127 in Appendix 8: Econometric modelling outputs and test results, the coefficient on tax credits is negative and significant, but the coefficient on employment growth is negative and all the other variables are not significant in most specifications. Note that the sample size of the regressions is lower as there are fewer data points on tax credits for which private R&D spending for the corresponding and the previous year (first lag) are both available.

Appendix 4: Do leverage rates differ across sectors in the UK?

Analysis using ONS data

Modelling approach

We have attempted to develop models to determine whether leverage rates differ across sectors in the UK. In particular, we determine whether there is sufficient statistical evidence to suggest that the historic UK leverage rates over the period 2000-2015 are different across product groups.

Our first approach to estimating the leverage rates across different product groups was to use panel data from the ONS. This dataset details the value of R&D conducted in the UK across 33 product groups and the time period (2000-2015). Product groups relate to the subject matter of the R&D, whereas most economic data, such as that used as control variables in our modelling, is categorised according to the industrial sector classification of the firm undertaking it. We would expect a reasonable degree of overlap between the two concepts, for example because we would expect most R&D relating to chemicals to be undertaken by companies in the chemicals sector. This will not always be the case, however. It is not difficult to imagine, for example, that companies classified within other manufacturing sectors might undertake R&D relating to chemicals.

While the ONS does publish BERD data based on the industrial sector of businesses, this is not available with a split by source of funding, meaning that it is not suitable for analysing public R&D leverage rates. For the purposes of our analysis we have therefore had to treat product groups as equivalent to industry sectors. The results from this part of the modelling should therefore be treated with a degree of caution.

The product groups in the BERD dataset were consolidated into larger groups to enable alignment with the sector aggregation of various control variables as shown in the table below.

Figure 77: Mapping product groups to sectors for ONS BERD data

Product Group	Aggregated product groups to align with economic sectors
Agriculture, hunting and forestry; Fishing	Agriculture, Forestry and Fishing
Extractive Industries	Mining & Quarrying
Food products and beverages; Tobacco products	Manufacturing
Textiles, clothing and leather products	
Pulp, paper and paper products; Printing; Wood and straw products	

Refined petroleum products and coke oven products	
Chemicals and chemical products	
Pharmaceuticals	
Rubber and plastic products	
Other non-metallic mineral products	
Casting of iron and steel	
Non-ferrous metals	
Fabricated metal products	
Machinery and equipment	
Computers and peripheral equipment	
Electrical equipment	
Consumer electronics and communication equipment	
Precision instruments	
Motor vehicles and parts	
Other transport equipment	
Shipbuilding	
Aerospace	
Other manufactured goods	
Electricity, gas and water supply	Utilities
Sewerage, waste management, remediation activities	
Construction	Construction
Wholesale and retail trade	Trade
Transport and storage	Transport & storage
Telecommunications	Information & Communication
Computer programming and information service activities	
Financial services and insurance	Financial & Real Estate
Real estate	
Miscellaneous business activities; Technical testing and analysis	Professional, Scientific & Technical Activities
Research and development services	
Public administration	Others

Source: Oxford Economics

It is also important to note that our independent variable of interest, public R&D, in this section of analysis is public BERD, which is different to the other chapters of the report where public GERD is used. This should be kept in mind when comparing results from this chapter to those obtained elsewhere in the analysis.

As discussed in the box in Section 3.3, within the GERD and BERD databases R&D funded through tax credits is counted within business-funded R&D. That is, business-funded R&D includes some spending which is indirectly supported by the public sector. As before we have adjusted the BERD data to remove the estimated component of business funded R&D which is actually funded through tax credits. The adjustment is made from 2000 onwards, when the tax credit scheme was introduced. From 1995 to 2000, the unadjusted and adjusted private BERD figures are equal.

Summary statistics of the variables used in this section of the modelling are presented in Figure 78 below.

Figure 78: Summary statistics of variables used in panel regression methods using ONS data

Variable	Min	Max	Mean
Private BERD adj (£, mn)	1	11,619	1,371
Public BERD (£, mn)	0	1,447	126
Interest rate	1.3%	5.3%	3.7%
GVA (£, mn)	9,106	173,326	72,081
GVA growth	-33%	49%	2%

Source: Oxford Economics analysis of ONS & OECD data as of June 2018

The use of panel data enables unobservable sector specific-effects to be accounted for within the modelling. Such effects might relate to institutional factors relating to particular sectors, for example. Omitting such factors from the modelling framework could lead to biased estimates of the relationship between public and private R&D.

The first step in our modelling approach was to establish whether a static or dynamic panel model specification is appropriate. Results from the Wooldridge test for serial correlation suggested that a dynamic panel approach was required in this case.[53]

Control variables were tested according to the systematic approach outlined in Section 3.6. However, because sector-level modelling was being undertaken we started by focusing on control variables that are available with sector-level detail. This greatly limited the pool of available control variables, such that the only sector-level control variables we could use were employment growth and GVA growth.

To test the robustness of our model, we conducted sensitivity tests in which national level control variables, such as interest rates, were included. A large number of specifications were tested (see Figure 135–Figure 139 in Appendix 8: Econometric

[53] The various panel data unit root tests require a balanced panel data without gaps. As we have an unbalanced panel with gaps, we have not been able to implement these tests. However, it is possible to use the results of the panel data regression (i.e. System GMM) estimates to establish stationarity (i.e. lack of unit roots). If the coefficient on the lag term has a value less than 1, then the assumption of stationarity is said to hold (Roodman (2006)). In our regressions in Figure 18 and Figure 21 the coefficient on the lag term is less than 1 which indicates that results are not affected by unit roots.

modelling outputs and test results), but our preferred model specification uses only GVA growth as a control variable. We accounted for potential endogeneity using lags as instruments.[54]

An important characteristic of our analysis is the use of interaction terms. There is a detailed explanation of the intuition and interpretation of these variables in Section 4.3.3. In this case we included a sector interaction term on our public BERD variable in order to estimate the leverage rate for a given sector, as distinct from the rest of the sample. This enabled us to statistically test whether the leverage rate in one sector in the UK was significantly different from the average across all other sectors in the UK. We repeated this process for all sectors by adding one sector interaction term at a time, and re-running the model for each individual sector using an interaction term for that sector.

Results

We found that the average leverage rate across all sectors is 0.3039 in our model specification in the short run. It is important to reiterate that our independent variable of interest, public R&D, in this section of analysis is public BERD, in contrast to the public GERD variable used elsewhere. Moreover, the results from this model only capture within-sector leverage, i.e. they will not detect spillovers which materialise in other parts of the economy. Therefore, the leverage rate is not directly comparable to those in the previous sections.

We were unable to find evidence of any statistically significant differences in the leverage rate across sectors. The few models which did indicate that there may be differences across sectors contained coefficients with implausible magnitudes and tended to fail diagnostic tests (see Figure 135–Figure 139 in Appendix 8: Econometric modelling outputs and test results). As such we did not deem those findings to be robust.

The elasticity estimate of 0.3039 translates to an average impact of £3.46 increase in private R&D investment for a £1 increase in direct public support to businesses in the short run and more than £10 in the long run. This is implausibly high compared with the results for direct public support to businesses in Section 5.3 and the evidence from the literature. The small sample size limits the number of instruments available which weakens the power of the Hansen test. Given the implausibly high leverage estimates along with the limited sample size, it would not be appropriate to draw any conclusions from this model.

Further, we find no statistical evidence of different elasticities across different sectors. However, as there are big differences in the ratio of public to private R&D

54 As discussed above, using lags as instruments is not the same as using lags as explanatory variables. The explanatory variables are used to estimate a causal relationship whereas instruments help mitigate the risk that these causal relationships are not biased. The causal relationship is not between the dependent variable and the instruments. Dynamic panel models allow us to use various lags of various explanatory variables as instruments. The lag choice is performed automatically by the estimator (we use “xtabond2” in Stata).

across different sectors, it would not be appropriate to apply the average elasticity estimate, of 0.3039, to the sector-specific public to private R&D spending ratio to obtain the sector-specific impact of a £1 increase in public spending.

The results of one of our specifications are presented in Figure 79. For each sector model, the coefficient on GVA growth has the expected positive sign and is statistically significant at the one percent level. The coefficient on public BERD, which represents the average leverage rate across the rest of the sample, is significant at the 10 percent level in all but one of the models. The estimated sector-specific leverage rate is insignificant in all models, except for construction and information & communication. However, the leverage rate is implausibly high in the case of construction, with an estimated leverage rate of 16, which implies a one percent change in public BERD in that sector is associated with a 16 percent increase in private BERD in that sector. As such, these models are not deemed to be robust.

Other specifications were tested, but the choice of sectoral control variables is much more limited relative to national control variables. These specifications either did not satisfy all the criteria above or, where they did, the sample size was significantly reduced due to availability of data for alternative control variables.

Figure 79: Results of panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI.
See Figure 135–Figure 139 in Appendix 8: Econometric modelling outputs and test results for other specifications

Variables	National	Ag., Forestry & Fishing	Mining & Quarryi-ng	Manufac-turing	Utilities	Constru-ction	Transpor-tation & Storage	Trade	Informat-ion & Commun-ication	Financial & Real Estate	Prof., Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.6490***	0.4039	0.4249	0.3460	0.4105	0.3868	0.7306***	0.3938	0.4631	0.4916*	0.4764*	0.4544
	(0.1569)	(0.2844)	(0.2773)	(0.2957)	(0.2781)	(0.2847)	(0.0753)	(0.2706)	(0.2730)	(0.2798)	(0.2563)	(0.2811)
GVA growth rate	1.4669***	1.2473***	1.2882***	1.2006***	1.1676***	1.2314***	1.4530***	1.2103***	1.2779***	1.2779***	1.3359***	1.2827***
	(0.2776)	(0.1506)	(0.1407)	(0.2022)	(0.1442)	(0.1498)	(0.1767)	(0.0964)	(0.1308)	(0.1636)	(0.1655)	(0.1319)
Public BERD (log)	0.3039**	0.3168*	0.3055*	0.2867*	0.2924*	0.3209*	0.2100***	0.3626**	0.3311**	0.2227*	0.3176	0.3336**
	(0.0980)	(0.1694)	(0.1702)	(0.1681)	(0.1545)	(0.1737)	(0.0667)	(0.1721)	(0.1646)	(0.1318)	(0.2062)	(0.1656)
Difference in leverage rates from UK leverage												
Sector-specific leverage		-0.2007	0.3866	0.2613	-0.2071	15.9916**	-0.1143	-0.1323	-0.6376***	0.1254	-0.0809	-0.1534
		(0.1775)	(0.3780)	(0.2590)	(0.1353)	(7.1132)	(0.1944)	(0.1486)	(0.1448)	(0.1086)	(0.1366)	(0.1325)
Constant	1.2063*	2.6228**	2.5259**	2.7678**	2.6722**	2.7309**	1.0517***	2.5626**	2.2301**	2.3218**	2.2507**	2.2803**
	(0.6540)	(1.1025)	(1.0464)	(1.1250)	(1.1414)	(1.1013)	(0.2862)	(1.0103)	(1.0241)	(1.1363)	(0.8932)	(1.0942)
Observations	100	100	100	100	100	100	100	100	100	100	100	100
Number of industrycodes	11	11	11	11	11	11	11	11	11	11	11	11
Number of instruments	10	8	9	9	9	8	9	9	9	9	9	9
AR2 p-value	0.115	0.161	0.149	0.144	0.216	0.169	0.0891	0.171	0.147	0.119	0.145	0.154
Sargan p-value	0.0251	0.0146	0.0252	0.0495	0.00728	0.0179	0.000792	0.0257	0.0297	0.00300	0.0159	0.0243
Hansen p-value	0.409	0.109	0.185	0.250	0.181	0.117	0.462	0.233	0.244	0.235	0.228	0.203

Source: Oxford Economics

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. Put simply, a high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying. restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private BERD, Public BERD and GVA growth rate are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

Analysis using OECD data

Modelling approach

Our second approach to estimating leverage rates across sectors was to use panel data from the OECD. This dataset details the value of R&D conducted across 26 OECD countries and 14 industries in the period from 2007 to 2015. As with the ONS data, in order to obtain a breakdown of R&D spending by sector we must use the BERD dataset.

Figure 80: Mapping product groups to sectors for ONS BERD data

OECD R&D Industry	Economic sectors for control variables
Agriculture forestry and fishing (A)	Agriculture, Forestry and Fishing
Mining and quarrying (B)	Mining & Quarrying
Manufacturing (C)	Manufacturing
Electricity, gas, steam, air conditioning and water supply; sewerage, waste management and remediation activities (D,E)	Utilities
Construction (F)	Construction
Transportation and storage (H)	Transportation & Storage
Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	Trade
Information and communication (J)	Information & Communication
Financial and insurance activities (K)	Financial & Real Estate
Real estate activities (L)	Financial & Real Estate
Professional, scientific, and technical activities (M)	Professional, Scientific & Technical Activities
Administrative and support service activities (N)	Others
Accommodation and food service activities (I)	Others

Source: Oxford Economics

Summary statistics of the variables used in this section of the modelling are presented in Figure. 81 below.

Figure 81: Summary statistics of variables used in panel regression methods using OECD data

Variable	Min	Max	Mean
Private BERD (US $, mn)	0	134,776	483
Public BERD (US $, mn)	0	3,596	20
Interest rate	-0.1%	16.9%	6.0%
GVA (US $, mn)	0	1,436,147	54,206
GVA growth	-58%	59%	2%

Source: Oxford Economics analysis of OECD data available as of June 2018

As with the model based on ONS data, the use of a panel enables us to account for unobservable effects. However, the OECD dataset contains an additional country dimension. As such, unobservable effects are specific to each country-sector pair, for example utilities in Germany.

The Wooldridge test suggested that a dynamic panel specification was once again needed due to the presence of serial correlation. Control variables were tested according to the same approach mentioned in the previous section, and again our preferred specification used country- and sector-specific GVA growth as a control variable. We accounted for potential endogeneity using lags as instruments.[55]

Consistent with the sector analysis based on the ONS dataset, we used interaction terms. However, the interpretation of the interaction terms is slightly different to that in the ONS analysis. We included a sector interaction term on our public BERD variable to estimate the extent to which the leverage rate for a given sector varies from that for the rest of the sample. This enabled us to test whether the leverage rate in one sector (e.g. manufacturing) across all OECD countries is significantly different from the average across all other sectors in all OECD countries. We repeated this process for all sectors by running a version of the model including an interaction term for each sector in turn.

Results

The average leverage rate across all countries and sectors was estimated to be 0.1306 in our preferred model specification in the short run (Figure 82). It is, once again, important to reiterate that our independent variable of interest, public R&D, in this section of analysis is public BERD, compared to the public GERD variable used elsewhere in the study. Therefore, the overall leverage rate is not directly comparable to those in the previous sections.

55 As discussed above, using lags as instruments is not the same as using lags as explanatory variables. The explanatory variables are used to estimate a causal relationship whereas instruments help mitigate the risk that these causal relationships are not biased. The causal relationship is not between the dependent variable and the instruments. Dynamic panel models allow us to use various lags of various explanatory variables as instruments. We use the ‘xtabond2’“xtabond2” command in Stata and test various lags of the explanatory variables as instruments.

Maintaining the same model specification, we estimated the differences in leverage rates between each of the 11 sectors and the rest of the sample. As with the analysis based on ONS data we did not find a statistically significant difference in the leverage rates for different sectors.

The coefficient on GVA growth remained stable across all regressions, ranging from 0.42 to 0.53, and was significant at the 10 percent level in all but one regression. The average leverage rate across all countries and sectors was significant at the one percent level in all specifications and ranged from 0.11 to 0.15. However, many of these specifications failed the Hansen test of overidentifying restrictions, suggesting that the instruments used may not be suitable for this analysis. We have tried alternate instruments, using fewer lags of the endogenous variables as instruments, but have obtained similar results.

Once again, we were therefore unable to obtain a satisfactory model in this part of the study. One potential issue could be the way that the OECD data have been compiled. Although they purport to show R&D investment by sector, the accompanying notes suggest that the data may have been compiled in slightly different ways by national statistical offices, and this may make it difficult to estimate robust relationships within a panel framework. [56]

[56] The OECD notes state that "not all countries follow a strict enterprise basis for allocating R&D expenditures to industrial classes".

Figure 82: Results of panel data regressions methods using OECD data

Dependent variable: Private BERD (log). Monetary variables specified in USD and deflated using CPI

See Figure 129 – Figure 134 in Appendix 8: Econometric modelling outputs and test results for other specifications.

Variables	OECD average	Ag., Forestry and Fishing	Mining & Quarryi-ng	Manufac-turing	Utilities	Constru-ction	Transpo-rtation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.8764***	0.8603***	0.8760***	0.8807***	0.8624***	0.8756***	0.8634***	0.8792***	0.8773***	0.8666***	0.8942***	0.8686***
	(0.0351)	(0.0436)	(0.0357)	(0.0347)	(0.0397)	(0.0339)	(0.0400)	(0.0343)	(0.0343)	(0.0388)	(0.0299)	(0.0342)
GVA growth rate	0.4238**	0.5323	0.5022*	0.4896*	0.4884*	0.4913*	0.5002*	0.4997*	0.4750*	0.5006*	0.4680*	0.4883*
	(0.1977)	(0.3748)	(0.2775)	(0.2846)	(0.2753)	(0.2814)	(0.2784)	(0.2804)	(0.2829)	(0.2788)	(0.2797)	(0.2793)
Public BERD (log) - OECD average	0.1306***	0.1473***	0.1301***	0.1362***	0.1385***	0.1303***	0.1376***	0.1268***	0.1288***	0.1467***	0.1119***	0.1312***
	(0.0367)	(0.0474)	(0.0370)	(0.0369)	(0.0388)	(0.0355)	(0.0399)	(0.0361)	(0.0364)	(0.0441)	(0.0342)	(0.0360)
Difference in leverage rates from OECD average leverage												
Industry-specific leverage		-0.0201	-0.0180	-0.1193	0.0221	0.0181	-0.1203	0.1177	-0.0205	0.3127	0.1674	-0.4021
		(0.1211)	(0.0137)	(0.0888)	(0.0251)	(0.0221)	(0.1203)	(0.1725)	(0.0220)	(0.2918)	(0.1791)	(0.4404)
Constant	0.3799***	0.5423***	0.3787***	0.3552***	0.4383***	0.3742***	0.4129***	0.3707***	0.3746***	0.3994***	0.3261***	0.4178***
	(0.1029)	(0.1943)	(0.1088)	(0.1057)	(0.1278)	(0.1009)	(0.1152)	(0.1015)	(0.1011)	(0.1118)	(0.0952)	(0.1019)
Observations	889	889	889	889	889	889	889	889	889	889	889	889
Number of country-sector combinations	163	163	163	163	163	163	163	163	163	163	163	163
Number of instruments	22	30	31	31	31	31	31	31	31	31	31	31
AR2 p-value	0.684	0.646	0.680	0.674	0.716	0.667	0.656	0.703	0.695	0.656	0.834	0.723
Hansen p-value	0.161	0.181	0.0152	0.0637	0.00998	0.0501	0.0476	0.0570	0.0220	0.00667	0.0687	0.0442

Source: Oxford Economics

Note: (1) Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; (2) The "AR2 p-value" reports the p-value for the Arellano-Bond test for AR(2) in first differences. A p-value of greater than 0.05 indicates that the null hypothesis of no autocorrelation is not rejected at the 5% level of significance. Put simply, a high p-value indicates that the model is robust to serial correlation. (3) The Hansen p-value reports the p-value for the Hansen test of overidentifying. restrictions. A p-value of greater than 0.05 indicates that the null hypothesis that the instruments as a group as exogenous is not rejected at the 5% level of significance. Again, a high p-value indicates that the instruments are suitable for our analysis. Lag private BERD, Public BERD and GVA growth rate are treated as endogenous and instrumented whereas interest rates are treated as exogenous.

Appendix 5: Review of R&D datasets

The data sources used for the study are described in the respective sections of the report. In designing our approach we had to be mindful that while a large amount of data are available, there are often many missing data points, particularly when drilling down to interrogate the data by funding source and performing sector. As such, we undertook detailed analysis of the data sources as part of the scoping work for this study to determine the best sources for addressing each research question. The findings of this exercise are presented in the tables below. As part of this we compared the international data available from OECD to that from Eurostat. On balance we decided to focus on the OECD in our cross-country panel analysis since it offers slightly greater coverage than the Eurostat equivalent.

Determining which data sources to use in our study

Figure 83: Suitability of data sources for the research questions

Research question and data needed	**Data availability (as of June 2018)**		
	ONS/HMRC	**OECD**	**Eurostat**
1 What is the best estimate and suitable uncertainty range for average leverage of private sector R&D investment resulting from public R&D investment in the UK? Variables needed: privately and publicly funded GERD over time.	PVT_GERD, PUB_GERD over 1980-2016 by product group. This will be adjusted to remove tax credits from business-funded R&D.	See question 5, with UK-specific interaction terms.	
2 Over what time profile would this best estimate of UK leverage materialise? Variables needed: privately and publicly funded GERD over time	As for question 1, with various lagged variables.		
3 What is the best estimate and suitable uncertainty range for leverage of private sector R&D investment resulting from the following types of public R&D investment in the UK:			
a) Higher education Variables needed: privately funded GERD and publicly funded HERD over time (and by country).	PVT_GERD, PUB_HERD. Data are available for 1980-2016, but	PVT_GERD, PUB_HERD. Panel of 22 countries with	PVT_GERD, PUB_HERD. Panel of 16 countries with

	we recommend using cross-country data to increase the number of observation.	complete data for 1995-2015.	complete data for 1995- 2015.
b) Direct support Variables needed: privately funded GERD and publicly funded BERD over time (and by country).	PVT_GERD, PUB_BERD. Data are available for 1980-2016, but we recommend using cross-country data to increase the number of observations.	PVT_GERD, PUB_BERD. Panel of 22 countries with complete data for 1995 to 2015.	PVT_GERD, PUB_BERD. Panel of 15 countries with complete data for 1995 to 2015.
c) Indirect support Variables needed: privately funded GERD and tax credits for BERD over time (and by country).	UK-wide analysis: PVT_GERD adjusted to exclude tax credits; HMRC data on tax credits (with estimated overseas R&D removed). Data are available for 1980-2016. Regional analysis: BERD and HMRC tax credit data by region. HMRC regional data covered only between 2013-14 and 2015-16.	PVT_GERD, Tax incentive support for BERD. One data point for 31 countries available at present, time series to be published in Autumn 2018.	No data on indirect R&D support from Eurostat.
4 Can a robust leverage rate be calculated across different sectors? What are the best estimate and suitable uncertainty range for different sectors? Variables needed: privately and publicly funded BERD over time and industrial sectors (and by country).	PVT_BERD, PUB_BERD by product group. Timespan 2001-16. Data are patchy: 20-40% of observations missing. It may not be possible to report results for all sectors and uncertainty ranges may be larger due to	PVT_BERD, PUB_BERD, by country and industry between 2007 and 2016. Data are very patchy. Only 525 country-sector combinations out of a theoretical total of 1,932 have at least eight	PVT_BERD, PUB_BERD, by country and broad NACE industry classifications between 1998 and 2009. Data are very patchy. Only 47 country-sector combinations out of a theoretical total of 205 have at least eight

	missing data points.	observations in 2007-016.	observations in 1998-2009. It may not be possible to report results for all sectors and uncertainty ranges may be larger due to missing data points.
5.i Can a robust leverage comparison be made across countries? What are the best estimate and suitable uncertainty range for comparator countries such as France, Germany, the US and Japan? Variables needed: privately and publicly funded GERD over time and by country.	No cross-country data available from the ONS	PVT_GERD, PUB_GERD. Panel of 22 countries with complete data for 1995 to 2015.	PVT_GERD, PUB_GERD. Panel of 17 countries with complete data for 1995 to 2015.
5.ii Why do some countries have greater leverage rates than others and what drives greater leverage rates? Variables needed: privately and publicly funded GERD over time and by country and selected control variables.	No cross-country data available from the ONS	Analysis will be based on cross-sectional comparison.	
7 Can leverage rates be calculated for regions of the UK? Variables needed: privately funded BERD and tax credits for BERD over time and by region.	BERD data available by region (with no breakdown by funding source), HMRC tax credit data available by region. Regional tax credits data available only between 2013-14 and 2015-16.	No regional data available	No regional data available
8 Can leverage rates be calculated for basic versus applied research? Variables needed: privately and publicly funded GERD over time, by type of research and by country.	Data on type of research not broken down by funding source		
9 Impact of foreign R&D Variables needed: privately funded GERD, excluding foreign-funded, GERD	Data are available for 1980-2016, but we recommend using cross-	PVT_GERD excluding foreign-funded, GERD funded from abroad,	Similar to OECD, but patchier. Panel of 16 countries with

funded from abroad, and publicly funded GERD.	country data to increase the number of observations (data available for the period 1980-2016 with no gaps)	PUB_GERD. Panel of 18 countries with complete data for 1995 to 2015.	complete data for 1995 to 2015.

Appendix 6: OECD data comparison

As mentioned in section 4.3.7, the OECD released additional GERD data in October 2018, during the latter stages of our research. This update extended the country coverage of the dataset and incorporated in additional years of data, mainly prior to 1980, for many countries. The tables included in this appendix present the availability of data for each country in the June and October datasets for different R&D metrics. Figure 84 presents data coverage for private GERD, Figure 85 for public HERD and Figure 86 for public BERD.

Figure 84: Comparison of June 2018 and October 2018 OECD R&D data coverage (private GERD)

Country	June data	October data
Argentina	NA	2004 - 2016 (13 obs)
Australia	1981 - 2008 (15 obs)	1978 - 2015 (34 obs)
Austria	1981 - 2016 (36 obs)	1970 - 2015 (17 obs)
Belgium	1983 - 2015 (30 obs)	1971 - 2015 (40 obs)
Canada	1981 - 2017 (37 obs)	1970 - 2017 (48 obs)
Chile	2007 - 2016 (10 obs)	2007 - 2016 (10 obs)
China	2000 - 2016 (15 obs)	2000 - 2016 (15 obs)
Czech Republic	1995 - 2015 (21 obs)	1995 - 2016 (22 obs)
Denmark	1981 - 2015 (27 obs)	1967 - 2015 (44 obs)
Estonia	1998 - 2015 (18 obs)	1995 - 2016 (22 obs)
Finland	1981 - 2015 (26 obs)	1971 - 2015 (32 obs)
France	1981 - 2015 (35 obs)	1966 - 2015 (50 obs)
Germany	1981 - 2015 (35 obs)	1971 - 2016 (42 obs)
Greece	1981 - 2016 (21 obs)	1981 - 2016 (20 obs)
Hungary	1987 - 2015 (29 obs)	1991 - 2015 (25 obs)
Iceland	1981 - 2016 (26 obs)	1971 - 2016 (31 obs)
Ireland	1981 - 2015 (35 obs)	1971 - 2016 (41 obs)
Israel	1991 - 2015 (25 obs)	1991 - 2015 (25 obs)
Italy	1981 - 2015 (27 obs)	1970 - 2015 (46 obs)
Japan	1981 - 2016 (36 obs)	1970 - 2016 (47 obs)
Latvia	1995 - 2015 (21 obs)	1995 - 2015 (21 obs)
Luxembourg	2000 - 2015 (10 obs)	2000 - 2015 (10 obs)
Mexico	1991 - 2016 (25 obs)	1989 - 2016 (26 obs)
Netherlands	1981 - 2015 (29 obs)	1969 - 2015 (43 obs)
New Zealand	1981 - 2015 (18 obs)	1972 - 2015 (28 obs)

Norway	1981 - 2015 (19 obs)	1970 - 2016 (34 obs)
Poland	1994 - 2015 (22 obs)	1994 - 2015 (22 obs)
Portugal	1982 - 2015 (34 obs)	1971 - 2015 (39 obs)
Romania	NA	1995 - 2015 (21 obs)
Russia	1994 - 2016 (23 obs)	1995 - 2016 (22 obs)
Singapore	NA	NA
Slovak Republic	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
Slovenia	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
South Africa	2001 - 2015 (14 obs)	2001 - 2015 (14 obs)
South Korea	1995 - 2016 (22 obs)	1995 - 2016 (22 obs)
Spain	1981 - 2015 (35 obs)	1970 - 2016 (46 obs)
Sweden	1981 - 2015 (18 obs)	1964 - 2015 (27 obs)
Switzerland	1981 - 2015 (12 obs)	1970 - 2015 (30 obs)
Turkey	1990 - 2015 (26 obs)	1990 - 2015 (26 obs)
United Kingdom	1981 - 2015 (33 obs)	1964 - 2015 (47 obs)
United States	1981 - 2016 (36 obs)	1970 - 2016 (47 obs)

Source: OECD

Figure 85: Comparison of June and October OECD R&D data coverage (public HERD)

Country	**June data**	**October data**
Argentina	NA	2004 - 2016 (13 obs)
Australia	1981 - 2014 (19 obs)	1978 - 2014 (20 obs)
Austria	1981 - 2015 (13 obs)	1970 - 2015 (15 obs)
Belgium	1983 - 2015 (31 obs)	1971 - 2015 (37 obs)
Canada	1981 - 2017 (37 obs)	1970 - 2017 (48 obs)
Chile	2007 - 2016 (10 obs)	2007 - 2016 (10 obs)
China	2000 - 2016 (15 obs)	2000 - 2016 (15 obs)
Czech Republic	1991 - 2015 (25 obs)	1991 - 2016 (26 obs)
Denmark	1981 - 2015 (32 obs)	1967 - 2015 (38 obs)
Estonia	1998 - 2015 (18 obs)	1995 - 2016 (22 obs)
Finland	1981 - 2015 (26 obs)	1971 - 2015 (31 obs)
France	1981 - 2015 (35 obs)	1966 - 2015 (48 obs)
Germany	1981 - 2015 (35 obs)	1973 - 2016 (41 obs)
Greece	1981 - 2016 (20 obs)	1979 - 2016 (21 obs)
Hungary	1987 - 2015 (29 obs)	1991 - 2015 (25 obs)
Iceland	1981 - 2016 (26 obs)	1971 - 2016 (31 obs)
Ireland	1981 - 2016 (36 obs)	1971 - 2016 (41 obs)

Israel	1991 - 2015 (25 obs)	1991 - 2015 (25 obs)
Italy	1981 - 2015 (27 obs)	1970 - 2015 (38 obs)
Japan	1981 - 2016 (36 obs)	1971 - 2016 (46 obs)
Latvia	1995 - 2015 (21 obs)	1995 - 2015 (21 obs)
Luxembourg	2000 - 2015 (10 obs)	2000 - 2015 (10 obs)
Mexico	1990 - 2016 (27 obs)	1990 - 2016 (27 obs)
Netherlands	1981 - 2015 (29 obs)	1969 - 2015 (41 obs)
New Zealand	1989 - 2015 (16 obs)	1972 - 2015 (23 obs)
Norway	1981 - 2015 (18 obs)	1970 - 2016 (27 obs)
Poland	1994 - 2015 (22 obs)	1994 - 2015 (22 obs)
Portugal	1982 - 2015 (34 obs)	1971 - 2015 (39 obs)
Romania	NA	1995 - 2015 (21 obs)
Russia	1994 - 2016 (23 obs)	1995 - 2016 (22 obs)
Singapore	NA	NA
Slovak Republic	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
Slovenia	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
South Africa	2001 - 2015 (14 obs)	2001 - 2015 (14 obs)
South Korea	1995 - 2016 (22 obs)	1995 - 2016 (22 obs)
Spain	1981 - 2015 (35 obs)	1970 - 2016 (46 obs)
Sweden	1981 - 2015 (19 obs)	1964 - 2015 (27 obs)
Switzerland	1981 - 2015 (17 obs)	1970 - 2015 (27 obs)
Turkey	1990 - 2015 (26 obs)	1990 - 2015 (26 obs)
United Kingdom	1981 - 2015 (33 obs)	1964 - 2015 (47 obs)
United States	1981 - 2016 (36 obs)	1970 - 2016 (47 obs)

Source: OECD

Figure 86: Comparison of June and October OECD R&D data coverage (public BERD)

Country	June data	October data
Argentina	NA	2004 - 2016 (7 obs)
Australia	1981 - 2015 (31 obs)	1978 - 2015 (32 obs)
Austria	1981 - 2015 (14 obs)	1970 - 2015 (17 obs)
Belgium	1981 - 2015 (33 obs)	1973 - 2015 (36 obs)
Canada	1981 - 2017 (37 obs)	1970 - 2017 (48 obs)
Chile	2007 - 2016 (10 obs)	2007 - 2016 (10 obs)
China	2000 - 2016 (15 obs)	2000 - 2016 (15 obs)
Czech Republic	1991 - 2015 (25 obs)	1991 - 2016 (26 obs)
Denmark	1981 - 2015 (29 obs)	1967 - 2015 (39 obs)

Estonia	1998 - 2015 (18 obs)	1998 - 2016 (19 obs)
Finland	1981 - 2015 (27 obs)	1971 - 2015 (32 obs)
France	1981 - 2015 (35 obs)	1966 - 2015 (50 obs)
Germany	1981 - 2016 (36 obs)	1971 - 2016 (42 obs)
Greece	1981 - 2016 (20 obs)	1979 - 2016 (21 obs)
Hungary	1987 - 2015 (29 obs)	1991 - 2015 (25 obs)
Iceland	1981 - 2016 (26 obs)	1979 - 2016 (27 obs)
Ireland	1981 - 2015 (35 obs)	1971 - 2015 (40 obs)
Israel	1991 - 2015 (25 obs)	1991 - 2015 (25 obs)
Italy	1981 - 2015 (35 obs)	1970 - 2015 (46 obs)
Japan	1981 - 2016 (36 obs)	1970 - 2016 (47 obs)
Latvia	1995 - 2015 (21 obs)	1995 - 2015 (21 obs)
Luxembourg	2000 - 2015 (6 obs)	2000 - 2015 (6 obs)
Mexico	1990 - 2016 (25 obs)	1990 - 2016 (25 obs)
Netherlands	1981 - 2015 (30 obs)	1969 - 2015 (42 obs)
New Zealand	1981 - 2015 (20 obs)	1972 - 2015 (27 obs)
Norway	1981 - 2015 (25 obs)	1970 - 2016 (34 obs)
Poland	1994 - 2015 (22 obs)	1994 - 2015 (22 obs)
Portugal	1982 - 2015 (34 obs)	1971 - 2015 (39 obs)
Romania	NA	1995 - 2015 (21 obs)
Russia	1994 - 2016 (23 obs)	1995 - 2016 (22 obs)
Singapore	NA	NA
Slovak Republic	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
Slovenia	1993 - 2015 (23 obs)	1993 - 2015 (23 obs)
South Africa	2001 - 2015 (14 obs)	2001 - 2015 (14 obs)
South Korea	1995 - 2016 (22 obs)	1995 - 2016 (22 obs)
Spain	1981 - 2015 (35 obs)	1970 - 2016 (46 obs)
Sweden	1981 - 2015 (18 obs)	1964 - 2015 (26 obs)
Switzerland	1981 - 2015 (14 obs)	1970 - 2015 (24 obs)
Turkey	1992 - 2015 (24 obs)	1992 - 2015 (24 obs)
United Kingdom	1981 - 2015 (33 obs)	1964 - 2015 (41 obs)
United States	1981 - 2016 (36 obs)	1970 - 2016 (47 obs)

Source: OECD

Appendix 7: Literature review summary tables

Figure 87: Summary of recent macro studies

Author	Approach	Data sources	Findings	Limitations/learnings	Control variables
Sussex et al. (2016)	Examines the relationship between public research expenditure in the pharmaceutical sector on private sector R&D expenditure in the UK. **Assesses impact of direct support and estimates the sum of direct leverage and indirect leverage within the healthcare sector but not across the wider economy.** Time series methods (Vector Error Correction Model, or VECM) applied to time series for biomedical and health R&D expenditure in the UK for ten disease areas (including "other") for the government, charity and private sectors. The VECM model describes the relationship between public sector expenditure (government and charities combined), private sector expenditure and global pharmaceutical sales as a combination of a long-term equilibrium and short-term movements.	MRC, DH, NHS Science, Engineering and Technology (SET) statistics, HEFCE funding data, Wellcome Trust and Association of Medical Research Charities (AMRC), Association of British Pharmaceutical Industry, IMS Health	An extra £1 of public research expenditure is associated with an additional £0.83–£1.07 of private sector R&D spend in the UK.	- VECM provides estimates for the short-run dynamics and the long-run relationships between variables (cointegration). - Where panel data are available, panel data methods allow the use of fixed/random effects to control for panel-specific unobservable factors.	Various lags of private and public R&D investment and global pharmaceutical sales.
Azoulay (2015)	Examines the impact of NIH funding on private sector patents in the US.	NIH, PubMed, United States Patent and	NIH funding leads to the development of private-sector	- The use of fixed effects captures panel specific unobservable factors	Drug value, fixed effects for disease-science, disease-

	Assesses impact of direct support. Estimates sum of direct and indirect impact on patents within the healthcare sector but not across the wider economy. Panel data methods using Instrumental Variable approach (static panel methods) to explore the causal impact of NIH research funding on patenting by private sector firms, from 1980 to 2012.	Trademark Office, FDA Orange Book, IMS Health	patents: a $10 million boost in NIH funding leads to a net increase of 2.3 patents.	whereas the use of instrumental variables mitigates the risk of bias due to two-way causality between patenting and research funding. - If the causal impact occurs over time and/or with a lag, the estimates identified using a static panel are likely to be biased.	year, time trends, number of patent applications.
Economic Insight (2015)	Mainly examines the impact of public funding of R&D in the UK and Europe on private R&D expenditure. **Assesses impact of direct support and estimates the sum of direct and indirect leverage**. Time series and panel data methods using macro and micro (higher education sector) data. A variety of models are used. These include pooled OLS regressions, static panel methods (with fixed and random effects) and time series methods (VECM models).	ONS, Eurostat, HESA, HEBCI, MRC	- Leverage rate of 0.68 – 0.81 for private funding in HEI. - An extra £1 of public funding gives rise to an increase in private funding of £1.13-1.60. - 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.	- The use of fixed effects captures panel specific unobservable factors. - Some models do not use instrumental variables which would mitigate the risk of bias due to two-way causality between patenting and research funding. - If the causal impact occurs over time and/or with a lag, the estimates identified using a static panel are likely to be biased. - Limited data points and control variables.	Main model includes one year lagged public funding, gross fixed capital and one year lagged private funding. Alternate model includes one year lagged public funding, gross fixed capital formation and wage (mean wage for professional occupations) as control variables
Mont-martin (2015)	Examines the effect of public R&D intensity to private R&D intensity. Macro panel data approach using data on	Macro panel data on 25 countries in the OECD in the 1990-2009	Long-run coefficient of additionality of 0.43.		

	25 countries over the period 1990-2009.	period.			
Mont-martin (2013)	Panel data methods are applied to a dataset covering 25 OECD countries over the period 1990 – 2007 to estimate the effect of direct and indirect R&D support on private R&D spending across countries.	Macro panel data on 25 countries in the OECD in the 1990-2007 period.	Only indirect aid is found to significantly influence private R&D intensity.		
Thomson (2013)	Panel data methods applied on a dataset with 26 OECD countries between 1983 and 2006. A variety of panel data methods are used. These include a simple log-linear equation in differences, dynamic Blundell Bond GMM estimator, least squares dummy variable approach. **Assesses impact of direct and indirect support and estimates the direct and indirect impact on R&D employment**. Assesses the net impact of direct and indirect R&D support on R&D employment in OECD countries.	OECD Main Science and Technology Indicators, WDI	Direct and indirect R&D support both have a positive effect on R&D employment.	- Study constructs a variable for the costs of R&D capital using data from a variety of sources, but there is no discussion of the calculation steps or the sources. - Finds that R&D is non-stationary (i.e. past values influence current values) and therefore differences the data to make the series stationary. - Uses techniques that capture both the long-run and short-run effects. - The study uses lags as instruments but limits the instrument count to 2-5 lags to avoid overfitting the model.	GDP; technological opportunity (proxied by the number of scientific publications); quality of postgraduate education (proxied by higher education R&D expenditure); capability building (proxied by government intramural R&D expenditure); and appropriability conditions (proxied by the strength of national IP rights).
Coccia (2010)	Examines the impact of public R&D expenditure on private R&D expenditure in European countries. Assesses impact of direct support and estimates the sum of direct and indirect leverage.	Eurostat	- Public R&D expenditure is a complement for private R&D expenditure. - Private R&D expenditure has to be higher than public in order to be a	- Limited controls may result in omitted variable bias. - The model does not fully exploit the panel dataset using fixed or random effects.	GDP per capita and GDP per capita growth

	Pooled regression with lag terms but in two stages: 1. First stage models government R&D expenditure using GDP per capita and GDP growth. 2. Second stage models business R&D expenditure using error from the first stage and the same control variables. Uses a panel of 31 countries over a 12-year period.		determinant of a country's productivity growth. - The composition of public and private investment in research depends on the level of a country's development.		
Bloom et al (2007)	Estimate an econometric model of R&D investment using a panel dataset of nine OECD countries between 1979 and 1997. This is used to estimate the effect of the cost of R&D (which is influenced by tax credits) on industry-funded R&D across countries.	Macro panel data on 9 OECD countries 1979–1997.	They find that tax incentives are effective in increasing R&D intensity. They find that a 10 percent fall in the cost of R&D stimulates just over a one percent rise in the level of R&D in the short run, but an impact of around ten times than in the long run.		
Falk (2006)	Examines the impact of different sources of public R&D funding on private R&D expenditure in OECD countries. **Assesses impact of direct and indirect support and estimates the sum of direct and indirect leverage.** Dynamic panel data methods using a panel of OECD (countries for the period of 1975–2002 with data measured as five-	OECD Main Science and Technology Indicators	- Tax incentives for R&D have a significant and positive impact on business R&D spending. - Expenditure for R&D performed by universities is significantly positively related to business enterprise	- The use of panel data methods helps mitigate the small sample size due to limited time series data. - The use of dynamic panel methods controls for dynamic effects which would otherwise bias results, and the use of instrumental variables mitigates the risk of bias due to two-way causality	GDP per capita as a measure of domestic demand; specialisation in high-tech industries indicated by the share of high-tech industries in exports; patent rights (using the "Ginarte-Park" index); GFCF share of GDP; the degree

	year averages).		sector expenditure on R&D.	between the independent and dependent variables. - Use of five-year averages allows the inclusion of control variables that are available at quinquennial frequency.	of openness (total trade); and human capital measured by the share of university graduates.
Becker and Pain (2003)	Estimate an econometric model of R&D expenditure using a panel of UK manufacturing industries. They examine the effect of the share of public R&D on R&D expenditure in UK manufacturing industries. .	UK panel by 11 broad manufacturing product groups 1993–2000	Industry characteristics and macroeconomic factors have an effect on R&D spending. A rise in the share of R&D funded by the government is found to have a significant positive impact on the aggregate level of R&D expenditure.		
Guellec and van Pottels-berghe de la Potterie (2001)	Attempt to quantify the aggregate net effect of government funding on business R&D in 17 OECD countries between 1979 and 1999.	Macro panel data on 17 OECD countries 1981– 1996	Direct government funding of R&D and tax incentives have a positive effect on business financed R&D but are found to be substitutes. Both direct funding and tax incentives are more effective when they are stable over time.		
Diamond (1998)	Estimates the effect of federal funding of basic research on private funding of basic research in the US using a timeseries		Government funding has not crowded out private funding of	Aggregate time series analysis must be treated with caution as it may suffer	

	dataset from 1953-1993.		science.	from issues such as unit roots and omitted variable bias.	
Lichten-berg (1987)	Estimates the effect of federally funded industrial research on privately funded industrial research in the US. Time series data from 1956 to 1983 is used.		Insignificant results are estimated.		

Figure 88: Summary of recent micro studies (direct leverage from direct support)

Author	Approach	Data source	Findings	Control variables
Czarnitzki and Delanote (2015)	Examines whether public R&D funding crowds out private R&D funding using a survey of German firms. The study uses Propensity Score Matching (Caliper Matching) to control for differences between firms.	Mannheim Innovation Panel, German Patent and Trade Mark Office, Credit reform database	- Reject full crowding out. - Treatment effect is highest for independent high-tech firms.	Employment; age of the firm; a dummy indicating whether the firm is an exporter; capital intensity (measured as fixed assets over employment); price cost margin; patent stock; and location dummy for East Germany.
Hottenrott and Lopes-Bento (2014)	Analyses whether public R&D subsidies lead to increased R&D spending and product innovation. Uses difference-in-differences analysis and Propensity Score Matching to control for differences between firms.	The Flemish part of the Community Innovation Survey, Bel-First data, ICAROS database, European Patent Office	- Targeted public subsidies trigger R&D spending, especially so in internationally collaborating SMEs. - Publicly-induced R&D translates into marketable product innovations.	Number of employees; firm size; dummy variable for SMEs; whether the firm is part of an enterprise group; if the firm has a foreign parent; age of the firm; patent stock (from the European Patent office); past funding; export tendencies; labour productivity; industry dummies.
Cerulli and Poti (2012)	Explores whether firms receiving R&D subsidies spend more on R&D than firms that do not receive R&D subsidies. The study uses Propensity Score Matching as well as OLS to control for differences among firms, and the Heckman Selection Model to control for the likelihood of R&D intensive firms receiving public subsidies.	Italian part of the Community Innovation Survey	- If a generic control unit spends €1,000 in R&D, a matched treated unit in receipt of R&D subsidies spends €4,620. - The R&D intensity level of treated firms is 2.67 times that of the control units.	Employment; share of turnover from exports; capital to labour ratio; cash flow per employee; total debt per employee; value of capitalised R&D per employee; industry; and sector dummy.
Yang et al. (2012)	Examines whether firms receiving public R&D support spend more on R&D than firms that do not receive public support. Also estimates the elasticity of private R&D spending with respect to public R&D spending.	Taiwan Economic Journal database, firms' annual reports, Investment Commission of the Ministry of Economic Affairs	- Recipients of R&D tax credits appear on average to have 53.8 percent higher R&D expenditure than other firms across all sectors. The impact of tax credits is particularly strong for firms in technologically advanced sectors, e.g. for electronics firms.	Employment; date of establishment; fixed capital stock; advertising expenditure; and profitability.

Author	Approach	Data source	Findings	Control variables
	Uses Propensity Score Matching (Kernel, nearest-neighbour and Caliper Matching) to control for differences between firms.		- The marginal effect (elasticity) is moderate, ranging from 0.094 to 0.120, and it tends to increase with the approaching expiration of the tax credits measure.	
Arvanitis et al. (2010)	Looks at the impact of the Swiss Commission of Technology's support on firms' innovation performance. Uses Propensity Score Matching to control for differences among firms.	Swiss Commission for Technology and Innovation (CTI) database, Swiss Innovation Survey	- CTI's promotional activities significantly improved the innovation performance of the firms that they supported. - The magnitude of the impact correlated positively with the relative size of the financial support.	Firm size; history of R&D activity; industry dummies; and whether the firm was founded before 1996.
Aschhoff (2009)	Examines the impact of R&D grants on firms' output using a survey of German firms. Uses Propensity Score Matching to control for differences in firms' characteristics.	Mannheim Innovation Panel, European Patent Office	- A positive effect of R&D grants on input and output is found. - The effect of private R&D increases with the frequent receipt of grants.	Whether firms conduct R&D on a regular/continuous basis; number of employees with a university degree; and average patent stock (from the European Patent Office). Geographic dummies are also included.
Aerts et al. (2008)	Examines the impact of public R&D support on firms' R&D intensity using surveys of Flemish and German firms. Uses non-parametric matching and conditional difference-in-difference estimators to control for differences among firms.	Flemish and German Community Innovation Survey, European Patent Office, National Bank of Belgium	- Reject crowding-out. - R&D intensity of German (Flemish) funded companies was 76-100 percent (64-91 percent) higher than the R&D intensity of non-funded companies.	Number of employees; firms' patent stock; dummy for whether a firm belongs to a group to control for different governance structures; exports to turnover measures; industry dummies to follow the differences between sectors; interaction terms between the industry dummies; and employment. Financial variables such as the value of fixed assets and cash flow are also used.
González and Pazó (2008)	Uses survey data for Spanish firms to test whether public R&D support crowds out private R&D spending. Uses a bias-corrected matching estimator (designed by	Survey on Firm Strategies (Encuesta Sobre Estrategias Empresariales)	- Reject full and partial crowding out. - Small firms operating in low tech sectors might not have engaged in R&D activities in the absence of subsidies. - Estimate an increase in aggregate	Firm size; age; technological sophistication; capital growth; domestic exporter; foreign capital; market power; industry; region and time dummies.

Author	Approach	Data source	Findings	Control variables
	Abadie and Imbens) to control for differences among firms.		R&D expenditure of 10.7 and 6 percent for small and large firms, respectively.	
Czarnitzki and Licht (2006)	Uses German firm level data to examine whether firms receiving public R&D support have greater R&D intensity. Uses Propensity Score Matching (nearest neighbour matching estimators) to control for differences among firms.	Mannheim Innovation Panel, German Patent and Trade Mark Office	- Supported Eastern German (Western German) firms exhibit an R&D intensity of 6.4 (4.4) percent on average, compared to an average of 2.25 (2.2) percent in the absence of promotion. - One-third of the beneficiary companies would not have been involved in R&D if they had not received support.	Firm size in terms of number of employees; Herfindahl Index for firm concentration at a three-digit industry level; firm age in years to capture specific funds available to young firms and young firms' particular needs; export activity dummy; patent stock; a dummy if a firm has its own R&D department; credit rating/access to capital market using the credit reform credit rating index; and specific industry and year dummies.

Figure 89: Summary table of recent studies which have looked at tax credits (direct leverage from indirect support)

Author	Approach	Data source	Findings	Limitations/learnings	Control variables
Dechez-leprêtre et al. (2016)	Estimates the impact of tax credits on business R&D spending. Uses regression discontinuity methods by exploiting a policy reform, which changed the asset-based size thresholds which define the eligibility criteria for access to tax credits.	Firm-level HMRC administrative tax data on the population of UK firms merged with firms' accounts (from FAME) and patent data (from PATSTAT) before and after the policy change	- Significant effects of the tax change on R&D and patenting. - R&D price elasticity is high, at 2.6, probably as the tax change relaxes financial constraints for small firms. - During 2006-11, BERD would be 10 percent lower without the tax relief scheme.	- The large effects come from smaller firms and should not be generalised across the entire size distribution. - There may be other effects that reduce innovation: for example, subsidies are captured in the form of higher wages rather than a higher volume of R&D.	Lagged dependent variable, firms' own R&D in 2007
HMRC Working Paper 17 (2015)	Examines the price elasticity of R&D expenditure, and calculates the impact of R&D tax credits on additional R&D expenditure. Uses a range of methods from OLS to dynamic panel (GMM (Arellano-Bond) estimator).	Firm-level HMRC administrative tax data merged with firms' accounts (from FAME) and ONS' Inter-Departmental Business Register.	- Reviewing literature, they find a wide range of estimates for price elasticity of R&D expenditure: from very inelastic (-0.07) to elastic (three studies find elasticities between -3 and -2.5). - Authors' own analysis suggests that for every £1 spent on R&D tax credits, £1.53-£2.35 additional R&D expenditure by UK companies is stimulated.	- Dynamic GMM can become unstable in the presence of a high number of endogenous variables relative to the sample size.	Turnover, number of employees, profit, liquidity ratio, credit constraints proxy, growth in GVA at industry level, high-tech dummy, time controls
Becker (2015)	Reviews the R&D literature on the impact of public policies to support private R&D investment.	NA	- Much of the recent evidence suggests that R&D tax credits have a positive effect on private R&D investment. - Tax credits have a significant effect on R&D expenditure in the short	The paper suggests that the impact of tax credits may vary by the amount of tax credits received. In other words, the relative impact of a small amount received in tax credits may be different from the	NA

Author	Approach	Data source	Findings	Limitations/learnings	Control variables
			run, but only a small impact in the long run.	impact of a larger amount received in tax credits.	
Castellacci and lie (2015)	Reviews the microeconometric literature on the effects of R&D tax credits on firms' innovation activities using meta-regression analysis. Sets up a new database collecting a large number of firm-level studies on the effects of R&D tax credits and investigates the factors that may explain differences from impacts reported in the literature.	A database of all papers with R&D as a key word	The additionality effect of R&D tax credits is on average stronger for SMEs, firms in the service sectors, and firms in low-tech sectors.	- Additionality effects across sectors are not accounted for in the existing literature. - The literature has focussed on the effects of fiscal incentives on firms' R&D investment, and largely neglected the effects of tax credits on firms' innovation output and economic performance.	The MRA regressions include controls for whether the study investigated high-tech or low-tech industries; manufacturing and service sectors; size of firm; whether the data are volume or value based; the presence of an incremental-based R&D tax incentives system; year of publication; use of instrumental variables; econometric technique; and country fixed-effects.
Czarnitzki, Hanel and Rosa (2011)	Examines the impact of R&D tax credits on innovation among Canadian firms. Uses a matching estimator, where firms receiving R&D support are matched with similar firms that do not receive R&D support, and then the difference in their R&D expenditure is attributed to the impact of public R&D support.	Canadian Survey of Innovation	- R&D tax credits have a positive impact on the innovation output of the recipient firms (recipients realise a higher number of product innovations, as well as sales with such products). - Tax credit recipients display a higher probability of introducing real market novelties in both the Canadian and global markets.	- Additionality effects across sectors are not accounted for in this study. - The two-way causality between control variables (firm size, for example) and private R&D expenditure may lead to biased results.	Firm size (measured by the number of employees), presence of an R&D department; whether firms contract out their R&D activities; attractiveness of new markets; price-cost margin; and industry concentration.

Author	Approach	Data source	Findings	Limitations/learnings	Control variables
Baghana and Mohnen (2009)	Estimates the price elasticity of R&D spending in the short-run and the long-run using survey data for Canadian firms. Uses a structural model of demand for R&D. Builds a model for R&D demand with R&D tax parameters.	Survey on Research and Development in Canadian Industry (RDCI), the Annual Survey of Manufactures (ASM) and administrative data from Revenue Quebec	- The estimated elasticity of R&D is -0.10 in the short run and -0.14 in the long run, with slightly higher elasticities for small firms than for large firms. - For small firms there is additionality.	- As with the previous study, additionality effects across sectors are not accounted for in this study. - The two-way causality between control variables (firm size, for example) and private R&D expenditure may lead to biased results.	Ratio of R&D expenditures divided by R&D stock; firm sales; industry sales and their growth.

Appendix 8: Econometric modelling outputs and test results

Leverage rate in the UK – panel data analysis: sensitivity to static panel and pooled regression methods and Nickell bias

Our preferred modelling approach has been to use dynamic panel methods. We discuss the limitations of pooled regressions and static panel methods in Section 3.4.2. In Figure 90, we present the results of various static panel data methods, i.e. fixed and random effects with and without instrumental variables. Models 1 to 4 include only the public R&D term and are likely to suffer from omitted variable bias. Models 5 to 8 include employment growth, which is not statistically significant in all four models. Models 9 to 12 include interest rates and employment growth, neither of which are statistically significant.

Figure 90: UK leverage rates - Sensitivity test: Static panel models
Dependent variable: Private GERD (log).
Monetary variables specified in GBP and deflated using the GDP deflator.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	**Static fixed effects**	**Static random effects**	**Static fixed effects with IV**	**Static random effects with IV**	**Static fixed effects**	**Static random effects**	**Static fixed effects with IV**	**Static random effects with IV**	**Static fixed effects**	**Static random effects**	**Static fixed effects with IV**	**Static random effects with IV**
Public GERD (log) - UK	1.3696	0.9689***	1.3696**	0.9703***	0.9222***	1.0186***	0.9222	1.0198***	0.8965***	1.0197***	0.8965	1.0208***
	(.)	(0.0850)	(0.6576)	(0.0628)	(0.0065)	(0.1381)	(0.5853)	(0.0581)	(0.0888)	(0.1362)	(0.5868)	(0.0543)
Public GERD (log) - other	0.8964***	0.9122***	0.8964***	0.9151***	0.9369***	0.9581***	0.9369***	0.9596***	0.9347***	0.9594***	0.9347***	0.9609***
	(0.1190)	(0.1091)	(0.0212)	(0.0198)	(0.2197)	(0.1818)	(0.0266)	(0.0235)	(0.2247)	(0.1789)	(0.0268)	(0.0233)
Employment growth rate					0.4223	0.5476	0.4223	0.5575	0.4512	0.6043	0.4512	0.6148
					(0.8121)	(0.7385)	(0.7318)	(0.7280)	(0.7689)	(0.7054)	(0.7333)	(0.7319)
Interest rates									-0.0023	-0.0027	-0.0023	-0.0027
									(0.0084)	(0.0073)	(0.0035)	(0.0034)
Constant	0.8582	0.8296	0.8582***	0.8108***	0.8033	0.5251	0.8033***	0.5153***	0.8396	0.5307	0.8396***	0.5213***
	(0.8223)	(0.7648)	(0.2566)	(0.1612)	(1.5514)	(1.2448)	(0.2807)	(0.1829)	(1.6329)	(1.2454)	(0.2860)	(0.1810)
Observations	1,143	1,143	1,143	1,143	753	753	753	753	753	753	753	753
R-squared	0.6191				0.6381				0.6383			
Number of country_code	40	40	40	40	35	35	35	35	35	35	35	35

Source: Oxford Economics

Nickell Bias

According the Hsiao (1986), the OLS coefficient of the lagged dependent variable is expected to suffer from an upward bias due to its ignorance of individual specific effects, whereas Nickel (1981) argues that the within estimator of the fixed effects model is expected to be downward biased. Hence, Blundell and Bond (1998) argue that a plausible parameter estimate should lie between the fixed effect and the OLS estimates. We present the OLS and static panel estimates in Figure 91 where the coefficient on the lag term from the dynamic panel is between the corresponding estimate from the fixed effect and OLS estimates.

Figure 91: UK leverage rates - Sensitivity test: Nickel bias and alternate specifications
Dependent variable: Private GERD (log).
Monetary variables specified in USD and deflated using the GDP deflator. Models based on the June 2018 dataset.

VARIABLES	OLS	Dynamic Panel	Fixed effects - IV
Private GERD (log) – lag	0.9315***	0.6414***	0.4618
	(0.0114)	(0.0996)	(0.5467)
Public GERD (log) – UK		0.3798***	0.5619
		(0.1105)	(1.2005)
Public GERD (log) – Other		0.3697***	0.7726
		(0.1129)	(1.2270)
Employment growth rate	1.9040***	1.3811**	6.0813
	(0.3986)	(0.6404)	(11.0158)
Interest rates	-0.0014	-0.0179**	-0.0092
	(0.0020)	(0.0070)	(0.0223)
Public GERD (log) – OECD average	0.0646***		
	(0.0128)		
Constant	0.1017***	0.1968	-1.5275
	(0.0366)	(0.2893)	(5.6129)
Observations	538	538	437
R-squared	0.9965		
Number of country_code		30	27

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to using time as a control variable and instrument

Only one of our main specifications includes decade-specific dummies (Model 3 in Figure 18 and Model 2 in Figure 21). However, Roodman (2006) recommends the use of time dummies in all specifications as this makes the assumptions underlying the diagnostics tests more likely to hold, and therefore makes the diagnostic tests more reliable.

Figure 92 presents the results of models with time dummies included in the regression in various ways. Model 1 uses the full sample and is the same as Model 1 in Figure 21. Model 2 uses time dummies as instruments but not as control variables whereas Model 3 uses decade-specific dummies as instruments but not as control variables. Model 2 suffers from instrument proliferation (as the number of instruments exceeds the number of countries) which overfits the endogenous variables and weakens the power of the Hansen test to detect overidentification. Model 4 is the same as Model 2 but imposes severe restrictions on the number of lags of other control variables to restrict the number of instruments, but these restrictions are not effective as the number of instruments is still relatively high. Models 5, 6 and 7 use time dummies as control variables and also suffer from the same issue. As such, we have not been able to build a satisfactory model using the time dummies as control variables or as instruments, and therefore we are not able to draw any meaningful conclusions from these models.

Time trends can also be included as a continuous variable (instead of dummies). Running a sensitivity with time trend included as a control variable will help us test if the underlying trend in R&D spending is likely to lead to bias our findings. We tested our regressions by including a trend variable and found that the results are similar.

Figure 92: UK leverage rates - Sensitivity test: Time dummies
Dependent variable: Private GERD (log).
Monetary variables specified in GBP and deflated using the GDP deflator. Models based on the October 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	**No time dummies**	**Time dummies as instruments**	**Decade dummies as instruments**	**Time dummies as instruments and all instruments restricted to 1 lag**	**AS (4), with time dummies as controls**	**As (5), excluding interest rates**	**With time dummies as controls and all variables except the lag dependent variable treated as exogenous**
Lag private R&D (log)	0.7375***	0.7782***	0.7791***	0.7815***	0.9025***	0.7537***	0.6223**
	(0.0303)	(0.0373)	(0.0441)	(0.0314)	(0.3446)	(0.0534)	(0.2542)
Public GERD (log) - UK	0.3216***	0.2378***	0.2425***	0.1422	0.1311	0.0717	0.1260
	(0.0507)	(0.0646)	(0.0597)	(0.1552)	(0.6104)	(0.2731)	(0.6326)
Public GERD (log) - others	0.3755***	0.2981***	0.3046***	0.2937***	0.5661**	0.3422***	0.4518
	(0.0384)	(0.0301)	(0.0291)	(0.0297)	(0.2717)	(0.0285)	(0.2927)
Employment growth rates	0.8381*	0.9249**	0.8274	0.7681*	-1.1358	0.7510	1.2480*
	(0.5007)	(0.4512)	(0.5079)	(0.4026)	(4.2630)	(0.5754)	(0.7176)
Interest rates	- 0.0061***	-0.0052**	-0.0052**	-0.0041	0.1116		
	(0.0022)	(0.0021)	(0.0021)	(0.0027)	(0.2396)		
Year dummies:							
_Iyear_1964					0.0017	-0.1542*	-0.3911
					(0.3960)	(0.0829)	(0.3264)

_Iyear_1965					-0.3211	-0.3027***	-0.5207*
					(0.2434)	(0.0694)	(0.3117)
_Iyear_1966					-0.4589	-0.3742***	-0.5909*
					(0.2849)	(0.0623)	(0.3134)
_Iyear_1967					-0.4609	-0.3237***	-0.5459
					(0.3319)	(0.0604)	(0.3368)
_Iyear_1968					-0.4899	-0.2643***	-0.4864
					(0.4387)	(0.0547)	(0.3551)
_Iyear_1969					-0.6661	-0.3301***	-0.5261*
					(0.7041)	(0.0438)	(0.2867)
_Iyear_1970					-0.6859	-0.3230***	-0.4974**
					(0.7776)	(0.0433)	(0.2388)
_Iyear_1971					-0.6234	-0.3446***	-0.5330*
					(0.5847)	(0.0476)	(0.2726)
_Iyear_1972					-0.2699	-0.2237**	-0.4138
					(0.3691)	(0.1023)	(0.2662)
_Iyear_1973					-0.3103	-0.2023**	-0.3949
					(0.4656)	(0.0859)	(0.2679)
_Iyear_1974					-0.4963	-0.2307***	-0.4006*
					(0.7476)	(0.0621)	(0.2261)
_Iyear_1975					-0.2909	-0.1589**	-0.3369

					(0.5176)	(0.0791)	(0.2384)
_Iyear_1976					-0.4715	-0.1247**	-0.3071
					(0.8431)	(0.0558)	(0.2738)
_Iyear_1977					-0.6264	-0.2450***	-0.4058*
					(0.9115)	(0.0663)	(0.2464)
_Iyear_1978					0.0179	-0.1378	-0.4509*
					(0.4766)	(0.1283)	(0.2368)
_Iyear_1979					-0.1256	0.0893	-0.1238
					(0.5339)	(0.3096)	(0.3521)
_Iyear_1980					-0.5002	-0.2617***	-0.4036**
					(0.7713)	(0.0660)	(0.1639)
_Iyear_1981					-0.5611	-0.1259*	-0.2751
					(1.1382)	(0.0700)	(0.1798)
_Iyear_1982					-0.4839	-0.1014	-0.2413
					(1.0404)	(0.0769)	(0.1697)
_Iyear_1983					-0.2999	-0.0912	-0.2333
					(0.6402)	(0.0668)	(0.1831)
_Iyear_1984					-0.3129	-0.0916	-0.2260
					(0.6380)	(0.0565)	(0.1605)
_Iyear_1985					-0.3799	-0.0788	-0.2056
					(0.7676)	(0.0564)	(0.1501)
_Iyear_1986					-0.0973	0.0320	-0.0676
					(0.5281)	(0.0817)	(0.2273)
_Iyear_1987					-0.3531	-0.0245	-0.1169
					(0.8764)	(0.0676)	(0.1975)

_Iyear_1988					-0.3428	-0.0400	-0.1221
					(0.8303)	(0.0590)	(0.1832)
_Iyear_1989					-0.3546	0.0091	-0.0729
					(0.9386)	(0.0542)	(0.1941)
_Iyear_1990					-0.4820	-0.0526	-0.1500
					(1.1154)	(0.0681)	(0.1998)
_Iyear_1991					-0.4221	-0.0558	-0.1440
					(0.9615)	(0.0674)	(0.1961)
_Iyear_1992					-0.4962	-0.0306	-0.1151
					(1.0949)	(0.0525)	(0.1575)
_Iyear_1993					-0.2675	0.0193	-0.0644
					(0.6889)	(0.0565)	(0.1482)
_Iyear_1994					-0.4789	-0.0732	-0.1367
					(0.9218)	(0.0587)	(0.1291)
_Iyear_1995					-0.3902	-0.0460	-0.1201
					(0.8113)	(0.0552)	(0.1233)
_Iyear_1996					-0.0064	-0.0815**	-0.1665***
					(0.1811)	(0.0411)	(0.0619)
_Iyear_1997					0.0646	-0.1323***	-0.2032***
					(0.3251)	(0.0466)	(0.0628)
_Iyear_1998					0.2365	-0.0602	-0.1405**
					(0.5130)	(0.0573)	(0.0624)
_Iyear_1999					-0.0298	-0.0062	-0.0960
					(0.2692)	(0.0573)	(0.0727)
_Iyear_2000					0.1988	0.0491	-0.0411
					(0.2773)	(0.0664)	(0.0825)

_Iyear_2001					0.0886	0.0597	-0.0248
					(0.2094)	(0.0663)	(0.0791)
_Iyear_2002					0.0139	0.0066	-0.0661
					(0.2206)	(0.0600)	(0.0717)
_Iyear_2003					0.0951	0.0181	-0.0633
					(0.1730)	(0.0625)	(0.0724)
_Iyear_2004					0.1122	0.0377	-0.0362
					(0.1668)	(0.0585)	(0.0689)
_Iyear_2005					0.1733	0.0447	-0.0409
					(0.1983)	(0.0495)	(0.0653)
_Iyear_2006					0.1355	0.0588	-0.0273
					(0.1548)	(0.0404)	(0.0532)
_Iyear_2007					0.0166	0.0033	-0.0730
					(0.1594)	(0.0376)	(0.0528)
_Iyear_2008					0.0077	0.0743**	-0.0172
					(0.2408)	(0.0339)	(0.0589)
_Iyear_2009					-0.1376	0.0149	-0.0452
					(0.3207)	(0.0447)	(0.0436)
_Iyear_2010					-0.0856	0.0036	-0.0611***
					(0.1972)	(0.0329)	(0.0207)
_Iyear_2011					-0.0707	0.0651*	
					(0.3098)	(0.0348)	
_Iyear_2012					-0.1446	-0.0411**	-0.0816
					(0.2362)	(0.0171)	(0.0513)
_Iyear_2013							-0.0481
							(0.0421)

_Iyear_2014					0.0948	-0.0239	-0.0608
					(0.1972)	(0.0242)	(0.0726)
_Iyear_2015					0.2176	-0.0009	-0.0303
					(0.3871)	(0.0360)	(0.0875)
_Iyear_2016					0.0389	-0.0004	-0.0633
					(0.2082)	(0.0552)	(0.1268)
_Iyear_2017					-0.2636	-0.1924**	-0.2728
					(0.2844)	(0.0805)	(0.2139)
Constant	-0.6729	-0.4158	-0.4700	-0.3801**	-3.7123	-0.4852	-0.1868
	(0.4755)	(0.2824)	(0.3432)	(0.1798)	(5.4004)	(0.5844)	(0.5368)
Observations	751	751	751	751	751	751	750
Number of country_code	35	35	35	35	35	35	35
Number of instruments	21	74	26	63	62	62	58
AR2 p-value	0.907	0.625	0.672	0.607	0.551	0.958	0.632

Source: Oxford Economics

Figure 93: UK leverage rates - Sensitivity test: Time as a continuous variable

Dependent variable: Private GERD (log).

Monetary variables specified in GBP and deflated using the GDP deflator. Models based on the October 2018 dataset.

VARIABLES	Model 1 (Fig. 21)	Model 1 (Fig. 21)	Model 1 (Fig. 21)	Model 2 (Fig. 21)	Model 2 (Fig. 21)	Model 2 (Fig. 21)	Model 3 (Fig. 21)	Model 3 (Fig. 21)	Model 3 (Fig. 21)	Model 4 (Fig. 21)	Model 4 (Fig. 21)	Model 4 (Fig. 21)
Time variable	**Excluded**	**Included**	**Included**	**Excluded**	**Included**	**Included**	**Excluded**	**Included**	**Included**	**Excluded**	**Included**	**Included**
Interest rate variable	**Included**	**Included**	**Excluded**	**Included**	**Included**	**Excluded**	**Included**	**Included**	**Excluded**	**Included**	**Included**	**Excluded**
Lag private R&D (log)	0.7375***	0.6962***	0.7051***	0.7984***	0.7258***	0.7329***	0.7385***	0.6987***	0.7080***	0.7402***	0.7072***	0.7198***
	(0.0303)	(0.0492)	(0.0497)	(0.0402)	(0.0391)	(0.0376)	(0.0305)	(0.0506)	(0.0520)	(0.0424)	(0.0596)	(0.0607)
Public GERD (log) - UK	0.3216***	0.2861***	0.2952***	0.2319***	0.2653***	0.2763***	0.3210***	0.2859***	0.2949***	0.3426***	0.3369***	0.3395***
	(0.0507)	(0.0572)	(0.0556)	(0.0588)	(0.0509)	(0.0475)	(0.0502)	(0.0562)	(0.0545)	(0.0282)	(0.0203)	(0.0246)
Public GERD (log) - others	0.3755***	0.3608***	0.3661***	0.2976***	0.3367***	0.3437***	0.3753***	0.3607***	0.3660***	0.3510***	0.3354***	0.3414***
	(0.0384)	(0.0311)	(0.0370)	(0.0314)	(0.0217)	(0.0260)	(0.0382)	(0.0309)	(0.0370)	(0.0384)	(0.0306)	(0.0375)
Employment growth rates	0.8381*	0.8212*	0.8405**	0.9447*	1.0196**	1.0552**	0.8581*	0.8385*	0.8540**	1.7056***	1.6978***	1.7149***
	(0.5007)	(0.4330)	(0.4099)	(0.5021)	(0.4585)	(0.4315)	(0.5123)	(0.4439)	(0.4224)	(0.4863)	(0.4427)	(0.4134)
Interest rates	-0.0061***	-0.0027		-0.0053**	-0.0030		-0.0061***	-0.0027		-0.0066***	-0.0037	
	(0.0022)	(0.0034)		(0.0022)	(0.0032)		(0.0022)	(0.0034)		(0.0024)	(0.0036)	
Year		0.0049***	0.0050***		0.0044***	0.0045***		0.0049***	0.0050***		0.0047***	0.0049***
		(0.0015)	(0.0014)		(0.0013)	(0.0013)		(0.0015)	(0.0015)		(0.0013)	(0.0012)
Constant	-0.6729	-10.1342***	-10.4603***	-0.5656*	-9.1002***	-9.4992***	-0.6796	-10.0486***	-10.3658***	-0.5849	-9.6164***	-10.1950***
	(0.4755)	(2.5940)	(2.4809)	(0.3018)	(2.3922)	(2.3752)	(0.4753)	(2.6497)	(2.5378)	(0.6169)	(2.2441)	(2.1391)
Observations	751	751	751	751	751	751	751	751	751	751	751	751
Number of country_code	35	35	35	35	35	35	35	35	35	35	35	35
Number of instruments	21	22	21	23	22	21	13	14	13	13	14	13
AR2 p-value	0.907	0.962	0.919	0.620	0.903	0.970	0.909	0.963	0.920	0.655	0.694	0.639
Hansen p-value	0.747	0.668	0.671	0.115	0.0777	0.0713	0.150	0.111	0.116	0.0776	0.0602	0.0589

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to restricting the sample

Given the gaps in our dataset, we have also considered restricting our data such that we have a more balanced dataset without gaps. Figure 94 presents the results of models estimated using various subsets of the dataset. Model 1 uses the full sample and is the same as Model 1 in Figure 21. The other models use the same specification but with restricted samples, except Model 3 which treats public R&D as partially endogenous (as opposed to being fully endogenous). In Model 3, only the coefficient on the lag term and the constant are significant. In the other models, the coefficient on the public R&D term, is significant and larger than those from our suggested sample. However, the coefficient on interest rates is not significant at the 5% level. As such, our preferred option is to use the larger dataset as it maximises our sample size and allows for specifications where the coefficient are of a sensible magnitude and are statistically significant.

Figure 94: UK leverage rates - Sensitivity test: Different sample coverage - by year

Dependent variable: Private GERD (log). Monetary variables are expressed in GBP and deflated using GDP deflator. Models based on the October 2018 dataset.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Full sample**	**1995-2016**	**1995-2016 (with partially endogenous public R&D)**	**1990-2016**	**1985-2016**
Lag private R&D (log)	0.7375***	0.6911***	0.9021***	0.6985***	0.6961***
	(0.0303)	(0.0705)	(0.0998)	(0.0741)	(0.0773)
Public R&D (log) - UK	0.3216***	0.4058***	-0.0223	0.4383***	0.4363***
	(0.0507)	(0.1385)	(0.1345)	(0.1530)	(0.1530)
Public R&D (log) - Other	0.3755***	0.4189***	-0.0571	0.4680***	0.5000***
	(0.0384)	(0.1568)	(0.1394)	(0.1747)	(0.1761)
Employment growth rate	0.8381*	1.3137**	0.1957	1.4703**	1.5511**
	(0.5007)	(0.5147)	(0.7568)	(0.6083)	(0.6754)
Interest rates	-0.0061***	-0.0047	-0.0025	-0.0058*	-0.0065*
	(0.0022)	(0.0032)	(0.0044)	(0.0035)	(0.0036)
Constant	-0.6729	-0.6200	1.1804**	-1.0339	-1.2457
	(0.4755)	(0.7359)	(0.5270)	(0.8534)	(0.8068)
Observations	751	556	556	615	667
Number of country_code	35	33	33	34	35
Number of instruments	21	21	21	21	21
AR2 p-value	0.907	0.761	0.268	0.651	0.605
Hansen p-value	0.747	0.394	0.508	0.325	0.311

Source: Oxford Economics

Figure 95: UK leverage rates – Sensitivity test: trimmed dataset (countries and years)
Dependent variable: Private GERD (log).
Monetary variables are expressed in GBP and US$ and deflated using GDP deflator. Models based on the October 2018 dataset.

VARIABLES	Model 1	Model2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Lag private GERD (log) - lag of dependent variable (GBP)	0.6788***	0.6810***	0.8304***	0.8303***	0.6627***	0.6640***		
	(0.0634)	(0.0583)	(0.0478)	(0.0459)	(0.0605)	(0.0540)		
Public GERD (log) - UK (GBP)	0.4053***	0.3892***	0.1735**	0.1686**	0.4196***	0.4021***		
	(0.1205)	(0.1180)	(0.0784)	(0.0755)	(0.1197)	(0.1174)		
Public GERD (log) - other (GBP)	0.4155***	0.3961***	0.1736**	0.1674**	0.4281***	0.4066***		
	(0.1382)	(0.1364)	(0.0864)	(0.0833)	(0.1392)	(0.1380)		
Employment growth rate	1.4315*	1.1913*	1.3397	1.1595	1.4079*	1.1528*	2.0226***	1.7327***
	(0.7646)	(0.6366)	(0.8409)	(0.7718)	(0.8237)	(0.6915)	(0.6940)	(0.6193)
Interest rates	-0.0053		-0.0037		-0.0052		-0.0046	
	(0.0037)		(0.0035)		(0.0038)		(0.0041)	
Lag private GERD (log) - lag of dependent variable (US $)							0.6597***	0.6552***
							(0.0458)	(0.0404)
Public GERD (log) - UK (US $)							0.3477***	0.3209***
							(0.0967)	(0.1002)
Public GERD (log) - other (US $)							0.3667***	0.3353***
							(0.1144)	(0.1165)
Constant	-0.5132	-0.4107	0.0765	0.1072	-0.4816	-0.3577	-0.0294	0.2327
	(0.7466)	(0.7676)	(0.3911)	(0.3726)	(0.8030)	(0.8300)	(0.7105)	(0.7349)
Observations	530	530	530	530	530	530	530	530
Number of country_code	27	27	27	27	27	27	27	27
Number of instruments	21	20	19	18	13	12	13	12
AR2 p-value	0.407	0.456	0.516	0.570	0.403	0.451	0.556	0.669
Sargan p-value	0	0	0	0	0	0	0	0
Hansen p-value	0.383	0.373	0.102	0.0853	0.191	0.281	0.207	0.201

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to excluding individual countries from the sample

We test whether the results presented in Figure 15 are biased due to a single country which has a significant influence on our results. We have re-run Model 4 presented in Fig. 15 but by dropping one country at a time from our sample. The results are presented in Figure 96, Figure 97 and Figure 98 below. The short run leverage rate varies between 0.27 and 0.36 whereas the long run leverage rate varies between 0.90 and 1.01. The coefficients are significant at the 5 percent level indicating that an individual country is not driving the results.

Figure 96: Panel regression results – sensitivity to excluding individual countries from the sample

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI.

Models based on the June 2018 dataset.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
	All included	Excluding Australia	Excluding Austria	Excluding Belgium	Excluding Canada	Excluding Chile	Excluding Czech Republic	Excluding Denmark	Excluding Finland	Excluding France	Excluding Germany
Lag private GERD (log) - lag of dependent variable	0.6865***	0.6829***	0.6906***	0.7202***	0.6571***	0.6731***	0.6909***	0.7031***	0.6895***	0.7094***	0.6942***
	(0.0846)	(0.0852)	(0.0863)	(0.0744)	(0.0902)	(0.0857)	(0.0880)	(0.0854)	(0.0841)	(0.0829)	(0.0850)
Public GERD (log)	0.3052***	0.3108***	0.3021***	0.2724***	0.3460***	0.3249***	0.2980***	0.2836***	0.3052***	0.2825***	0.2931***
	(0.0912)	(0.0913)	(0.0926)	(0.0830)	(0.0962)	(0.0903)	(0.0930)	(0.0949)	(0.0902)	(0.0923)	(0.0920)
Employment growth rate	1.3367**	1.3629**	1.3315**	1.4336**	1.2919**	1.2469**	1.3429**	1.3439**	1.3951**	1.3781**	1.3206**
	(0.5815)	(0.5838)	(0.5904)	(0.5643)	(0.6547)	(0.6231)	(0.5934)	(0.5684)	(0.5749)	(0.5743)	(0.5900)
Interest rates	-0.0162**	-0.0161**	-0.0158**	-0.0143**	-0.0180**	-0.0170**	-0.0163**	-0.0158**	-0.0157**	-0.0143**	-0.0158**
	(0.0065)	(0.0066)	(0.0066)	(0.0060)	(0.0072)	(0.0067)	(0.0071)	(0.0064)	(0.0064)	(0.0064)	(0.0066)
Constant	0.3313	0.3151	0.3192	0.2892	0.2691	0.2941	0.3538	0.3599	0.2983	0.3105	0.3572
	(0.2680)	(0.2644)	(0.2662)	(0.2452)	(0.2683)	(0.2507)	(0.3002)	(0.2797)	(0.2552)	(0.2822)	(0.2971)
Observations	538	536	511	512	502	529	523	525	520	504	514
Number of countries	30	29	29	29	29	29	29	29	29	29	29
number of instruments	19	19	19	19	19	19	19	19	19	19	19
AR2 p-value	0.851	0.843	0.797	0.806	0.764	0.804	0.770	0.869	0.804	0.888	0.796
Hansen p-value	0.0871	0.0841	0.114	0.107	0.0917	0.0769	0.0856	0.0935	0.105	0.123	0.118

Source: Oxford Economics

Figure 97: Panel regression results – sensitivity to excluding individual countries from the sample (continued)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI.
Models based on the June 2018 dataset.

Variables	Model 1	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21
	All included	Excluding Greece	Excluding Hungary	Excluding Iceland	Excluding Ireland	Excluding Israel	Excluding Italy	Excluding Japan	Excluding Korea	Excluding Latvia	Excluding Luxembourg
Lag private GERD (log) - lag of dependent variable	0.6865***	0.6896***	0.6853***	0.7146***	0.7000***	0.6403***	0.7060***	0.6920***	0.6865***	0.6694***	0.6547***
	(0.0846)	(0.0811)	(0.0881)	(0.0797)	(0.0791)	(0.0875)	(0.0797)	(0.0930)	(0.0846)	(0.1041)	(0.0859)
Public GERD (log)	0.3052***	0.3090***	0.3093***	0.2788***	0.2966***	0.3561***	0.2925***	0.2750***	0.3052***	0.2976**	0.3369***
	(0.0912)	(0.0902)	(0.0940)	(0.0834)	(0.0878)	(0.0914)	(0.0895)	(0.1001)	(0.0912)	(0.1249)	(0.0865)
Employment growth rate	1.3367**	1.5946***	1.3697**	1.3789**	1.6368***	1.1469*	1.3652**	1.1912**	1.3367**	1.2585	1.2022*
	(0.5815)	(0.5029)	(0.5959)	(0.5441)	(0.5050)	(0.6120)	(0.5677)	(0.5840)	(0.5815)	(0.7690)	(0.6156)
Interest rates	-0.0162**	-0.0158**	-0.0161**	-0.0143**	-0.0150**	-0.0188***	-0.0142**	-0.0154**	-0.0162**	-0.0195***	-0.0188***
	(0.0065)	(0.0062)	(0.0067)	(0.0062)	(0.0061)	(0.0069)	(0.0061)	(0.0068)	(0.0065)	(0.0073)	(0.0070)
Constant	0.3313	0.2697	0.3086	0.2930	0.2719	0.3164	0.2585	0.5158	0.3313	0.5615	0.3634
	(0.2680)	(0.2304)	(0.2754)	(0.2367)	(0.2515)	(0.2726)	(0.2583)	(0.3475)	(0.2680)	(0.3753)	(0.2682)
Observations	538	530	522	534	518	519	523	510	538	523	534
Number of countries	30	29	29	29	29	29	29	29	30	29	29
number of instruments	19	19	19	19	19	19	19	19	19	19	19
AR2 p-value	0.851	0.751	0.844	0.856	0.844	0.771	0.858	0.835	0.851	0.0237	0.909
Hansen p-value	0.0871	0.0883	0.0790	0.116	0.0888	0.106	0.0925	0.129	0.0871	0.0897	0.0798

Source: Oxford Economics

Figure 98: Panel regression results – sensitivity to excluding individual countries from the sample (continued)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI.

Models based on the June 2018 dataset.

Variables	Model 1	Model 22	Model 23	Model 24	Model 25	Model 26	Model 27	Model 28	Model 29	Model 30	Model 31
	All included	Excluding Netherlands	Excluding New Zealand	Excluding Norway	Excluding Poland	Excluding Portugal	Excluding Slovak Republic	Excluding Slovenia	Excluding Spain	Excluding United Kingdom	Excluding United States
Lag private GERD (log) - lag of dependent variable	0.6865***	0.7059***	0.6789***	0.6882***	0.6865***	0.7077***	0.6515***	0.6603***	0.7088***	0.6879***	0.6727***
	(0.0846)	(0.0832)	(0.0864)	(0.0843)	(0.0895)	(0.0849)	(0.0928)	(0.0932)	(0.0876)	(0.0867)	(0.0867)
Public GERD (log)	0.3052***	0.2827***	0.3123***	0.3030***	0.2961***	0.2864***	0.3289***	0.3430***	0.2734***	0.3036***	0.3245***
	(0.0912)	(0.0919)	(0.0933)	(0.0909)	(0.0954)	(0.0919)	(0.0932)	(0.0979)	(0.0896)	(0.0933)	(0.0930)
Employment growth rate	1.3367**	1.3726**	1.3332**	1.3366**	1.3795**	1.4508**	1.2519*	1.3791**	0.9925	1.3255**	1.3434**
	(0.5815)	(0.5667)	(0.5724)	(0.5807)	(0.5715)	(0.5765)	(0.6470)	(0.6365)	(0.6101)	(0.6024)	(0.6328)
Interest rates	-0.0162**	-0.0149**	-0.0162**	-0.0162**	-0.0165**	-0.0148**	-0.0195**	-0.0169**	-0.0174**	-0.0169**	-0.0161**
	(0.0065)	(0.0063)	(0.0064)	(0.0065)	(0.0069)	(0.0066)	(0.0081)	(0.0071)	(0.0077)	(0.0068)	(0.0070)
Constant	0.3313	0.3430	0.3404	0.3341	0.4128	0.3016	0.4624	0.2485	0.4125	0.3306	0.2902
	(0.2680)	(0.2694)	(0.2664)	(0.2682)	(0.2947)	(0.2589)	(0.3731)	(0.2637)	(0.2675)	(0.2772)	(0.2968)
Observations	538	516	534	537	523	518	523	525	504	508	503
Number of countries	30	29	29	29	29	29	29	29	29	29	29
number of instruments	19	19	19	19	19	19	19	19	19	19	19
AR2 p-value	0.851	0.788	0.828	0.853	0.795	0.837	0.898	0.944	0.868	0.853	0.817
Hansen p-value	0.0871	0.0994	0.107	0.0842	0.0955	0.117	0.0964	0.0951	0.104	0.109	0.0972

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to using weighted regressions

We tested weighted regression models using GDP and various R&D levels as weights (see Figure 99). We found that the results are not significantly different from those of our preferred models. Therefore, our preferred specifications are not biased due to the implicit allocation of equal weights to large and small countries.

Figure 99: Average Leverage Rate regression models - dynamic panel using OECD data - UK leverage rates - weighted regressions

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI.

Models based on the June 2018 dataset.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
VARIABLES	**Pub GERD as weights**	**GDP as weights**	**Total GERD as weights**	**Pub GERD as weights**	**GDP as weights**	**Total GERD as weights**	**Pub GERD as weights**	**GDP as weights**	**Total GERD as weights**
Lag private GERD (log) - lag of dependent variable	0.6340***	0.6401***	0.6396***	0.6277***	0.6068***	0.6293***	0.6277***	0.6378***	0.6163***
	(0.1609)	(0.1780)	(0.1615)	(0.1280)	(0.1679)	(0.1319)	(0.1276)	(0.1599)	(0.1411)
Public GERD (log) – UK	0.2649*	0.3152*	0.2384*	0.3040***	0.3555**	0.2739***	0.3397**	0.3189*	0.3332**
	(0.1376)	(0.1786)	(0.1326)	(0.1088)	(0.1598)	(0.0992)	(0.1525)	(0.1667)	(0.1660)
Public GERD (log) - other	0.2685**	0.3118*	0.2466*	0.3043***	0.3513**	0.2794***	0.3332**	0.3152**	0.3305**
	(0.1331)	(0.1730)	(0.1293)	(0.1072)	(0.1556)	(0.0989)	(0.1445)	(0.1593)	(0.1574)
Employment growth rate	1.7246***	2.0469***	1.7442***	1.8015***	1.8670***	1.7874***	1.8292***	1.9173***	1.8917***
	(0.4115)	(0.3390)	(0.3729)	(0.3592)	(0.2355)	(0.3291)	(0.3101)	(0.2269)	(0.3845)
Interest rates	-0.0299*	-0.0246**	-0.0298*	-0.0299**	-0.0265**	-0.0303**	-0.0270***	-0.0246**	-0.0278***
	(0.0153)	(0.0122)	(0.0161)	(0.0121)	(0.0113)	(0.0134)	(0.0086)	(0.0111)	(0.0101)
Exchange rates							0.0233	0.0046	0.0212
							(0.0202)	(0.0266)	(0.0221)
Constant	1.4211	0.8312	1.6085	1.1073*	0.7947	1.3761*	0.7664	0.8205	0.9421
	(1.0406)	(0.7433)	(1.0418)	(0.6110)	(0.6090)	(0.7320)	(0.5220)	(0.7183)	(0.6653)
Observations	538	510	538	538	510	538	538	510	538
Number of countries	30	29	30	30	29	30	30	29	30

Number of instruments	16	16	16	19	19	19	20	20	20
AR2 p-value (See note 1)	0.0636	0.0757	0.0385	0.0735	0.0755	0.0453	0.0896	0.0721	0.0698
Hansen p-value (See note 2)	0.501	0.611	0.635	0.324	0.612	0.289	0.679	0.686	0.616

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to choice of deflator (CPI and GDP Deflator)

Our models used either CPI or GDP deflators to convert data into real values. Figure 100 presents the results of regressions using alternate control variables with monetary values deflated using the GDP deflator and with CPI. We find that that the choice of deflator had little impact on results, reflecting the very high correlation between the two types of deflator.

Figure 100: OECD leverage rates - Sensitivity test: Using GDP deflator instead of CPI

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI or the GDP deflator. Models based on the October 2018 dataset.

	Model 1	**Model 1**	**Model 2**	**Model 2**	**Model 3**	**Model 3**
VARIABLES	**GDP Deflator**	**CPI**	**GDP Deflator**	**CPI**	**GDP Deflator**	**CPI**
Lag private GERD (log) - lag of dependent variable	0.7044***	0.7375***	0.7962***	0.7903***	0.7385***	0.7360***
	(0.0442)	(0.0303)	(0.0410)	(0.0480)	(0.0305)	(0.0381)
Public GERD (log)	0.3139***	0.3216***	0.2339***	0.2323***	0.3210***	0.3212***
	(0.0452)	(0.0507)	(0.0589)	(0.0581)	(0.0502)	(0.0490)
GDP growth rate	0.3533***	0.3755***	0.2992***	0.2894***	0.3753***	0.3699***
	(0.0230)	(0.0384)	(0.0308)	(0.0308)	(0.0382)	(0.0387)
Interest rates	0.5190	0.8381*	0.9068*	1.1608**	0.8581*	1.1229**
	(0.5432)	(0.5007)	(0.5254)	(0.5213)	(0.5123)	(0.5249)
Employment growth rate	-0.0060***	-0.0061***	-0.0053**	-0.0054**	-0.0061***	-0.0062***
	(0.0017)	(0.0022)	(0.0022)	(0.0021)	(0.0022)	(0.0022)
Constant	-0.2496	-0.6729	-0.5602*	-0.4480	-0.6796	-0.6258
	(0.4902)	(0.4755)	(0.3080)	(0.3343)	(0.4753)	(0.5488)
Observations	731	751	751	751	751	751
Number of country_code	34	35	35	35	35	35
Number of instruments	21	21	22	22	13	13
AR2 p-value	0.973	0.907	0.632	0.618	0.909	0.888

Hansen p-value	0.719	0.747	0.0928	0.114	0.150	0.102

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: testing R&D employment as a control variable

One of the key control variables in our models is employment growth. We have also tested whether R&D employment can be used as a control variable. The results are shown in Figure 101. The Pooled OLS regression (column 1) and Fixed Effects regressions (column 4) suffer from the flaws discussed due to their inability to appropriately account for the lag term. The dynamic panel models (Model 2 and Model 3) include R&D employment levels and R&D employment growth respectively. The R&D employment term is not significant in these models, and so we are unable to draw conclusions about the leverage rate from these models.

Figure 101: Leverage rates - Sensitivity test: Including R&D employment

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)
VARIABLES	**OLS**	**Dynamic Panel**	**Dynamic Panel**	**Fixed effects - IV**
Private GERD (log) – lag	0.9021***	0.7457***	0.7136***	0.7530***
	(0.0154)	(0.1044)	(0.0990)	(0.1547)
Public GERD (log)	0.0926***	0.2245*	0.2747**	0.1194
	(0.0170)	(0.1280)	(0.1182)	(0.3392)
R&D employment (log)	0.0414**	-0.0696		-0.0517
	(0.0208)	(0.1986)		(0.0727)
Employment growth rate	1.8523***			-0.4656
	(0.4264)			(2.6116)
Interest rates	-0.0016	-0.0204**	-0.0166***	-0.0200
	(0.0022)	(0.0091)	(0.0060)	(0.0122)
R&D employment growth rate			0.1705	
			(0.2596)	
Constant	0.0309	0.6540	0.3407	1.4241
	(0.0599)	(0.5041)	(0.3019)	(1.5886)
Observations	466	505	492	370
R-squared	0.9958			
Number of country_code		30	30	25

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to instrumentation approach

The System GMM approach allows for variables to be treated as exogenous, endogenous or pre-determined. Exogenous variables are those that are independent of current disturbances (i.e. the variable is not correlated with the error term). Endogenous variables are those that are not independent of the error term (i.e. correlated with the error term). Pre-determined variables are those that are not strictly endogenous even if independent of current disturbances, they are still influenced by past ones.

In our regressions in Figure 18 and Figure 21, we have treated the lag dependent variable (lagged private R&D expenditure) both as pre-determined and endogenous. Particularly, in three out of the eight models (Model 1 and Model 4 in Figure 18 and Model 2 in Figure 21), the lagged private R&D term is treated as endogenous instead of pre-determined.

Using the June 2018 dataset, we have tested whether the choice of treating the lag private R&D term as pre-determined instead of endogenous has a significant effect on the coefficient. The results are shown in Figure 102 which shows that treating the lag dependent variable as pre-determined (instead of endogenous) does not change the results materially.

Figure 102: Leverage rates – Sensitivity test: instrumentation approach (pre-determined vs endogenous)

Dependent variable: Private GERD (log). Monetary variables specified in GBP (Model 1 and 2) or USD (Model 3) and deflated using CPI using the June 2018 dataset.

VARIABLES	Model 1	Model1	Model 2	Model 2	Model 3	Model 3
Instrumentation approach for the lagged dependent variable	Endogenous	Pre-determined	Endogenous	Pre-determined	Endogenous	Pre-determined
Lag private GERD (log) - lag of dependent variable	0.7177***	0.7025***	0.7458***	0.7422***	0.6414***	0.6422***
	(0.0960)	(0.0744)	(0.0812)	(0.0705)	(0.0996)	(0.0890)
Public GERD (log) - UK	0.2949***	0.3125***	0.2568***	0.2644***	0.3798***	0.3775***
	(0.1015)	(0.0758)	(0.0885)	(0.0730)	(0.1105)	(0.0954)
Public GERD (log) - other	0.3155***	0.3303***	0.2845***	0.2882***	0.3697***	0.3655***
	(0.1035)	(0.0810)	(0.0892)	(0.0775)	(0.1129)	(0.0972)
Employment growth rate	0.9153**	0.8581**	0.7657**	0.6669*	1.3811**	1.3099**
	(0.4264)	(0.4248)	(0.3648)	(0.3629)	(0.6404)	(0.6352)
Interest rates	-0.0125**	-0.0119**	-0.0103*	-0.0105**	-0.0179**	-0.0181***
	(0.0056)	(0.0054)	(0.0057)	(0.0050)	(0.0070)	(0.0069)
Constant					0.1968	0.2247
					(0.2893)	(0.2929)
Observations	538	538	538	538	538	538
Number of country_code	30	30	30	30	30	30
Number of instruments	14	15	17	18	19	20
AR2 p-value	0.462	0.453	0.442	0.442	0.799	0.812
Sargan p-value	5.41e-10	7.95e-08	7.20e-11	3.90e-09	0	0
Hansen p-value	0.0553	0.0596	0.173	0.160	0.130	0.159

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to using the Difference GMM approach

We selected the System GMM approach over the Difference GMM approach as the instruments generated by the former allows for the use of time-invariant instruments, thus enabling a wider choice of models and, potentially, a more efficient model (see Section 3.4.2 for further details). We have also tested whether the models using the Difference GMM approach produce very different results but were unable to find a satisfactory model using the Difference GMM approach. The results presented in Figure 103 below show various specifications using different instruments under the Difference GMM approach. Across all models the coefficient on the control variables (employment growth rate and interest rates) is not significant. Therefore, we were unable to use these models to draw any inferences on leverage rates from these models.

Figure 103: Leverage rates – Sensitivity test: Difference GMM models

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using the GDP deflator using the October 2018 dataset.

VARIABLES	Model 1	Model2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Lag private GERD (log) - lag of dependent variable	0.6460***	0.6751***	0.7544***	0.6464***	0.6627***	0.6610***	0.6753***	0.6612***	0.6595***
	(0.0460)	(0.0447)	(0.0519)	(0.0457)	(0.0423)	(0.0435)	(0.0442)	(0.0421)	(0.0424)
Public GERD (log) - UK	-0.0463	-0.1078	0.1118***	-0.1901	-0.1995	-0.1317	-0.1494	-0.1023	-0.0612
	(0.2297)	(0.2912)	(0.0303)	(0.4335)	(0.3868)	(0.2858)	(0.3452)	(0.2811)	(0.2248)
Public GERD (log) - other	0.3322***	0.3523***	0.3397***	0.3326***	0.3434***	0.3417***	0.3525***	0.3425***	0.3409***
	(0.0220)	(0.0399)	(0.0197)	(0.0220)	(0.0279)	(0.0300)	(0.0399)	(0.0276)	(0.0293)
Employment growth rate	0.0629	0.1492	0.5237	0.0669	0.0782	0.0746	0.1506	0.0722	0.0659
	(0.5520)	(0.5654)	(0.5003)	(0.5513)	(0.5624)	(0.5748)	(0.5709)	(0.5388)	(0.5492)
Interest rates	-0.0019	-0.0009	0.0005	-0.0019	-0.0014	-0.0014	-0.0009	-0.0014	-0.0014
	(0.0024)	(0.0025)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0025)	(0.0024)	(0.0025)
Observations	732	732	732	732	732	732	732	732	732
Number of country_code	35	35	35	35	35	35	35	35	35
Number of instruments	11	14	5	7	11	15	12	17	21
AR2 p-value	0.884	0.987	0.962	0.886	0.959	0.949	0.986	0.954	0.944

Source: Oxford Economics

Leverage rate in the UK – panel data analysis: sensitivity to Use of alternate approaches to calculating the ratio of private and public R&D

In Section 3.10, we discuss how we convert the short and long run leverage elasticities, obtained from the regression results, into monetary terms per unit of public R&D spending to obtain our headline results. This is done by multiplying the elasticities with the ratio of private to public R&D spending, but the results are sensitive to exactly how the calculations are done. For example, the median ratio might be used instead of the mean, or the ratio might be calculated for the most recent years only instead of the entire sample. We have undertaken sensitivity testing to explore the impact of making alternative assumptions in this calculation and the findings are reported in Figure 104. Depending on the ratio used, the short run monetary impact can vary between £0.44 and £0.73 per £1 of public spending in contrast with the full sample mean which gives us £0.55 per £1 of public spending. Similarly, the long run impact varies between £1.63 and £2.67 per £1 of public spending compared to a £2.03 impact calculated using the mean ratio for the full sample.

Within the specifications presented throughout the report, we have translated the elasticities from our regressions using the mean ratio of private and public R&D spending across the entire sample used for the corresponding regression. This ensures that the leverage rate estimates and the corresponding monetary impacts are calculated for a consistent time period.

Figure 104: Use of alternate measures of calculating the ratio of private and public R&D

Average/median	Time period covered	Ratio	Short run leverage elasticities (median of the eight preferred models)	Long run elasticities (median of the eight preferred models)	Short run impact	Long run impact
Using the mean of public and private spending	1964-2015	1.77	0.31	1.15	0.55	2.03
	1981-2015	1.94			0.61	2.23
	2001-2015	2.16			0.67	2.48
	2011-2015	2.33			0.73	2.67
Using the median of public and private spending	1964-2015	1.76			0.55	2.02
	1981-2015	1.94			0.60	2.22
	2001-2015	1.45			0.45	1.66
	2011-2015	1.42			0.44	1.63

Source: Oxford Economics

Leverage rate by types of public support - panel data analysis: Alternate specifications

In Section 5.3, we presented our preferred specifications to inform our estimates of the leverage rate by type of public support. Figure 105 below presents the results from other models tested using alternate control variables. In these models, the coefficient on the control variables either does not have the expected sign or is not statistically significant. Therefore, we are not able to draw any meaningful conclusions from these models.

Figure 105: Average Leverage Rate regression models - dynamic panel using OECD data: alternate specifications based on different control variables

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI.

Models based on the June 2018 dataset.

VARIABLES	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel
Lag private GERD (log) - lag of dependent variable	0.7448***	0.5449***	1.0230***	0.6064***	0.9676***	0.8795***	0.9324***	0.7957***	0.7418***	0.7571***	0.8104***	0.9727***	0.8306***	0.8334***	0.9570***	0.8402***	0.7216***	0.5567***
	(0.0737)	(0.0750)	(0.0721)	(0.1429)	(0.0636)	(0.0897)	(0.0829)	(0.1106)	(0.0756)	(0.0694)	(0.0708)	(0.0582)	(0.1435)	(0.0584)	(0.0667)	(0.0844)	(0.0706)	(0.0750)
Employment growth	1.4795***	1.2849**							1.5244***	1.6133***	1.3268**			1.1907**	1.9408***	1.8993***	1.3978**	1.2948**
	(0.5419)	(0.6337)							(0.5298)	(0.4693)	(0.6135)			(0.6054)	(0.6122)	(0.5409)	(0.5768)	(0.6414)
Interest rates	-0.0121*	-0.0183**	0.0023	-0.0445***	0.0041	-0.0207**	0.0067	-0.0064	-0.0113*	-0.0099*	-0.0172*	0.0078	0.0113	-0.0155*	0.0004	-0.0016	-0.0148	-0.0162
	(0.0072)	(0.0079)	(0.0081)	(0.0094)	(0.0099)	(0.0092)	(0.0106)	(0.0093)	(0.0068)	(0.0059)	(0.0100)	(0.0092)	(0.0111)	(0.0081)	(0.0056)	(0.0049)	(0.0090)	(0.0100)
Public HERD (log)	0.1406**	0.3197***	-0.0195	-0.3532	0.0518	-0.1100	0.0997***	0.1418	0.1525**	0.1318**	0.0343	0.0484	0.1964		0.0172	0.1413	0.1278*	0.3348***
	(0.0586)	(0.0610)	(0.0390)	(0.2690)	(0.0342)	(0.1322)	(0.0346)	(0.1190)	(0.0597)	(0.0515)	(0.0681)	(0.0500)	(0.1352)		(0.1039)	(0.1293)	(0.0687)	(0.0883)
Public BERD (log)	0.0962**	0.1290***	-0.0224	0.1578***	-0.0084	0.0735	-0.0143	0.0023	0.0894**	0.1003***	0.0935**	0.0037	0.0207	0.1046**			0.1085***	0.1282***
	(0.0417)	(0.0490)	(0.0259)	(0.0567)	(0.0504)	(0.0616)	(0.0490)	(0.0399)	(0.0351)	(0.0367)	(0.0429)	(0.0350)	(0.1002)	(0.0440)			(0.0414)	(0.0468)
GDP growth rates			0.9515***															
			(0.1442)															
GDP level (logs)				0.6062**														
				(0.2440)														
GVA growth rates					0.8633***													
					(0.1267)													
Capital stock growth rates						-4.2510**												
						(1.7201)												
GFCF growth rates							0.5996***											
							(0.0991)											
Inventory change								0.0097**										
								(0.0043)										
HHI										0.2500***	0.2825***	0.2266	4.0059					
										(0.0712)	(0.0927)	(0.1567)	(3.3361)					
Exchange rates (log)										0.0078								
										(0.0181)								
Export share of GDP											-0.0026	0.0017	0.0010					
											(0.0023)	(0.0014)	(0.0018)					
Compensation growth												0.8665***						
												(0.1026)						
QALI growth													1.9672***					
													(0.4178)					
Other public GERD (log)																	0.0380	-0.0318
																	(0.0515)	(0.0783)
Constant	0.6717**	0.8949***	0.0946	-2.7227	-0.0479	1.6367**	-0.0762	0.7318*	0.6449**	0.5639**	1.0253**	-0.2464	-0.4687	0.9328**	0.2640	0.3538	0.6438**	0.8959***
	(0.3137)	(0.3042)	(0.4698)	(1.8766)	(0.3634)	(0.6795)	(0.3977)	(0.3948)	(0.3022)	(0.2520)	(0.4627)	(0.3388)	(0.8193)	(0.3709)	(0.3747)	(0.3461)	(0.2876)	(0.3074)
Observations	499	499	519	519	381	266	452	317	499	499	499	383	177	499	503	503	499	499
Number of countries	28	28	28	28	27	17	29	25	28	28	28	28	18	28	29	29	28	28
Number of instruments	17	19	17	17	17	17	17	17	18	25	25	25	25	15	14	16	20	22
AR2 p-value	0.729	0.657	0.251	0.918	0.231	0.0277	0.261	0.421	0.721	0.697	0.892	0.229	0.116	0.868	0.834	0.739	0.721	0.649
Hansen p-value	0.166	0.554	0.156	0.159	0.5	0.324	0.453	0.0959	0.218	0.245	0.255	0.765	0.835	0.165	0.0901	0.0961	0.243	0.553

Source: Oxford Economics

Leverage rate by types of public support – panel data analysis: Sensitivity to using R&D to GDP ratio instead of levels

Our preferred specifications model the log of private R&D expenditure with the log of public R&D expenditure and other control variables. An alternate approach would have been to use the ratios of public R&D and private R&D spending to GDP. Figure 106 shows the results of model specifications using the private R&D to GDP ratio as the dependent variable and the public R&D to GDP ratio as the key independent variable, along with other controls in a dynamic panel setting. We were unable to find a satisfactory specification using the ratio of R&D intensity to GDP ratio that satisfies our diagnostic tests.

Figure 106: Average Leverage Rate regression models - dynamic panel using OECD data -share of GDP specification sensitivity

Dependent variable: Private GERD (share of GDP). Models based on the October 2018 dataset.

	(1)	(2)	(3)	(4)
VARIABLES	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**
Lag private GERD (share of GDP) - lag of dependent variable	1.0122***	1.0248***	1.0076***	1.0058***
	(0.0449)	(0.0450)	(0.0377)	(0.0356)
Public GERD (share of GDP) – UK	0.5459*	0.4627	0.3046	0.2596
	(0.3050)	(0.2850)	(0.2369)	(0.2028)
Public GERD (share of GDP) - other	0.5569**	0.4775*	0.3250	0.2655
	(0.2658)	(0.2514)	(0.2134)	(0.1814)
Employment growth rate	0.0052	0.0021	0.0008	0.0005
	(0.0048)	(0.0045)	(0.0036)	(0.0033)
Interest rates	0.0000	0.0000	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0000)	(0.0000)
Exchange rates				0.0001*
				(0.0000)
Constant	-0.0037***	-0.0033**	-0.0020*	-0.0017*
	(0.0014)	(0.0013)	(0.0010)	(0.0009)
Observations	510	510	510	510
Number of country_code	29	29	29	29
Number of instruments	16	21	19	20
AR2 p-value	0.715	0.738	0.717	0.715
Hansen p-value	0.932	0.513	0.619	0.860

Source: Oxford Economics

Leverage rate by types of public support – panel data analysis: Sensitivity to ratio of type of public spending to total public spending on R&D

Our preferred specifications model the log of private R&D expenditure with the log of public R&D expenditure and other control variables. An alternate approach would have been to use the ratios of public HERD and public BERD to total public GERD. Figure 107 shows the results of model specifications using these ratios as the dependent variable in a dynamic panel setting. We were unable to find a satisfactory specification where all the other control variables (i.e. employment growth and interest rates) were significant. Further, the coefficient on the public GERD term was not comparable with our findings from more robust specifications. Therefore, it is not possible to draw reliable conclusions from these findings.

Figure 107: UK leverage rates - Sensitivity test: Using ratios of public to private R&D

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using the GDP deflator. Models based on the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	**With public BERD and HERD levels (log)**	**With public GERD levels (log)**	**As (2), with HERD to public GERD ratio**	**As (2), with BERD to public GERD ratio**	**As (2), with tax credits to public GERD ratio**	**As (3), with public BERD to public GERD ratio**	**As (6), with tax credits to public GERD ratio**
Lag private R&D (log)	0.7162***	0.7981***	0.8028***	0.7746***	0.7796***	0.7778***	0.7726***
	(0.0822)	(0.0629)	(0.0602)	(0.0795)	(0.0771)	(0.0770)	(0.0862)
Employment growth rates	1.1975**	1.3712***	1.3426***	1.2025**	1.9382*	1.1904**	1.8516*
	(0.5039)	(0.4218)	(0.4434)	(0.5274)	(1.0509)	(0.5341)	(1.1082)
Interest rates	-0.0136*	-0.0095*	-0.0100*	-0.0133	0.0111	-0.0135	0.0092
	(0.0074)	(0.0051)	(0.0058)	(0.0081)	(0.0202)	(0.0084)	(0.0203)
Public HERD (log)	0.1494**						
	(0.0592)						
Public BERD (log)	0.1098**						
	(0.0484)						
Public GERD (log)		0.1785***	0.1719***	0.1985**	0.2737***	0.1944**	0.2790***
		(0.0638)	(0.0632)	(0.0805)	(0.0796)	(0.0797)	(0.0832)
Public HERD (ratio)			-0.0424			-0.0235	0.0218
			(0.1179)			(0.0943)	(0.1777)
Public BERD (ratio)				0.3109		0.3041	0.1996
				(0.3857)		(0.3802)	(0.6281)
Tax credits (ratio)					-0.3038		-0.3450
					(0.4323)		(0.3959)
Constant	0.7830***	0.3653**	0.4030*	0.3838**	-0.2952	0.4043*	-0.3007
	(0.2280)	(0.1596)	(0.2308)	(0.1618)	(0.4836)	(0.2183)	(0.4451)
Observations	504	504	504	504	288	504	288
Number of country_code	29	29	29	29	25	29	25
Number of instruments	20	20	20	20	18	20	18
AR2 p-value	0.662	0.614	0.614	0.664	0.601	0.675	0.627
Sargan p-value	6.70e-07	1.36e-09	8.43e-10	5.29e-09	3.34e-06	2.59e-09	1.41e-06
Hansen p-value	0.276	0.122	0.102	0.169	0.351	0.136	0.191

Source: Oxford Economics

Leverage rate by types of public support– panel data analysis: Sensitivity to tax credit adjustments

A further consideration when using the BERD and GERD data is that they record R&D funded through tax credits as privately-funded R&D, even though it has been funded by an offsetting tax reduction (a form of indirect support to R&D). We incorporated an adjustment into the data to exclude the estimated value of tax-credit-funded R&D. Figure 108 compares the regression models based on the unadjusted and adjusted series respectively and show that the adjustment for tax credits does not have a significant impact on our estimates of leverage.

Figure 108: OECD leverage rates – Sensitivity test: Private R&D not adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI. Models based on the June 2018 dataset.

VARIABLES	Model 1	Model 1	Model 2	Model 2	Model 3	Model 3
	Unadjusted	**Adjusted**	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Lag private GERD (log) - lag of dependent variable	0.5479***	0.5456***	0.5393***	0.5467***	0.7162***	0.7699***
	(0.0884)	(0.0946)	(0.0884)	(0.0788)	(0.0822)	(0.0730)
Employment growth rate	1.9431***	1.8882***	1.0337*	1.3886**	1.1975**	1.4414***
	(0.3756)	(0.3842)	(0.5966)	(0.5573)	(0.5039)	(0.4486)
Interest rates	-0.0026	-0.0028	-0.0146*	-0.0078	-0.0136*	-0.0093
	(0.0040)	(0.0040)	(0.0081)	(0.0072)	(0.0074)	(0.0061)
Public GERD (log) – Universities and research councils	0.4376***	0.3975***	0.3163***	0.3221***	0.1494**	0.1100**
	(0.0866)	(0.0923)	(0.0709)	(0.0630)	(0.0592)	(0.0507)
Public GERD (log) – Direct support to business	0.1129	0.1263	0.1155**	0.1042**	0.1098**	0.0998**
	(0.0780)	(0.0825)	(0.0558)	(0.0515)	(0.0484)	(0.0444)
Constant	-0.0229	0.1943	1.0311***	0.9318***	0.7830***	0.6365***
	(0.2513)	(0.2398)	(0.2830)	(0.2690)	(0.2280)	(0.1994)
Observations	691	691	504	504	504	504
Number of countries	32	32	29	29	29	29
Number of instruments	14	14	18	18	20	20
AR2 p-value	0.642	0.716	0.647	0.599	0.662	0.668

Hansen p-value	0.642	0.635	0.632	0.703	0.276	0.297

Source: Oxford Economics

Leverage rate across different countries – panel data analysis: Alternate specifications

In Section 7.2.2, we presented the results of our cross-country comparison of leverage estimates. The results Section 7.2.2 are based on the same specification across countries to maximise the comparability of results. Our findings are summarised in Figure 49. To reflect that leverage rates can vary depending on the precise model specification used, we have estimated a range for each country using different model specifications but the same underlying dataset. These alternate specifications are presented in Figure 109.

Figure 109: Average Leverage Rate regression models - dynamic panel using OECD data - cross country comparison

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI.

Models based on June 2018 dataset.

VARIABLES	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel
	OECD 1	OECD 2	OECD 3	ES 1	ES 2	ES 3	UK 1	UK 2	UK 3	FR 1	FR 2	FR 3	DE 1	DE 2	DE 3	US 1	US 2	US 3
Lag private GERD (log) - lag of dependent variable	0.6865***	0.7871***	0.7681***	0.6782***	0.6641***	0.6906***	0.6666***	0.6414***	0.6799***	0.6611***	0.6361***	0.6696***	0.6655***	0.6432***	0.6780***	0.6805***	0.6499***	0.6878***
	(0.0846)	(0.0708)	(0.0745)	(0.0823)	(0.0929)	(0.0969)	(0.0890)	(0.0996)	(0.1031)	(0.0883)	(0.0982)	(0.1031)	(0.0936)	(0.1012)	(0.1048)	(0.0868)	(0.0975)	(0.0997)
Public GERD (log) - country specific				0.2936***	0.3203***	0.2872***	0.3327***	0.3798***	0.3250***	0.3339***	0.3793***	0.3313***	0.3377***	0.3755***	0.3274***	0.3079***	0.3630***	0.3091***
				(0.0770)	(0.0885)	(0.0966)	(0.0959)	(0.1105)	(0.1154)	(0.0914)	(0.1062)	(0.1126)	(0.1017)	(0.1117)	(0.1147)	(0.0929)	(0.1079)	(0.1101)
Public GERD (log) - TOTAL/OTHER	0.3052***	0.2035**	0.2277**	0.3052***	0.3359***	0.2986***	0.3171***	0.3697***	0.3090***	0.3268***	0.3794***	0.3242***	0.2976***	0.3635***	0.3010**	0.3005***	0.3681***	0.3052***
	(0.0912)	(0.0862)	(0.0916)	(0.0827)	(0.0943)	(0.1022)	(0.0982)	(0.1129)	(0.1172)	(0.0978)	(0.1121)	(0.1184)	(0.1056)	(0.1156)	(0.1177)	(0.0979)	(0.1147)	(0.1163)
Employment growth rate	1.3367**	1.3729***	1.3726***	1.8920***	1.4286**	1.4079**	1.8004***	1.3811**	1.3150**	1.7900***	1.3685**	1.2889**	1.6541***	1.3165**	1.1895**	1.8235***	1.4505**	1.3639**
	(0.5815)	(0.4950)	(0.5086)	(0.5496)	(0.5981)	(0.5785)	(0.5583)	(0.6404)	(0.5729)	(0.5664)	(0.6484)	(0.5879)	(0.5572)	(0.6409)	(0.5699)	(0.5511)	(0.6512)	(0.5800)
Interest rates	-0.0162**	-0.0101**	-0.0106**	-0.0161**	-0.0161**	-0.0150**	-0.0177***	-0.0179**	-0.0165**	-0.0178***	-0.0178**	-0.0168**	-0.0175**	-0.0175**	-0.0161**	-0.0169**	-0.0166**	-0.0156**
	(0.0065)	(0.0046)	(0.0047)	(0.0067)	(0.0071)	(0.0068)	(0.0067)	(0.0070)	(0.0067)	(0.0067)	(0.0069)	(0.0067)	(0.0071)	(0.0070)	(0.0068)	(0.0067)	(0.0069)	(0.0065)
Exchange rates						0.0081			0.0126			0.0114			0.0128			0.0104
						(0.0128)			(0.0134)			(0.0132)			(0.0148)			(0.0123)
Constant	0.3313	0.2609	0.0074	0.4031	0.2808	0.3415*	0.4010	0.1968	0.3386	0.3742	0.1687	0.3099	0.5596	0.2305	0.4161	0.4152	0.1386	0.3040
	(0.2680)	(0.2252)	(0.0098)	(0.2619)	(0.2148)	(0.2025)	(0.2981)	(0.2893)	(0.2430)	(0.2954)	(0.2840)	(0.2463)	(0.3529)	(0.3010)	(0.2552)	(0.3175)	(0.3212)	(0.2648)
Observations	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538
Number of country_code	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Number of instruments	19	9	10	16	19	20	16	19	20	16	19	20	16	19	20	16	19	20
AR2 p-value (See note 1)	0.851	0.894	0.879	0.829	0.807	0.839	0.841	0.799	0.853	0.833	0.789	0.842	0.849	0.8	0.857	0.848	0.785	0.845
Hansen p-value (See note 2)	0.0871	0.0602	0.0598	0.0137	0.106	0.09	0.108	0.13	0.208	0.0842	0.137	0.172	0.0965	0.127	0.172	0.0805	0.13	0.155

Source: Oxford Economics

Figure 110: Average Leverage Rate regression models – dynamic panel using OECD data – cross country comparison (continued)

Dependent variable: Private GERD (log). Monetary variables specified in USD and deflated using CPI.

Models based on June 2018 dataset.

VARIABLES	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel	Dynamic Panel
	IT 1	IT 2	IT 3	JP 1	JP 2	JP 3	NOR 1	NOR 2	NOR 3	FIN 1	FIN 2	FIN 3	CAN 1	CAN 2	CAN 3
Lag private GERD (log) - lag of dependent variable	0.6743***	0.6513***	0.6841***	0.6650***	0.6450***	0.6857***	0.6707***	0.6458***	0.6818***	0.6788***	0.6536***	0.6836***	0.6722***	0.6456***	0.6851***
	(0.0812)	(0.0937)	(0.0982)	(0.0926)	(0.1002)	(0.1022)	(0.0879)	(0.1005)	(0.1038)	(0.0858)	(0.0975)	(0.1007)	(0.0888)	(0.1016)	(0.1029)
Public GERD (log) - country specific	0.3110***	0.3563***	0.3069***	0.3245***	0.3634***	0.3069***	0.3293***	0.3820***	0.3235***	0.3357***	0.3862***	0.3410***	0.3097***	0.3560***	0.3007***
	(0.0884)	(0.1082)	(0.1141)	(0.0992)	(0.1062)	(0.1067)	(0.0982)	(0.1159)	(0.1190)	(0.0988)	(0.1160)	(0.1216)	(0.0941)	(0.1123)	(0.1133)
Public GERD (log) - TOTAL/OTHER	0.3261***	0.3761***	0.3221***	0.2936***	0.3376***	0.2819***	0.3178***	0.3658***	0.3117***	0.3088***	0.3551***	0.3092***	0.3206***	0.3715***	0.3120***
	(0.0919)	(0.1121)	(0.1178)	(0.1007)	(0.1054)	(0.1078)	(0.0965)	(0.1143)	(0.1187)	(0.0941)	(0.1099)	(0.1148)	(0.0980)	(0.1172)	(0.1179)
Employment growth rate	1.8872***	1.4522**	1.3782**	1.6542***	1.1931**	1.1680**	1.8259***	1.3707**	1.3279**	1.9188***	1.4924**	1.4457***	1.8362***	1.4223**	1.3718**
	(0.5601)	(0.6394)	(0.5780)	(0.5473)	(0.6026)	(0.5628)	(0.5547)	(0.6309)	(0.5711)	(0.5278)	(0.5932)	(0.5436)	(0.5568)	(0.6364)	(0.5728)
Interest rates	-0.0156***	-0.0157**	-0.0147**	-0.0161**	-0.0168**	-0.0155**	-0.0170**	-0.0175**	-0.0159**	-0.0155**	-0.0160**	-0.0145**	-0.0164**	-0.0169**	-0.0153**
	(0.0060)	(0.0064)	(0.0061)	(0.0069)	(0.0071)	(0.0071)	(0.0066)	(0.0070)	(0.0067)	(0.0064)	(0.0067)	(0.0063)	(0.0067)	(0.0071)	(0.0067)
Exchange rates			0.0095			-0.0035			0.0100			0.0124			0.0091
			(0.0117)			(0.0193)			(0.0131)			(0.0135)			(0.0124)
Constant	0.2622	0.0574	0.2012	0.5915	0.4145	0.5150*	0.3642	0.1945	0.3072	0.3529	0.1974	0.2934	0.3324	0.1552	0.2819
	(0.2620)	(0.2838)	(0.2474)	(0.3745)	(0.2810)	(0.2839)	(0.2763)	(0.2760)	(0.2394)	(0.2665)	(0.2614)	(0.2293)	(0.2709)	(0.2886)	(0.2407)
Observations	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538
Number of country_code	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Number of instruments	16	19	20	16	19	20	11	14	15	16	19	20	16	19	20
AR2 p-value (See note 1)	0.81	0.767	0.817	0.835	0.816	0.859	0.832	0.799	0.843	0.819	0.785	0.823	0.823	0.785	0.835
Hansen p-value (See note 2)	0.0644	0.164	0.188	0.121	0.151	0.201	0.00562	0.022	0.03	0.223	0.209	0.374	0.0721	0.134	0.146

Source: Oxford Economics

Leverage rate in the UK – time series analysis

In Appendix 2, we investigated the overall UK leverage rate based on time series analysis of ONS data. In Figure 66 and Figure 67, we presented the results from ECM, IV and OLS regressions. In the tables below (Figure 111 - Figure 122), we present alternate specifications, using different control variables, from OLS, ECM and IV regressions. The BERD and GERD data record R&D funded through tax credits as privately-funded R&D, even though it has been funded by an offsetting tax reduction (a form of indirect support to R&D). In the specifications below, we have tested models with and without the adjustment for tax credits. Our approach to adjust the data is described in Section 3.3.

The results presented here are similar to those from Figure 62 and Figure 63. We were unable to establish a satisfactory model for estimating the leverage rate using a time series approach. In the regressions below, the coefficients on the control variables are not significant or do not have the right sign or magnitude. Therefore, we are not able to draw any meaningful conclusions from these models or test these further. The lack of statistical significance is likely due to the small sample size.

Figure 111: UK leverage rate – time series (ECM) – private GERD adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
VARIABLES	**ECM - A**	**ECM - B**	**ECM - C**	**ECM - D**	**ECM - E**	**ECM - F**	**ECM - G**	**ECM - H**	**ECM - I**	**ECM - J**	**ECM - K**	**ECM - L**	**ECM - M**	**ECM - M**
Residual term	-0.0960	-0.9215***	-0.8117*	-0.9741*	-1.0187	-0.9909	-0.8384	-0.7849	-0.6301	-0.5565	-1.2681	-0.4988*	-0.9208**	-0.6875***
	(0.1774)	(0.2898)	(0.4502)	(0.4487)	(0.5782)	(0.6159)	(0.6412)	(0.6601)	(0.6828)	(0.5016)	(1.1080)	(0.2720)	(0.3233)	(0.2176)
Private GERD lag (logs)	-0.0325	-0.0605	-0.0150	0.0656	0.0209	0.2143	0.0282	0.1135	0.1857	0.3047	0.4591	0.1072	-0.0554	-0.0746
	(0.2476)	(0.2263)	(0.2936)	(0.2858)	(0.3222)	(0.3768)	(0.3699)	(0.3733)	(0.3540)	(0.3313)	(0.5504)	(0.2050)	(0.2462)	(0.1753)
Public GERD (logs)				1.3767	1.4120	1.8629	0.5686	0.3036	-0.0022	0.0255	-0.4811			
				(0.9494)	(1.1722)	(1.3002)	(1.1994)	(1.2470)	(1.2230)	(1.0422)	(1.6380)			
Employment (logs)		0.0539	1.5189	0.5763	0.7542	-1.0933	1.3131	0.8432	-0.5002		-4.3548		0.1022	0.6886
		(1.1493)	(1.7535)	(1.7940)	(2.2193)	(2.8294)	(2.2946)	(2.3155)	(2.4251)		(6.0043)		(1.3451)	(0.8644)
GDP (logs)			-0.3181	-0.7947	-0.9270	-0.9148	-1.6083	-1.8542	-1.4007	-2.5968*	-0.3834			
			(0.8426)	(0.8785)	(1.4417)	(1.4593)	(1.3603)	(1.3835)	(1.3634)	(1.2244)	(2.2874)			
Inventory change (logs)						0.7216	0.5257	0.5362	0.7240	1.0963*	1.8846			
						(0.8668)	(0.6809)	(0.6783)	(0.6682)	(0.5404)	(1.5416)			
R&D wages (logs)					-0.2126	-0.5341					0.0631			
					(1.0918)	(1.0895)					(1.7733)			
Compensation of employees (logs)							0.9966	1.0752	0.7643	1.2939	-0.5599			
							(1.0361)	(1.0419)	(1.0249)	(0.8967)	(2.6671)			
Total Trade								0.2731	0.1749	0.2225	0.1030			
								(0.2941)	(0.2905)	(0.2909)	(0.3473)			
FTSE 250 index									0.1535		0.2658			
									(0.1231)		(0.4282)			
AIM All Share Index										0.0553	0.0127			
										(0.0546)	(0.1325)			
Capital stock												0.7817		
												(1.2302)		
Interest rates													-0.0013	
													(0.0236)	
HHI														6.5075***
														(1.7670)
Constant	0.0240**	0.0252	0.0143	0.0030	0.0033	0.0081	0.0077	0.0103	0.0174	0.0308	0.0510	0.0021	0.0241	0.0213*
	(0.0112)	(0.0151)	(0.0184)	(0.0192)	(0.0217)	(0.0292)	(0.0238)	(0.0238)	(0.0232)	(0.0222)	(0.0419)	(0.0246)	(0.0212)	(0.0117)
Observations	24	19	17	17	16	16	17	17	17	17	16	22	19	19
R-squared	0.0138	0.4620	0.3164	0.4231	0.4250	0.4734	0.4675	0.5300	0.6271	0.5913	0.7220	0.1794	0.4691	0.6985

Source: Oxford Economics

Figure 112: UK leverage rate – time series (ECM) – private GERD adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
VARIABLES	**ECM - O**	**ECM - P**	**ECM - Q**	**ECM - R**	**ECM - S**	**ECM - T**	**ECM - U**	**ECM - V**	**ECM - W**	**ECM - X**	**ECM - Y**	**ECM - Z**	**ECM - AA**	**ECM - AB**
Residual term	-0.9093***	-0.9564***	-0.9564***	-0.9564***	-1.4527***	-0.0822	-0.8633***	-0.0451	-0.7522**	-0.8633***	-0.9119***	-0.9628***	-0.8633***	-0.9278***
	(0.2794)	(0.3063)	(0.3063)	(0.3063)	(0.3385)	(0.1626)	(0.2898)	(0.1438)	(0.2726)	(0.2898)	(0.3003)	(0.2860)	(0.2898)	(0.2761)
Private GERD lag (logs)	-0.0997	-0.0923	-0.0923	-0.0923	-0.3042						0.0646	0.0989		
	(0.2194)	(0.2331)	(0.2331)	(0.2331)	(0.2261)						(0.2344)	(0.2233)		
Employment (logs)	1.0659	0.0578	0.0578	0.0578	0.2095		0.3018		0.1231	0.3018	0.1140	0.3887	0.3018	0.6158
	(1.2567)	(1.1745)	(1.1745)	(1.1745)	(0.7343)		(1.1441)		(1.0393)	(1.1441)	(1.1822)	(1.0975)	(1.1441)	(1.0558)
Exchange rates (logs)	0.1997													
	(0.1773)													
Exports share of GDP		0.0028	0.0028	0.0028										
		(0.0085)	(0.0085)	(0.0085)										
QALI (logs)					-0.2594									
					(0.7704)									
Public GERD (first differences of logs) - 1st lag						0.1176	0.0769			0.0769	0.0952		0.0769	
						(0.2354)	(0.2310)			(0.2310)	(0.2345)		(0.2310)	
Public GERD (first differences of logs) - 2nd lag								0.1691				0.3728		0.3551
								(0.2379)				(0.2298)		(0.2227)
Public GERD (first differences of logs) - 3rd lag									-0.4295*					
									(0.2410)					
Constant	0.0169	0.0251	0.0251	0.0251	0.0212*	0.0228*	0.0204	0.0227*	0.0291*	0.0204	0.0214	0.0138	0.0204	0.0127
	(0.0158)	(0.0155)	(0.0155)	(0.0155)	(0.0102)	(0.0110)	(0.0151)	(0.0110)	(0.0141)	(0.0151)	(0.0156)	(0.0153)	(0.0151)	(0.0146)
Observations	19	19	19	19	11	24	19	24	19	19	19	19	19	19
R-squared	0.5327	0.4727	0.4727	0.4727	0.8136	0.0237	0.4390	0.0251	0.5406	0.4390	0.4617	0.5203	0.4390	0.5040

Source: Oxford Economics

Figure 113: UK leverage rate – time series (ECM) – private GERD not adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
VARIABLES	**ECM - A**	**ECM - B**	**ECM - C**	**ECM - D**	**ECM - E**	**ECM - F**	**ECM - G**	**ECM - H**	**ECM - I**	**ECM - J**	**ECM - K**	**ECM - L**	**ECM - M**	**ECM - M**
Residual term	-0.0885	-0.8220***	-0.7239*	-0.7601*	-0.7782	-1.0007*	-0.9943**	-0.9566**	-0.8124*	-0.6404**	-1.4195**	-0.4558	-0.9351***	-0.7714***
	(0.1598)	(0.2652)	(0.3827)	(0.3639)	(0.4746)	(0.4657)	(0.4378)	(0.4010)	(0.3568)	(0.2582)	(0.4502)	(0.2752)	(0.2809)	(0.2461)
Private GERD lag (logs)	0.1426													
	(0.2546)													
Public GERD (logs)	0.0905	-0.0769	-0.0390	0.0674	0.0525	0.1864	0.0853	0.1513	0.1997	0.3547*	0.3683	0.1306	-0.1143	-0.0845
	(0.2266)	(0.1813)	(0.2142)	(0.2002)	(0.2296)	(0.2465)	(0.2289)	(0.2116)	(0.1790)	(0.1758)	(0.2289)	(0.1961)	(0.1902)	(0.1653)
Employment (logs)		0.5010	1.9014	1.0473	1.3433	-0.2090	0.8978	0.5387	-0.4138		-2.2303		0.3095	0.5617
		(0.8713)	(1.2402)	(1.2425)	(1.5457)	(1.9151)	(1.4441)	(1.3313)	(1.2177)		(2.5248)		(0.9508)	(0.8016)
GDP (logs)			-0.4463	-0.6647	-0.9047	-0.9356	-1.0533	-1.2757	-0.9308	-2.2056**	-0.7962			
			(0.6188)	(0.6133)	(0.9693)	(0.9466)	(0.8477)	(0.7842)	(0.6826)	(0.6656)	(0.9519)			
GFCF (logs)				0.9763	1.1118	1.5308*	0.9620	0.6747	0.4212	0.1818	0.4028			
				(0.6477)	(0.8161)	(0.7819)	(0.7625)	(0.7196)	(0.6253)	(0.5576)	(0.6741)			
R&D wages (logs)					-0.0010	-0.2486					0.4549			
					(0.7507)	(0.7103)					(0.7423)			
Inventory change (logs)						0.5517	0.2968	0.2912	0.4221	0.8702**	1.1508			
						(0.5730)	(0.4123)	(0.3753)	(0.3245)	(0.2915)	(0.6501)			
Compensation of employees (logs)							0.4224	0.5068	0.2961	0.9684*	-0.5408			
							(0.6597)	(0.6039)	(0.5211)	(0.4808)	(1.1255)			
Total Trade								0.2702	0.1874	0.2316	0.1166			
								(0.1662)	(0.1474)	(0.1547)	(0.1420)			
FTSE 250 index									0.1195*		0.1223			
									(0.0622)		(0.1753)			
AIM All Share Index										0.0490	0.0538			
										(0.0287)	(0.0543)			
Capital stock												0.3655		
												(1.1038)		
Interest rates													0.0064	
													(0.0171)	
HHI														3.1681*
														(1.5960)
Constant	0.0182	0.0237*	0.0159	0.0061	0.0051	0.0093	0.0047	0.0067	0.0115	0.0266*	0.0364	0.0133	0.0277*	0.0229*
	(0.0114)	(0.0119)	(0.0138)	(0.0141)	(0.0161)	(0.0190)	(0.0147)	(0.0134)	(0.0116)	(0.0119)	(0.0180)	(0.0223)	(0.0157)	(0.0109)
Observations	23	19	17	17	16	16	17	17	17	17	16	22	19	19
R-squared	0.0380	0.4878	0.3957	0.5049	0.5172	0.6114	0.6389	0.7339	0.8338	0.8026	0.9176	0.1623	0.5478	0.6035

Source: Oxford Economics

Figure 114: UK leverage rate – time series (ECM) – private GERD not adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	ECM - O	ECM - P	ECM - Q	ECM - R	ECM - S	ECM - T	ECM - U	ECM - V	ECM - W	ECM - U	ECM - Y	ECM - Z	ECM - AA	ECM - AB
Residual term	-0.9577***	-0.8251***	-0.8251***	-0.8251***	-1.5376***	-0.0057	-0.7626**	0.0623	-0.7447***	-0.7626**	-0.7840**	-0.7570***	-0.7461**	-0.7447***
	(0.2589)	(0.2726)	(0.2726)	(0.2726)	(0.3554)	(0.1497)	(0.2627)	(0.1355)	(0.2424)	(0.2627)	(0.2745)	(0.2540)	(0.2754)	(0.2424)
Private GERD lag (logs)						0.0435		0.0281						
						(0.2434)		(0.2508)						
Public GERD (logs)	-0.1384	-0.0482	-0.0482	-0.0482	-0.3870						0.0938	-0.0477		
	(0.1719)	(0.1841)	(0.1841)	(0.1841)	(0.2190)						(0.1802)	(0.1745)		
Employment (logs)	1.0280	0.4630	0.4630	0.4630	0.2103		0.7393		0.4037	0.7393	0.6328	0.4295	0.9241	0.4037
	(0.9039)	(0.9031)	(0.9031)	(0.9031)	(0.7174)		(0.8522)		(0.8302)	(0.8522)	(0.8844)	(0.8520)	(0.8755)	(0.8302)
Exchange rates (logs)	0.1223													
	(0.1308)													
Exports share of GDP		-0.0004	-0.0004	-0.0004										
		(0.0064)	(0.0064)	(0.0064)										
QALI (logs)					-0.0330									
					(0.7075)									
Public GERD (first differences of logs) - 1st lag						0.2110	0.0708			0.0708	0.0755			
						(0.2035)	(0.1792)			(0.1792)	(0.1833)			
Public GERD (first differences of logs) - 2nd lag								-0.0600					0.0175	
								(0.2009)					(0.1873)	
Public GERD (first differences of logs) - 3rd lag									-0.2947			-0.3001		-0.2947
									(0.1846)			(0.1911)		(0.1846)
Constant	0.0204	0.0238*	0.0238*	0.0238*	0.0280**	0.0197*	0.0190	0.0231**	0.0273**	0.0190	0.0189	0.0278**	0.0182	0.0273**
	(0.0118)	(0.0123)	(0.0123)	(0.0123)	(0.0097)	(0.0107)	(0.0117)	(0.0108)	(0.0115)	(0.0117)	(0.0122)	(0.0122)	(0.0124)	(0.0115)
Observations	19	19	19	19	11	23	19	23	19	19	19	19	19	19
R-squared	0.5867	0.4930	0.4930	0.4930	0.8369	0.0603	0.4770	0.0186	0.5372	0.4770	0.4878	0.5408	0.4340	0.5372

Source: Oxford Economics

Figure 115: UK leverage rate – time series (IV reg) – private GERD not adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	IVREG - A	IVREG - B	IVREG - C	IVREG - D	IVREG - E	IVREG - F	IVREG - G	IVREG - H	IVREG - I	IVREG - J	IVREG - K
Public GERD (log differences)	0.6703	0.3787	-0.6889	0.0023	-0.2036	2.0050	-0.2945	-1.0678	-1.0977	-1.1564	-6.9048
	(2.8680)	(4.7110)	(0.7160)	(1.0543)	(1.7615)	(18.4570)	(1.4326)	(1.1301)	(0.8079)	(0.8310)	(123.3457)
GFCF (log differences)				0.0750	-0.1415	-1.1447	-1.9430	-0.3612	0.1348	-0.6632	-20.6547
				(2.9809)	(2.3606)	(15.6401)	(5.7159)	(4.2922)	(3.7072)	(3.5680)	(420.9265)
Employment (log differences)		3.5226**	0.5553	3.2497	2.5847	0.0015	-5.7941	-4.3150	3.7644	-2.6806	-44.4089
		(1.4120)	(7.3384)	(6.4046)	(3.1793)	(21.9523)	(10.6136)	(11.8960)	(15.2430)	(8.3549)	(957.4875)
GDP (log differences)			1.0224	0.0689	0.2900	1.3115	2.8831	3.4404	-1.2429	2.3625	17.4536
			(2.8920)	(3.2331)	(2.2930)	(12.0424)	(4.3885)	(5.7585)	(11.3679)	(3.7409)	(354.3248)
Inventory change (log)						2.1297	1.4730	0.1796	-0.3771	0.1276	5.6499
						(15.4449)	(2.6609)	(2.8604)	(1.9812)	(2.6104)	(123.8215)
R&D wages (log differences)					0.2206	-4.1986					-5.3350
					(3.3185)	(37.0319)					(115.5522)
Compensation of employees (log differences)							-1.0159	-0.4808	1.9805	0.1902	9.2978
							(3.7058)	(3.0379)	(6.5142)	(1.9669)	(187.4470)
Total trade (log differences)								-0.4437	0.2956	-0.1467	-3.3439
								(0.8149)	(1.9528)	(1.1055)	(66.7192)
FTSE index (log differences)									-0.2499		-0.5960
									(0.7393)		(13.3744)
AIM All Share Index (log differences)										-0.0345	0.8004
										(0.1214)	(15.7324)
Constant	0.0159	-0.0123	0.0130	-0.0098	-0.0021	0.0088	0.0714	0.0401	-0.0027	0.0301	0.6018
	(0.0368)	(0.0875)	(0.0233)	(0.0624)	(0.0620)	(0.3182)	(0.1388)	(0.0955)	(0.1238)	(0.0866)	(11.9813)
Observations	24	19	18	17	16	16	16	16	16	16	15
R-squared			0.1906	0.2056	0.4138						

Source: Oxford Economics

Figure 116: UK leverage rate – time series (IV reg) – private GERD not adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	IVREG - L	IVREG - M	IVREG - N	IVREG - O	IVREG - P	IVREG - Q	IVREG - R	IVREG - S	IVREG - T	IVREG - U
Public GERD (log differences)	2.2880	-0.3384	-0.3384	1.0649	-0.7949	-0.6622			-1.1840	
	(35.4491)	(0.9010)	(0.9010)	(5.0933)	(2.7348)	(1.2636)			(2.6233)	
Employment (log differences)		3.4008**	3.4008**	1.6933	3.0480	4.6999	0.7012	3.5372*	2.3001	2.7454
		(1.1764)	(1.1764)	(2.3540)	(2.7869)	(5.9857)	(10.8182)	(2.0209)	(4.9377)	(4.8597)
Capital stock (log differences)	-2.8743									
	(39.4727)									
Interest rates (differences)		0.0100	0.0100							
		(0.0508)	(0.0508)							
HHI (differences)				-1.2547						
				(2.7718)						
Exchange rates (log differences)					-0.1663					
					(0.9225)					
Exports share of GDP (log differences)						0.0108				
						(0.0491)				
Public GERD (log differences) - 1st lag							3.3074		1.2322	0.3334
							(9.3568)		(1.4477)	(1.2797)
Public GERD (log differences) - 2nd lag								-0.0538		0.4035
								(1.6476)		(3.6077)
Constant	0.0372	0.0037	0.0037	-0.0087	0.0132	-0.0079	-0.0301	-0.0054	0.0061	-0.0101
	(0.1835)	(0.0265)	(0.0265)	(0.0531)	(0.0741)	(0.0521)	(0.1094)	(0.0156)	(0.0506)	(0.0291)
Observations	21	19	19	20	19	19	19	19	19	19
R-squared		0.3238	0.3238					0.2029		0.2761

Source: Oxford Economics

Figure 117: UK leverage rate – time series (IV reg) – private GERD adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	IVREG - A	IVREG - B	IVREG - C	IVREG - D	IVREG - E	IVREG - F	IVREG - G	IVREG - H	IVREG - I	IVREG - J	IVREG - K
Public GERD (log differences)	-0.0774	-0.8748	-0.3430	0.1468	0.0417	8.6053	-0.6639	-1.3193	-1.3465	-1.3847	-7.1791
	(2.1198)	(4.3946)	(0.8977)	(1.3612)	(2.3727)	(72.1952)	(1.4310)	(1.2109)	(0.8666)	(0.9700)	(126.9530)
GFCF (log differences)				-0.4183	-0.5269	-4.4163	-1.9901	-0.6493	-0.1988	-0.8719	-21.0735
				(4.0563)	(3.8283)	(61.3952)	(6.2451)	(4.8327)	(4.4312)	(4.3986)	(433.9386)
Employment (log differences)		3.4531	3.3958	4.4268	4.1335	-5.8824	-5.9661	-4.7125	2.6262	-3.5076	-45.9064
		(2.0268)	(7.1862)	(9.6272)	(4.5699)	(83.9654)	(11.4269)	(13.0820)	(16.2928)	(9.4969)	(987.7666)
GDP (log differences)			-0.0226	-0.1715	-0.1256	3.8353	3.3086	3.7810	-0.4729	2.9863	18.4585
			(2.8105)	(4.3692)	(3.1893)	(44.6037)	(4.6723)	(6.4035)	(13.0689)	(4.5128)	(365.1863)
Inventory change (log)						8.2575	0.9757	-0.1206	-0.6263	-0.1589	5.4176
						(62.1409)	(2.7236)	(3.2678)	(2.1610)	(3.1811)	(127.9072)
R&D wages (log differences)					0.1722	-16.9626					-5.2245
					(4.8287)	(141.1755)					(118.7365)
Compensation of employees (log differences)							-0.7417	-0.2881	1.9475	0.2066	9.1364
							(3.7287)	(3.2360)	(7.2920)	(2.2207)	(192.8320)
Total trade (log differences)								-0.3761	0.2954	-0.1571	-3.4134
								(0.9249)	(2.2852)	(1.2901)	(68.6770)
FTSE index (log differences)									-0.2270		-0.5765
									(0.8176)		(13.7419)
AIM All Share Index (log differences)										-0.0254	0.8159
										(0.1365)	(16.2016)
Constant	0.0257	0.0090	0.0002	-0.0092	-0.0051	0.0373	0.0619	0.0354	-0.0035	0.0280	0.6068
	(0.0301)	(0.0849)	(0.0246)	(0.0836)	(0.0894)	(1.2217)	(0.1447)	(0.1059)	(0.1401)	(0.1058)	(12.3507)
Observations	24	19	18	17	16	16	16	16	16	16	15
R-squared	0.0225	0.1785	0.3483	0.0297	0.1520						

Source: Oxford Economics

Figure 118: UK leverage rate – time series (IV reg) – private GERD adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	IVREG - L	IVREG - M	IVREG - N	IVREG - O	IVREG - P	IVREG - Q	IVREG - R	IVREG - S	IVREG - T	IVREG - U	IVREG - V
Public GERD (log differences)	2.8014	0.1373	0.1373	0.1861	-1.4802	-0.0789	-1.7023	-0.8350			
	(43.0850)	(0.9377)	(0.9377)	(2.8066)	(4.5470)	(1.5215)	(1.8724)	(1.9113)			
Employment (log differences)		3.6249**	3.6249**	1.8469	3.2082	2.5529	3.5803	1.7005	5.2249	0.5092	-23.1295
		(1.2745)	(1.2745)	(1.1314)	(4.5737)	(6.8730)	(3.0676)	(10.1217)	(5.5179)	(13.6359)	(477.4133)
Capital stock (log differences)	-3.5884										
	(47.8204)										
Interest rates (differences)		-0.0141	-0.0141								
		(0.0683)	(0.0683)								
HHI (differences)				-3.9735							
				(2.4906)							
Exchange rates (log differences)					-0.0858						
					(1.5438)						
Exports share of GDP (log differences)						-0.0083					
						(0.0572)					
Public GERD (log differences) - 1st lag							-0.2705		-1.9856		
							(2.5287)		(3.3424)		
Public GERD (log differences) - 2nd lag								1.5697		2.7238	
								(7.2446)		(8.0435)	
Public GERD (log differences) - 3rd lag											-20.2115
											(353.6688)
Constant	0.0392	-0.0136	-0.0136	-0.0048	0.0222	0.0056	0.0256	0.0008	0.0082	-0.0196	0.5655
	(0.2201)	(0.0361)	(0.0361)	(0.0337)	(0.1201)	(0.0533)	(0.0446)	(0.0727)	(0.0453)	(0.0498)	(10.1424)
Observations	21	19	19	20	19	19	19	19	19	19	19
R-squared		0.1787	0.1787	0.1631		0.2393					

Source: Oxford Economics

Figure 119: UK leverage rate - time series (OLS) – private GERD not adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	**OLS - A**	**OLS - B**	**OLS - C**	**OLS - D**	**OLS - E**	**OLS - F**	**OLS - G**	**OLS - H**	**OLS - I**	**OLS - J**	**OLS - K**
Public GERD (log differences)	-0.1537	-0.1864	-0.2945	-0.2698	-0.3156	-0.3405	-0.4484	-0.4765	-0.4784	-0.4774	0.0508
	(0.2179)	(0.2261)	(0.2536)	(0.2466)	(0.2452)	(0.2950)	(0.3463)	(0.3915)	(0.4131)	(0.4165)	(0.5279)
GFCF (log differences)				0.7311	0.3702	0.3929	0.1011	0.2374	0.2532	0.2359	-0.3968
				(0.5865)	(0.5475)	(0.5980)	(0.5587)	(0.5209)	(0.5538)	(0.5497)	(1.1942)
Employment (log differences)		2.2794***	2.2428**	1.8603**	2.5663**	2.8063**	3.1759***	3.3428***	3.4193**	3.3672**	-3.1519
		(0.4851)	(0.8393)	(0.6459)	(0.8397)	(1.1389)	(0.9179)	(0.9664)	(1.0877)	(1.0706)	(3.7963)
GDP (log differences)			0.2371	-0.0074	-0.4434	-0.3822	-0.2148	-0.1169	-0.1468	-0.1126	1.4525
			(0.4277)	(0.5192)	(0.6960)	(0.7843)	(0.8994)	(1.0207)	(1.2180)	(1.0808)	(1.3283)
Inventory change (log)						-0.1304	-0.4652	-0.4585	-0.4667	-0.4675	1.3016
						(0.5154)	(0.4458)	(0.4767)	(0.4751)	(0.5256)	(1.1064)
R&D wages (log differences)					0.9108*	0.9190*					2.3863*
					(0.4892)	(0.5047)					(0.9697)
Compensation of employees (log differences)							0.7652	0.7300	0.7477	0.7331	-2.5819
							(0.5349)	(0.5281)	(0.5726)	(0.5512)	(1.3713)
Total trade (log differences)								-0.1305	-0.1231	-0.1253	-0.1489
								(0.2107)	(0.2437)	(0.2604)	(0.2743)
FTSE index (log differences)									-0.0095		0.4966
									(0.0775)		(0.2542)
AIM All Share Index (log differences)										-0.0026	-0.1030
										(0.0299)	(0.0696)
Constant	0.0267***	0.0060	0.0056	-0.0009	-0.0007	-0.0037	-0.0098	-0.0107	-0.0110	-0.0112	0.0248
	(0.0087)	(0.0095)	(0.0103)	(0.0112)	(0.0129)	(0.0155)	(0.0107)	(0.0100)	(0.0106)	(0.0119)	(0.0197)
Observations	24	20	18	18	17	17	17	17	17	17	16
R-squared	0.0263	0.3128	0.4010	0.4495	0.5262	0.5292	0.5293	0.5468	0.5473	0.5470	0.7063

Source: Oxford Economics

Figure 120: UK leverage rate - time series (OLS) – private GERD not adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
VARIABLES	**OLS - L**	**OLS - M**	**OLS - N**	**OLS - O**	**OLS - P**	**OLS - Q**	**OLS - R**	**OLS - S**	**OLS - T**
Public GERD (log differences)	-0.2597	-0.2113	-0.1886	-0.1776	-0.1895	-0.1939	-0.1492		
	(0.2165)	(0.2374)	(0.2389)	(0.2247)	(0.2421)	(0.2185)	(0.1986)		
GFCF (log differences)									
Employment (log differences)	2.5527***	2.1482***	2.2892***	2.5683***	2.2547***	2.2394***	2.4585***	2.1875***	2.4277***
	(0.7618)	(0.7157)	(0.5202)	(0.7036)	(0.5091)	(0.4633)	(0.5157)	(0.5339)	(0.4848)
Capital stock (log differences)	1.5166*								
	(0.8092)								
Interest rates (differences)		0.0077							
		(0.0203)							
HHI (differences)			0.0551						
			(0.3509)						
Exchange rates (log differences)				0.1728					
				(0.2016)					
Exports share of GDP (log differences)					-0.0025				
					(0.0062)				
Public GERD (log differences) - 1st lag						0.0956		0.0802	
						(0.1521)		(0.1693)	
Public GERD (log differences) - 2nd lag							0.2753		0.2962*
							(0.1698)		(0.1632)
Constant	-0.0265	0.0102	0.0061	0.0022	0.0066	0.0052	-0.0003	0.0032	-0.0024
	(0.0172)	(0.0149)	(0.0099)	(0.0135)	(0.0104)	(0.0097)	(0.0096)	(0.0085)	(0.0079)
Observations	17	20	20	20	20	20	20	20	20
R-squared	0.3815	0.3206	0.3131	0.3386	0.3182	0.3231	0.3947	0.2805	0.3698

Source: Oxford Economics

Figure 121: UK leverage rate - time series (OLS) – private GERD adjusted for tax credits

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
VARIABLES	**OLS - A**	**OLS - B**	**OLS - C**	**OLS - D**	**OLS - E**	**OLS - F**	**OLS - G**	**OLS - H**	**OLS - I**	**OLS - J**	**OLS - K**
Public GERD (log differences)	-0.2419	-0.2827	-0.4082	-0.3872	-0.4327	-0.6043	-0.5197	-0.5397	-0.5390	-0.5388	-0.0298
	(0.2614)	(0.2739)	(0.3128)	(0.3163)	(0.3136)	(0.4215)	(0.3657)	(0.4125)	(0.4321)	(0.4362)	(0.5528)
GFCF (log differences)				0.6187	0.2561	0.4116	0.1092	0.2061	0.2000	0.2077	-0.3390
				(0.6821)	(0.7235)	(0.8174)	(0.5845)	(0.5475)	(0.6043)	(0.5975)	(1.2690)
Employment (log differences)		2.6445***	2.6048**	2.2811**	3.1360**	4.7841**	3.4589***	3.5777***	3.5479**	3.5517**	-2.5179
		(0.6985)	(1.0489)	(1.0051)	(1.2217)	(1.8223)	(0.8695)	(0.9336)	(1.1116)	(1.0667)	(3.7862)
GDP (log differences)			0.2734	0.0665	-0.4863	-0.0663	-0.1379	-0.0683	-0.0566	-0.0729	1.3416
			(0.4510)	(0.5647)	(0.8094)	(0.8907)	(0.9288)	(1.0512)	(1.2617)	(1.1205)	(1.3659)
Inventory change (log)						-0.8954	-0.6620	-0.6573	-0.6541	-0.6477	1.0100
						(0.6777)	(0.4412)	(0.4715)	(0.4625)	(0.5172)	(1.0806)
R&D wages (log differences)					1.0708	1.1269*					2.4555*
					(0.6659)	(0.5705)					(0.9993)
Compensation of employees (log differences)							0.8392	0.8142	0.8074	0.8110	-2.4091
							(0.5552)	(0.5577)	(0.6182)	(0.5969)	(1.3277)
Total trade (log differences)								-0.0928	-0.0957	-0.0983	-0.1226
								(0.2355)	(0.2684)	(0.2851)	(0.3132)
FTSE index (log differences)									0.0037		0.4851
									(0.0849)		(0.2541)
AIM All Share Index (log differences)										0.0028	-0.0955
										(0.0341)	(0.0705)
Constant	0.0278**	0.0038	0.0032	-0.0023	-0.0024	-0.0227	-0.0203*	-0.0209*	-0.0208*	-0.0204	0.0125
	(0.0113)	(0.0109)	(0.0125)	(0.0142)	(0.0166)	(0.0189)	(0.0100)	(0.0094)	(0.0100)	(0.0114)	(0.0189)
Observations	24	20	18	18	17	17	17	17	17	17	16
R-squared	0.0418	0.2846	0.3607	0.3824	0.4444	0.5276	0.5473	0.5554	0.5554	0.5555	0.6856

Source: Oxford Economics

Figure 122: UK leverage rate - time series (OLS) – private GERD adjusted for tax credits (continued)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
VARIABLES	**OLS - L**	**OLS - M**	**OLS - N**	**OLS - O**	**OLS - P**	**OLS - Q**	**OLS - R**	**OLS - S**	**OLS - T**
Public GERD (log differences)	-0.3085	-0.2907	-0.2083	-0.2587	-0.2802	-0.2846	-0.2541		
	(0.2348)	(0.2810)	(0.2579)	(0.2557)	(0.2808)	(0.2716)	(0.2636)		
Employment (log differences)	2.7307***	2.6026**	2.3179***	3.4306***	2.6640***	2.6346***	2.7821***	2.5584***	2.7298***
	(0.7905)	(0.9613)	(0.6805)	(1.0791)	(0.7460)	(0.7287)	(0.6912)	(0.8097)	(0.6450)
Capital stock (log differences)	1.5984*								
	(0.8626)								
Interest rates (differences)		0.0025							
		(0.0232)							
HHI (differences)			-1.8428***						
			(0.6080)						
Exchange rates (log differences)				0.4703					
				(0.3168)					
Exports share of GDP (log differences)					0.0019				
					(0.0077)				
Public GERD (log differences) - 1st lag						0.0237		0.0011	
						(0.1953)		(0.2236)	
Public GERD (log differences) - 2nd lag							0.2116		0.2472
							(0.2112)		(0.1887)
Constant	-0.0327	0.0051	0.0014	-0.0066	0.0033	0.0036	-0.0011	0.0007	-0.0046
	(0.0189)	(0.0158)	(0.0118)	(0.0166)	(0.0122)	(0.0118)	(0.0125)	(0.0097)	(0.0095)
Observations	17	20	20	20	20	20	20	20	20
R-squared	0.3848	0.2851	0.4430	0.4046	0.2867	0.2850	0.3150	0.2274	0.2696

Source: Oxford Economics

Leverage rate for indirect support – time series analysis

In Appendix 3: Leverage rates for indirect support (tax credits), we investigated the leverage rate achieved through indirect support using ONS data. In Figure 66, we presented the results from ECM, IV and OLS regressions. In the tables below (Figure 123, Figure 124 and Figure 125), we present alternate specifications, using different control variables, from OLS, ECM and IV regressions. The results presented here are similar to those from Figure 69. As shown below, various modelling specifications and combinations of control variables were tested to investigate the leverage rate achieved through indirect support, but we were unable to establish a robust statistically significant relationship.

Figure 123: UK leverage rate (tax) time series (OLS) – private GERD adjusted for tax credits

Dependent variable: Private GERD (first differences of logs).

Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	**OLS - A**	**OLS - B**	**OLS - C**	**OLS - D**	**OLS - E**	**OLS - F**	**OLS - G**	**OLS - H**	**OLS - I**
Tax credits (log - first differences)	-0.0277	-0.0333	-0.0500	-0.0501	-0.0408	-0.0598	-0.0837	-0.0828	-0.1040
	(0.0330)	(0.0399)	(0.0555)	(0.0573)	(0.0536)	(0.0547)	(0.0644)	(0.0991)	(0.0776)
GFCF (log - first differences)				0.2859	0.5234	0.6409	0.4628		0.8643
				(0.6004)	(0.8296)	(0.8040)	(0.7459)		(0.8670)
Employment (log - first differences)		1.6465**	1.0150	0.9190	1.7397	0.0182	-1.2260	0.1511	-1.2849
		(0.5408)	(1.3384)	(1.4361)	(1.4897)	(1.4804)	(1.6101)	(2.6263)	(1.5607)
GDP (log - first differences)			0.4365	0.3270	-0.3985	-1.3064	1.1139	1.4059	1.4938
			(0.8197)	(0.8751)	(1.0664)	(0.9729)	(1.3300)	(2.0572)	(1.6232)
Inventory change (log - first differences)						1.1118**	0.5982	-0.0100	0.6489
						(0.4300)	(0.6012)	(1.6698)	(0.6923)
R&D wage (log - first differences)					0.9165	2.0495*			
					(1.0069)	(1.0721)			
Compensation of employees (log - first differences)							-0.7798	-0.6806	-1.1103
							(1.0215)	(1.3360)	(1.1980)
Capital stock (log - first differences)								0.1518	
								(2.4586)	
Total trade (log - first differences)								-0.0878	-0.2131
								(0.3091)	(0.2005)
Constant	0.0039	-0.0089	-0.0068	-0.0090	-0.0116	0.0186	0.0122	-0.0051	0.0140
	(0.0135)	(0.0121)	(0.0144)	(0.0148)	(0.0151)	(0.0204)	(0.0260)	(0.0539)	(0.0265)
Observations	14	14	14	14	14	14	14	12	14
R-squared	0.0303	0.2672	0.2893	0.2994	0.3419	0.5312	0.4137	0.3226	0.4777

Source: Oxford Economics

Figure 124: UK leverage rate (tax) time series (ECM) – private GERD adjusted for tax credits

Dependent variable: Private GERD (first differences of logs).

Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	**ECM - A**	**ECM - B**	**ECM - C**	**ECM - D**	**ECM - E**	**ECM - F**	**ECM - G**	**ECM - H**	**ECM - I**
Residual term	-0.3168	-0.6775*	-0.8159	-0.9150**	-0.8871*	-1.3944***	-1.1590**	-1.0938**	-0.9227**
	(0.3081)	(0.3418)	(0.4812)	(0.3664)	(0.3886)	(0.3087)	(0.3212)	(0.3259)	(0.2627)
Tax credits (logs)	-0.0468	-0.0403	-0.0203	-0.0263	-0.0308	-0.0251	-0.0176	-0.0067	0.0056
	(0.0447)	(0.0352)	(0.0496)	(0.0382)	(0.0418)	(0.0285)	(0.0298)	(0.0312)	(0.0226)
GFCF (logs)				1.2072*	1.0855	0.6173	0.5481	0.3075	
				(0.5313)	(0.6073)	(0.4061)	(0.4182)	(0.4686)	
Employment (logs)		1.1751	1.1877	0.8992	0.5808	-0.9741	-0.0272	0.1325	2.1643
		(0.7883)	(1.3232)	(1.0610)	(1.3395)	(1.0803)	(1.2248)	(1.2253)	(0.9424)
GDP (logs)			0.1333	-0.3899	-0.1257	-0.6830	-1.3193*	-1.5780*	-1.5977*
			(0.6798)	(0.5781)	(0.9173)	(0.6768)	(0.6778)	(0.7120)	(0.6333)
Inventory change (logs)						0.8982**	0.7395*	0.6954*	-0.7028
						(0.3564)	(0.3052)	(0.3079)	(0.4220)
R&D wages (logs)					-0.4035	-0.1140			
					(0.8703)	(0.6712)			
Compensation of employees (logs)							0.5929	0.8213	2.0209**
							(0.5488)	(0.5868)	(0.3893)
Total trade (logs)								0.1250	0.1736
								(0.1120)	(0.0803)
Capital stock (logs)									-1.0241
									(0.5964)
Constant	0.0103	0.0003	-0.0063	-0.0146	-0.0127	0.0155	0.0086	0.0069	-0.0185
	(0.0142)	(0.0121)	(0.0136)	(0.0117)	(0.0126)	(0.0128)	(0.0127)	(0.0128)	(0.0141)
Observations	14	14	14	14	14	14	14	14	12
R-squared	0.1977	0.5777	0.5551	0.7390	0.7456	0.9024	0.9000	0.9172	0.9699

Source: Oxford Economics

Figure 125: UK leverage rate (tax) time series (IV) – private GERD adjusted for tax credits

Dependent variable: Private GERD (first differences of logs).

Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	**IVREG - A**	**IVREG - B**	**IVREG - C**	**IVREG - D**	**IVREG - E**	**IVREG - F**	**IVREG - G**	**IVREG - H**	**IVREG - I**
Tax credits (log - first differences)	-0.1145**	-0.2843	0.1340	3.0195	-0.1975	-0.0933	-0.1916	-0.1044	-0.1970
	(0.0461)	(0.3750)	(0.3375)	(175.6713)	(0.6224)	(0.0783)	(0.2285)	(0.3533)	(0.3940)
GFCF ((log - first differences)				-87.9805	2.6463	-1.6595	-3.5606		-0.1575
				(4,932.9363)	(18.6465)	(2.4426)	(6.2165)		(5.6180)
Employment (log - first differences)		16.0930	11.6695	77.6768	3.4420	4.2836	-3.8807	-1.3575	4.0402
		(22.1307)	(10.9131)	(4,126.8803)	(10.7482)	(5.3019)	(15.5730)	(11.4662)	(17.4700)
GDP (log - first differences)			-4.2642	-10.1380	-1.3246	-0.8750	2.2107	-5.8422	3.6959
			(5.2728)	(554.2222)	(2.9287)	(1.5965)	(6.1028)	(14.1162)	(10.4648)
Inventory change (log - first differences)						0.4323	1.9636	8.7678	-0.6968
						(1.2389)	(2.9456)	(14.9806)	(2.3118)
R&D wages (log - first differences)					1.7414	1.2656			
					(4.3026)	(2.0547)			
Compensation of employees (log - first differences)							-0.3103	-0.7793	-2.9087
							(2.7798)	(9.1686)	(9.7618)
Capital stock (log - first differences)								8.1734	
								(13.1384)	
Total trade (log - first differences)								-0.3908	-1.1044
								(1.2791)	(1.5769)
Constant	0.0169	-0.0960	-0.0650	0.3076	-0.0219	0.0135	0.0923	0.0693	0.0077
	(0.0164)	(0.1243)	(0.0792)	(18.2186)	(0.0843)	(0.0531)	(0.1921)	(0.1889)	(0.1455)
Observations	13	13	13	13	13	13	13	11	13
R-squared	0.0096								

Source: Oxford Economics

Leverage rate for indirect support – regional panel data analysis using HMRC data

We tested modelling approaches using regional tax credits data from the HMRC. In Figure 126 below we present specifications, using both a dynamic panel approach (Models 1 and 2, which are the same as in Figure 71) and a static panel approach (Models 3 – 6). In these alternative models (Models 3 – 6) we were unable to produce a specification in which the control variables are statistically significant. We were therefore unable to produce a model that would enable us to draw meaningful conclusions regarding the leverage rate for indirect support.

Figure 126: Regional panel estimates of leverage rate (tax credits)

Dependent variable: Private GERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

VARIABLES	Model 1	Model2	Model 3	Model 4	Model 5	Model 6
Lag of Private GERD (logs)	0.9828***	1.0919***				
	(0.0442)	(0.1172)				
Tax credits (log)	0.0991	0.1177			0.2195***	0.2170***
	(0.0671)	(0.1219)			(0.0507)	(0.0550)
GVA growth rate	2.9887**		2.2943*		2.5207	
	(1.4043)		(1.2718)		(1.9556)	
Employment growth rate		0.3926		1.0977		-0.6072
		(3.1869)		(2.3008)		(1.8923)
Tax credits growth			0.1770	0.5079		
			(0.1987)	(0.3236)		
Constant	-0.3852	-1.1753	0.0133	-0.0903		
	(0.4965)	(0.9197)	(0.0645)	(0.1021)		
Observations	33	33	11	11	22	22
R-squared			0.4806	-0.3450	0.6934	0.4075
Number of region_code	11	11	11	11	11	11

Source: Oxford Economics

Leverage rate for indirect support – panel data analysis using OECD data

We have used several modelling approaches and model specifications to estimate the leverage rate for indirect support (i.e. tax credits). All models use the log of private R&D as the dependent variable, except Models 4 and 5 where the growth rate of private R&D is used. Models 1 through 5 use static panel methods (which suffer from the limitations discussed in Section 3.4). All other models use dynamic panel methods. Model 1 includes only tax credits as an independent variable and is likely to suffer from omitted variable bias. Different combinations of control variables are used in all other models, but we have not been able to find one where the control variables are statistically significant. As such, we have not been able to develop a model that would allow us to draw meaningful conclusions about the leverage rate for indirect support.

Figure 127: Results of panel data regressions methods

Dependent variable: Private GERD (log), except (4) and (5) where Private GERD (growth) is used.

Monetary variables specified in USD and deflated using CPI using the June 2018 dataset.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
VARIABLES	**Static Panel**	**Static Panel - Fixed Eff.**	**Static Panel - Random Eff.**	**Static Panel - Fixed Eff.**	**Static Panel - Random Eff.**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**	**Dynamic Panel**
Lag private adjusted GERD (log)		0.8460***	0.9842***			0.9396***	0.9386***	0.6724***	0.6743***	0.6604***	0.8087***	0.9246***	0.8615***	0.9870***	1.0166***	0.7680***	0.7323***	0.9895***
		(0.0232)	(0.0154)			(0.0971)	(0.0875)	(0.0954)	(0.0916)	(0.0949)	(0.1989)	(0.0944)	(0.0916)	(0.0401)	(0.0875)	(0.1141)	(0.0525)	(0.0331)
Tax credits (log)	0.1562***	0.0020	-0.0030			-0.0366	-0.0195	-0.0482**	-0.0480**	-0.0508**	-0.0365**	-0.0451***	-0.0416***	-0.0386**	-0.0312	-0.0424***	-0.0422***	-0.0389**
	(0.0454)	(0.0168)	(0.0121)			(0.0300)	(0.0268)	(0.0231)	(0.0232)	(0.0235)	(0.0164)	(0.0139)	(0.0147)	(0.0188)	(0.0201)	(0.0149)	(0.0130)	(0.0182)
Lag private adjusted GERD (growth				0.1845*	0.2312***													
				(0.0946)	(0.0816)													
Tax credits (growth)				-0.0020	-0.0047													
				(0.0094)	(0.0100)													
Employment levels (log)							0.0518	-0.0308	-0.0304	-0.0312								
							(0.0858)	(0.0828)	(0.0826)	(0.0834)								
Public GERD (log)								0.4089***	0.4071***	0.4305***								
								(0.0702)	(0.0696)	(0.0791)								
Employment growth rates											-0.7791	-0.9314	-1.0275	-0.9981	-0.4786	-0.2724	-0.2805	-0.9090
											(0.8086)	(0.8884)	(0.8024)	(0.9039)	(0.6091)	(0.7304)	(0.7200)	(0.7737)
Interest rates											-0.0169	-0.0133	-0.0229***	-0.0109	0.0010	-0.0180***	-0.0198***	-0.0092
											(0.0124)	(0.0109)	(0.0079)	(0.0103)	(0.0082)	(0.0060)	(0.0049)	(0.0099)
Public GERD (log) – Universities and resea											0.2068	0.0641	0.1061		0.0077	0.0902	0.1445*	
											(0.2088)	(0.0838)	(0.0860)		(0.0876)	(0.1838)	(0.0742)	
Public GERD (log) – Direct support to busir											-0.0158	0.0090	0.0154	-0.0063		0.0214	0.0092	
											(0.0497)	(0.0401)	(0.0424)	(0.0383)		(0.0426)	(0.0493)	
HHI													0.5484**					
													(0.2530)					
Exchange rates (log)													-0.0064					
													(0.0219)					
Public GERD (log) – other																0.1560*	0.1482**	
																(0.0814)	(0.0688)	
Constant	7.3681***	1.2936***	0.1756*	0.0226***	0.0161	0.7292	0.1630	0.0138	0.0073	-0.0419	0.4623	0.4393	0.5755**	0.4317	0.0094	0.4425***	0.4676**	0.3730
	(0.2368)	(0.1826)	(0.0900)	(0.0043)	(0.0100)	(0.6771)	(0.3016)	(0.3611)	(0.3574)	(0.3712)	(0.3219)	(0.3166)	(0.2616)	(0.3055)	(0.1490)	(0.1601)	(0.1839)	(0.2643)
Observations	287	242	242	210	210	242	219	219	219	219	211	211	211	211	211	211	211	219
R-squared	0.2264	0.8292		0.0340														
Number of country_code	31	28	28	24	24	28	25	25	25	25	25	25	25	25	25	25	25	25
Number of instruments	n.a.	n.a.	n.a.	n.a.	n.a.	5	11	14	15	13	18	19	22	16	17	22	24	12
AR2 p-value	n.a.	n.a.	n.a.	n.a.	n.a.	0.299	0.378	0.894	0.890	0.923	0.734	0.907	0.631	0.942	0.817	0.965	0.938	0.727
Hansen p-value	n.a.	n.a.	n.a.	n.a.	n.a.	0.360	0.275	0.270	0.344	0.308	0.415	0.297	0.373	0.421	0.401	0.471	0.569	0.248

Source: Oxford Economics

Leverage rate for indirect support – panel data analysis using b-index

An alternate way of measuring indirect support is to use the “B-index”, which is a measure of the level of pre-tax profit a “representative” company needs to generate to break even on a marginal, unitary outlay on R&D, taking into account provisions in the tax system that allow for special treatment of R&D expenditures. Figure 128 shows the results of an OLS, fixed effects and dynamic panel regression using a panel dataset for OECD countries. We were not able to find a satisfactory regression specification using dynamic panel methods. In the dynamic panel regression, the coefficient on employment growth and interest rates is not significant.

Figure 128: Leverage rates estimation - Sensitivity tests: B-index
Dependent variable: Private GERD (log).
Monetary values specified in GBP and deflated using the GDP deflator.
Models based on the October 2018 OECD dataset.

	(1)	(2)	(3)
VARIABLES	**OLS**	**Dynamic Panel**	**Fixed effects - IV**
Lag private GERD (log) - lag of dependent variable	0.9218***	0.6849***	0.5166
	(0.0134)	(0.1189)	(0.6013)
Public GERD (log)	0.0794***	0.3298***	0.3480
	(0.0156)	(0.1196)	(0.6412)
B Index	-0.1646***	-0.3966	-1.1078
	(0.0524)	(0.3573)	(0.7260)
Employment growth rate	2.1614***	1.1211	-4.8020
	(0.5299)	(0.8129)	(8.1429)
Interest rates	0.0046	-0.0106	-0.1239
	(0.0039)	(0.0125)	(0.2453)
Constant	0.0642	0.1776	2.0765
	(0.0540)	(0.2047)	(3.0699)
Observations	345	345	277
R-squared	0.9968		
Number of country_code	27	27	26

Source: Oxford Economics

Leverage rates across sectors in the UK using OECD data

In this section, we present alternate specifications for panel data regressions using OECD data similar to those presented in Figure 79. The regressions below do not satisfy various diagnostic tests. For example, the coefficient on the lag term and other control variables is not significant in some of the models presented below. Therefore, it is not possible to draw robust conclusions on the differences in leverage rates across different sectors.

Figure 129: Results of panel data regressions methods using OECD data (alternate specification 1)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.5366**	0.4934	0.4814*	0.4008	0.4702**	0.4859	0.4585	0.6191***	0.5140*	0.7619***	0.5598**
	(0.2688)	(0.3302)	(0.2870)	(0.4166)	(0.1857)	(0.3211)	(0.2860)	(0.2195)	(0.2824)	(0.1632)	(0.2519)
GVA growth rate	0.7894	0.7212	0.9563	1.1159	0.8491**	0.8425	0.9173*	0.5808	0.8281	0.2904	0.7060
	(0.5448)	(0.5691)	(0.6232)	(0.9277)	(0.3309)	(0.6160)	(0.5434)	(0.4026)	(0.5654)	(0.3287)	(0.4746)
Public BERD (log) - OECD average	-0.0144	-0.1152	0.0247	-0.2007	-0.0796	-0.0645	-0.1072	0.0858	-0.0423	0.2197	0.0159
	(0.2313)	(0.3245)	(0.2577)	(0.4619)	(0.1371)	(0.2861)	(0.2391)	(0.1919)	(0.2563)	(0.1728)	(0.2150)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	0.2068	0.5104	-0.4679	0.2907	0.4213**	0.2027	0.4299	0.1310	0.0872	0.1514	0.0169
	(0.3766)	(0.5119)	(0.3131)	(0.4959)	(0.1997)	(0.4394)	(0.4810)	(0.1604)	(0.2299)	(0.3670)	(0.7299)
Constant	2.2531	2.3223	2.5034	3.2076	2.5090***	2.5936	2.8135	1.5991	2.4191	0.7379	2.0881
	(1.6380)	(1.8587)	(1.7755)	(2.6681)	(0.9661)	(1.9880)	(1.7127)	(1.2645)	(1.7537)	(1.0274)	(1.5266)
Observations	889	889	889	889	889	889	889	889	889	889	889
Number of country-sector combinations	163	163	163	163	163	163	163	163	163	163	163
Number of instruments	9	9	9	9	9	9	9	9	9	9	9
AR2 p-value	0.537	0.680	0.845	0.621	0.536	0.594	0.628	0.578	0.627	0.621	0.597
Hansen p-value	0.269	0.426	0.369	0.464	0.130	0.362	0.0847	0.0596	0.174	0.235	0.246

Source: Oxford Economics

Figure 130: Results of panel data regressions methods using OECD data (alternate specification 2)

Dependent variable: Private GERD (log).

Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.8487***	0.3753	1.0750***	0.8646***	0.6637*	0.8073***	0.8252***	1.0880**	0.8013***	1.1774*	0.9413***
	(0.2537)	(0.3977)	(0.2943)	(0.2837)	(0.3588)	(0.2548)	(0.2622)	(0.5121)	(0.2357)	(0.6348)	(0.3348)
GVA growth rate	0.0648	0.6553	-0.1659	-0.0090	0.3272	0.1789	0.1077	-0.2882	0.2040	-0.4778	-0.0530
	(0.3723)	(0.5324)	(0.5294)	(0.4383)	(0.4886)	(0.3182)	(0.3977)	(0.7468)	(0.3154)	(1.0595)	(0.4804)
Interest rates	0.0107	-0.1225	0.0658	0.0163	-0.0407	-0.0086	0.0027	0.0706	-0.0070	0.1054	0.0307
	(0.0720)	(0.0971)	(0.0859)	(0.0806)	(0.1059)	(0.0676)	(0.0742)	(0.1337)	(0.0666)	(0.1876)	(0.0911)
Public BERD (log) - OECD average	0.3641*	-0.0992	0.5618**	0.4202	0.2711	0.3178	0.3535	0.5476	0.2997	0.6238	0.4321
	(0.2202)	(0.3633)	(0.2802)	(0.2775)	(0.2910)	(0.2110)	(0.2506)	(0.4320)	(0.2071)	(0.5553)	(0.2839)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	-0.1798	0.7066	-0.4240	-0.2753	-0.0423	-0.2935	-0.1312	-0.3157	0.0844	-0.7855	-0.9666
	(0.3119)	(0.7791)	(0.5228)	(0.2717)	(0.4007)	(0.2780)	(0.4141)	(0.4921)	(0.3106)	(1.3633)	(1.4866)
Constant	-0.0180	3.2441	-1.6694	-0.1771	1.2744	0.3519	0.1411	-1.6164	0.4063	-2.5347	-0.6714
	(1.8493)	(2.4951)	(2.1518)	(2.0963)	(2.5154)	(1.8313)	(1.9847)	(3.5294)	(1.7144)	(4.8847)	(2.4437)
Observations	805	805	805	805	805	805	805	805	805	805	805
Number of country-sector combinations	147	147	147	147	147	147	147	147	147	147	147
Number of instruments	13	13	13	13	13	13	13	13	13	13	13
AR2 p-value	0.595	0.585	0.781	0.740	0.473	0.560	0.511	0.677	0.562	0.530	0.661
Hansen p-value	0.345	0.562	0.874	0.609	0.258	0.196	0.498	0.838	0.260	0.973	0.599

Source: Oxford Economics

Figure 131: Results of panel data regressions methods using OECD data (alternate specification 3)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.8462***	0.4719**	0.9295***	0.8910**	0.7399***	0.8295***	0.8468***	0.9288***	0.7827***	0.9718**	0.8815***
	(0.2606)	(0.1996)	(0.2937)	(0.3585)	(0.2586)	(0.2515)	(0.2478)	(0.3606)	(0.2177)	(0.4305)	(0.3135)
Employment growth rate	0.1637	1.7924	0.1958	-0.1988	0.9068	0.1337	0.3191	-0.4688	0.5480	-0.2098	0.1687
	(2.1249)	(1.4778)	(2.4737)	(2.8025)	(1.3465)	(2.1050)	(1.9278)	(2.9089)	(1.6818)	(2.9671)	(2.3240)
Interest rates	0.0451	-0.0858	0.0576	0.0602	0.0044	0.0225	0.0356	0.0547	0.0163	0.0797	0.0489
	(0.0851)	(0.0585)	(0.0943)	(0.1201)	(0.0877)	(0.0720)	(0.0799)	(0.1052)	(0.0635)	(0.1419)	(0.0981)
Public BERD (log) - OECD average	0.6539*	0.0469	0.7913**	0.8043	0.5363	0.6095*	0.6031*	0.7449	0.5468**	0.7790	0.6683*
	(0.3394)	(0.2919)	(0.3733)	(0.5453)	(0.3698)	(0.3288)	(0.3545)	(0.4843)	(0.2563)	(0.5418)	(0.3911)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	-0.6158	0.5901	-0.5854	-0.6616	-0.1798	-0.5310	0.3056	-0.3936	-0.0670	-0.4543	0.0000
	(0.5043)	(0.6494)	(0.4972)	(0.5271)	(0.4292)	(0.4760)	(0.6758)	(0.4708)	(0.4022)	(0.9202)	(0.0000)
Constant	-0.6975	2.3931*	-1.3580	-1.1453	0.2641	-0.4567	-0.5720	-1.1187	-0.0845	-1.7176	-0.9274
	(2.0542)	(1.3566)	(2.2355)	(2.9633)	(2.0192)	(1.9492)	(2.0255)	(2.6891)	(1.5710)	(3.5659)	(2.4831)
Observations	836	836	836	836	836	836	836	836	836	836	836
Number of country-sector combinations	151	151	151	151	151	151	151	151	151	151	151
Number of instruments	14	14	14	14	14	14	14	14	14	14	11
AR2 p-value	0.459	0.521	0.479	0.708	0.354	0.411	0.553	0.444	0.320	0.417	0.394
Hansen p-value	0.650	0.559	0.755	0.781	0.290	0.710	0.753	0.778	0.299	0.880	0.515

Source: Oxford Economics

Figure 132: Results of panel data regressions methods using OECD data (alternate specification 4)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	1.1060**	0.8932***	1.2097*	1.1009*	0.8531**	1.1562*	0.9855**	1.1850*	1.0937**	1.1790*	1.1492*
	(0.5548)	(0.3230)	(0.6196)	(0.5703)	(0.4228)	(0.6201)	(0.3834)	(0.6815)	(0.5194)	(0.6423)	(0.6216)
GFCF growth rate	-0.0317	0.1462	-0.0930	0.0004	0.1716	-0.1032	0.0658	0.0369	0.0041	-0.0382	-0.0362
	(0.4914)	(0.3051)	(0.5035)	(0.4830)	(0.2398)	(0.5537)	(0.3756)	(0.4236)	(0.4931)	(0.5202)	(0.5355)
Interest rates	0.0790	0.0226	0.0970	0.0784	0.0147	0.0809	0.0473	0.0915	0.0740	0.1005	0.0883
	(0.1444)	(0.0859)	(0.1631)	(0.1484)	(0.1108)	(0.1559)	(0.1016)	(0.1649)	(0.1372)	(0.1734)	(0.1648)
Public BERD (log) - OECD average	0.4636	0.3078	0.5407	0.5009	0.3880	0.4768	0.4200	0.5069	0.4641	0.5173	0.4719
	(0.3198)	(0.2027)	(0.3390)	(0.3564)	(0.2516)	(0.3495)	(0.2811)	(0.3914)	(0.3656)	(0.3960)	(0.3379)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	-0.2611	0.2939	-0.3942	-0.3270	-0.1620	-0.4539	-0.1214	-0.3007	-0.0833	-0.8541	0.2564
	(0.5437)	(0.5731)	(0.5847)	(0.3037)	(0.4357)	(0.4119)	(0.5075)	(0.5135)	(0.5555)	(1.2569)	(1.0849)
Constant	-1.7229	-0.3607	-2.4057	-1.7088	-0.0307	-2.0044	-0.9366	-2.0835	-1.6508	-2.2959	-1.9990
	(3.8129)	(2.1405)	(4.2182)	(3.9198)	(2.7218)	(4.2326)	(2.7513)	(4.3892)	(3.6980)	(4.5355)	(4.2832)
Observations	822	822	822	822	822	822	822	822	822	822	822
Number of country-sector combinations	152	152	152	152	152	152	152	152	152	152	152
Number of instruments	14	14	14	14	14	14	14	14	14	14	14
AR2 p-value	0.467	0.462	0.551	0.599	0.429	0.480	0.383	0.451	0.413	0.328	0.427
Hansen p-value	0.747	0.759	0.958	0.892	0.601	0.899	0.821	0.923	0.709	0.957	0.802

Source: Oxford Economics

Figure 133: Results of panel data regressions methods using OECD data (alternate specification 5)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	1.0082***	0.9193***	1.0645***	0.9839***	0.8576***	1.0662***	0.9586***	1.0037***	0.9819***	1.0692***	1.0135***
	(0.2409)	(0.1567)	(0.2599)	(0.2405)	(0.2677)	(0.2824)	(0.2152)	(0.2259)	(0.2134)	(0.3255)	(0.2543)
Compensation growth rate	-0.3671	-0.0600	-0.4564	-0.3918	0.1604	-0.4230	-0.1661	-0.3509	-0.2085	-0.6166	-0.3948
	(0.8944)	(0.4965)	(0.9763)	(0.9335)	(0.8680)	(1.0007)	(0.8476)	(0.8366)	(0.7921)	(1.2457)	(0.9527)
Interest rates	0.0550	0.0279	0.0581	0.0484	0.0127	0.0572	0.0391	0.0496	0.0438	0.0713	0.0483
	(0.0676)	(0.0418)	(0.0735)	(0.0673)	(0.0738)	(0.0745)	(0.0595)	(0.0612)	(0.0592)	(0.0935)	(0.0690)
Public BERD (log) - OECD average	0.4821**	0.3819**	0.5612**	0.5222*	0.4250*	0.5051*	0.4525*	0.4699**	0.4493*	0.5446	0.4861*
	(0.2449)	(0.1791)	(0.2710)	(0.2754)	(0.2400)	(0.2795)	(0.2409)	(0.2357)	(0.2551)	(0.3321)	(0.2534)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	-0.3195	0.1308	-0.4825	-0.3772	-0.2226	-0.5531	-0.2680	-0.0939	-0.0035	-0.5658	-1.1065
	(0.4695)	(0.5726)	(0.4989)	(0.2787)	(0.3492)	(0.3837)	(0.4218)	(0.1813)	(0.4552)	(0.7369)	(1.7665)
Constant	-1.1882	-0.5507	-1.5666	-1.0520	-0.0903	-1.5220	-0.8393	-1.0868	-0.9596	-1.7015	-1.1879
	(1.7800)	(1.0209)	(1.8971)	(1.7738)	(1.8059)	(2.0753)	(1.6267)	(1.6034)	(1.6064)	(2.5066)	(1.8672)
Observations	790	790	790	790	790	790	790	790	790	790	790
Number of country-sector combinations	146	146	146	146	146	146	146	146	146	146	146
Number of instruments	14	14	14	14	14	14	14	14	14	14	14
AR2 p-value	0.524	0.503	0.611	0.655	0.486	0.541	0.420	0.497	0.488	0.342	0.528
Hansen p-value	0.727	0.833	0.925	0.817	0.573	0.905	0.701	0.871	0.674	0.976	0.711

Source: Oxford Economics

Figure 134: Results of panel data regressions methods using OECD data (alternate specification 6)

Dependent variable: Private GERD (log). Monetary variables are expressed in USD and deflated using CPI. Models based on the June 2018 dataset.

Variables	Ag., Forestry and Fishing	Mining & Quarrying	Manufac-turing	Utilities	Constru-ction	Trans-portation & Storage	Trade	Info. & Commun-ication	Financial & Real Estate	Prof, Scientific & Technical	Others
Lag private BERD (log) - lag of dependent variable	0.8424***	0.8640***	0.8634***	0.8520***	0.8584***	0.8544***	0.8507***	0.8877***	0.7633***	0.8485***	0.8600***
	(0.1603)	(0.1557)	(0.1686)	(0.1830)	(0.1734)	(0.1709)	(0.1687)	(0.1892)	(0.2393)	(0.1591)	(0.1756)
Compensation growth rate	-0.1598	-0.1759	-0.1222	-0.1654	-0.1819	-0.1846	-0.1645	-0.2708	-0.4288	-0.1689	-0.1719
	(0.2258)	(0.2174)	(0.2017)	(0.2406)	(0.2329)	(0.2320)	(0.2246)	(0.2403)	(0.3496)	(0.2217)	(0.2330)
Interest rates	-0.0006	0.0006	0.0005	0.0004	-0.0007	-0.0016	-0.0004	0.0012	-0.0132	0.0010	-0.0007
	(0.0125)	(0.0116)	(0.0120)	(0.0136)	(0.0116)	(0.0117)	(0.0109)	(0.0123)	(0.0208)	(0.0108)	(0.0126)
Public BERD (log) - OECD average	0.2757***	0.2618**	0.2837**	0.3167**	0.2887***	0.2654***	0.2652**	0.2916***	0.0638	0.2719***	0.2695**
	(0.1022)	(0.1141)	(0.1230)	(0.1264)	(0.1048)	(0.1029)	(0.1096)	(0.1029)	(0.0918)	(0.1036)	(0.1075)
Difference in leverage rates from OECD average leverage											
Industry-specific leverage	0.1117	-0.0057	-0.1220	-0.2568	-0.1050*	-0.2128	-0.1535	-0.2718	0.8627***	-0.1362	-0.1491
	(0.4557)	(0.2995)	(0.2456)	(0.2518)	(0.0619)	(0.3544)	(0.1659)	(0.3092)	(0.2954)	(0.0936)	(0.3229)
Constant	0.2076	0.1398	0.1082	0.1455	0.1565	0.1851	0.1930	0.0929	1.0484	0.1807	0.1468
	(0.6039)	(0.6333)	(0.6213)	(0.7094)	(0.6718)	(0.6528)	(0.6187)	(0.7219)	(1.2616)	(0.5933)	(0.6797)
Observations	467	467	467	467	467	467	467	467	467	467	467
Number of country-sector combinations	83	83	83	83	83	83	83	83	83	83	83
Number of instruments	14	14	14	14	14	14	14	14	14	14	14
AR2 p-value	0.790	0.785	0.831	0.902	0.797	0.788	0.771	0.797	0.630	0.735	0.801
Hansen p-value	0.681	0.876	0.913	0.943	0.924	0.595	0.694	0.989	0.642	0.981	0.983

Source: Oxford Economics

Leverage rates across sectors in the UK using ONS data

We have attempted to develop models to determine whether leverage rates differ across sectors in the UK using ONS data. We were unable to find evidence of any statistically significant differences in the leverage rate across sectors. The few models which did indicate there may be differences contained coefficients with implausible magnitudes and tended to fail diagnostic tests. As such we did not deem those findings to be robust.

Figure 135: Panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

Sector	Agriculture, Forestry and Fishing	Mining & Quarrying	Manufacturing	Utilities	Construction	Transportation & Storage	Trade	Information & Communication	Financial & Real Estate	Professional, Scientific & Technical Activities	Others
	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
VARIABLES	Dynamic Panel - 12-A	Dynamic Panel - 12-B	Dynamic Panel - 12-C	Dynamic Panel - 12-D	Dynamic Panel - 12-E	Dynamic Panel - 12-F	Dynamic Panel - 12-G	Dynamic Panel - 12-H	Dynamic Panel - 12-J	Dynamic Panel - 12-M	Dynamic Panel - 12-O
Private BERD (logs)	0.4039	0.4249	0.3460	0.4105	0.3868	0.7306***	0.3938	0.4631*	0.4916*	0.4764*	0.4544
	(0.2844)	(0.2773)	(0.2957)	(0.2781)	(0.2847)	(0.0753)	(0.2706)	(0.2730)	(0.2798)	(0.2563)	(0.2811)
Public BERD (logs)	0.3168*	0.3055*	0.2867*	0.2924*	0.3209*	0.2100***	0.3626**	0.3311**	0.2227*	0.3176	0.3336**
	(0.1694)	(0.1702)	(0.1681)	(0.1545)	(0.1737)	(0.0667)	(0.1721)	(0.1646)	(0.1318)	(0.2062)	(0.1656)
GVA growth	1.2473***	1.2882***	1.2006***	1.1676***	1.2314***	1.4530***	1.2103***	1.2779***	1.2779***	1.3359***	1.2827***
	(0.1506)	(0.1407)	(0.2022)	(0.1442)	(0.1498)	(0.1767)	(0.0964)	(0.1308)	(0.1636)	(0.1655)	(0.1319)
Sector-specific leverage	-0.2007	0.3866	0.2613	-0.2071	15.9916**	-0.1143	-0.1323	-0.6376***	0.1254	-0.0809	-0.1534
	(0.1775)	(0.3780)	(0.2590)	(0.1353)	(7.1132)	(0.1944)	(0.1486)	(0.1448)	(0.1086)	(0.1366)	(0.1325)
Constant	2.6228**	2.5259**	2.7678**	2.6722**	2.7309**	1.0517***	2.5626**	2.2301**	2.3218**	2.2507**	2.2803**
	(1.1025)	(1.0464)	(1.1250)	(1.1414)	(1.1013)	(0.2862)	(1.0103)	(1.0241)	(1.1363)	(0.8932)	(1.0942)
Observations	100	100	100	100	100	100	100	100	100	100	100
Number of industry_code	11	11	11	11	11	11	11	11	11	11	11
number of instruments	8	9	9	9	8	9	9	9	9	9	9
AR2 p-value	0.161	0.149	0.144	0.216	0.169	0.0891	0.171	0.147	0.119	0.145	0.154
Hansen p-value	0.109	0.185	0.250	0.181	0.117	0.462	0.233	0.244	0.235	0.228	0.203

Source: Oxford Economics

Figure 136: Panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

Sector	Agriculture, Forestry and Fishing	Mining & Quarrying	Manufacturing	Utilities	Construction	Transportation & Storage	Trade	Information & Communication	Financial & Real Estate	Professional, Scientific & Technical Activities	Others
	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
VARIABLES	Dynamic Panel - 13-A	Dynamic Panel - 13-B	Dynamic Panel - 13-C	Dynamic Panel - 13-D	Dynamic Panel - 13-E	Dynamic Panel - 13-F	Dynamic Panel - 13-G	Dynamic Panel - 13-H	Dynamic Panel - 13-J	Dynamic Panel - 13-M	Dynamic Panel - 13-O
Private BERD (logs)	0.4280	0.4488	0.3530	0.4544*	0.4108	0.7019***	0.4075	0.4993*	0.5003*	0.4882**	0.4796*
	(0.2891)	(0.2789)	(0.2864)	(0.2480)	(0.2915)	(0.1174)	(0.2698)	(0.2608)	(0.2949)	(0.2316)	(0.2668)
Public BERD (logs)	0.3102**	0.2981*	0.2620**	0.3048**	0.3138**	0.2177***	0.3563**	0.3232**	0.2194*	0.3105*	0.3228**
	(0.1545)	(0.1538)	(0.1315)	(0.1352)	(0.1577)	(0.0612)	(0.1653)	(0.1408)	(0.1329)	(0.1823)	(0.1440)
GVA growth	1.1862***	1.2279***	1.0344***	0.9724***	1.1676***	1.2484***	1.1929***	1.1731***	1.2588***	1.2410***	1.1946***
	(0.1778)	(0.1412)	(0.1664)	(0.1644)	(0.1801)	(0.3087)	(0.1190)	(0.2565)	(0.1777)	(0.1789)	(0.2262)
Sector-specific leverage	-0.1961	0.4484	0.3510	-0.2307	15.8648**	-0.1817	-0.1188	-0.6915***	0.1261	-0.0845	-0.1843*
	(0.1714)	(0.3981)	(0.3537)	(0.1434)	(7.0655)	(0.1895)	(0.1281)	(0.1499)	(0.1096)	(0.1203)	(0.1013)
Interest rates	-0.0397	-0.0420	-0.0766	-0.1063	-0.0415	-0.1302	-0.0177	-0.0654	-0.0126	-0.0555	-0.0597
	(0.1484)	(0.1433)	(0.0971)	(0.1024)	(0.1504)	(0.0993)	(0.0945)	(0.1383)	(0.1366)	(0.1139)	(0.1344)
Constant	2.6346**	2.5490**	2.9633**	2.7328***	2.7500***	1.6496**	2.5581***	2.2613**	2.3226**	2.3924***	2.3678**
	(1.0440)	(0.9918)	(1.1629)	(1.0553)	(1.0338)	(0.7677)	(0.9920)	(0.9432)	(1.1347)	(0.8429)	(0.9998)
Observations	100	100	100	100	100	100	100	100	100	100	100
Number of industry_code	11	11	11	11	11	11	11	11	11	11	11
number of instruments	8	9	9	9	8	9	9	9	9	9	9
AR2 p-value	0.0992	0.0924	0.0631	0.0666	0.101	0.0583	0.140	0.0699	0.111	0.0860	0.0829
Hansen p-value	0.0524	0.108	0.185	0.141	0.0571	0.0995	0.136	0.158	0.138	0.134	0.138

Source: Oxford Economics

Figure 137: Panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

Sector	Agriculture, Forestry and Fishing	Mining & Quarrying	Manufacturing	Utilities	Construction	Transportation & Storage	Trade	Information & Communication	Financial & Real Estate	Professional, Scientific & Technical Activities	Others
	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)
VARIABLES	Dynamic Panel - 14-A	Dynamic Panel - 14-B	Dynamic Panel - 14-C	Dynamic Panel - 14-D	Dynamic Panel - 14-E	Dynamic Panel - 14-F	Dynamic Panel - 14-G	Dynamic Panel - 14-H	Dynamic Panel - 14-J	Dynamic Panel - 14-M	Dynamic Panel - 14-O
Private BERD (logs)	0.3142	0.3235	0.2469	0.2927	0.3242	0.6939***	0.2790	0.4147	0.5511	0.4311	0.3817
	(0.4232)	(0.4069)	(0.4023)	(0.3717)	(0.4157)	(0.1469)	(0.4253)	(0.3870)	(0.3513)	(0.3159)	(0.3917)
Public BERD (logs)	0.3764	0.3664	0.3102	0.3954	0.3766	0.2196**	0.4266	0.3730	0.1929	0.3573	0.3763
	(0.2477)	(0.2449)	(0.2107)	(0.2184)	(0.2457)	(0.0788)	(0.2711)	(0.2153)	(0.1496)	(0.2558)	(0.2215)
Sector-specific leverage	-0.3857	0.1880	0.4132	-0.2577	18.1768*	-0.1724	-0.1519	-0.7672***	0.1462	-0.1283	-0.2577**
	(0.3035)	(0.7285)	(0.4416)	(0.1614)	(8.9481)	(0.2533)	(0.1712)	(0.1552)	(0.1396)	(0.1733)	(0.1121)
Interest rates	-0.0131	-0.0205	-0.0630	-0.0866	-0.0153	-0.1499	0.0052	-0.0557	-0.0517	-0.0585	-0.0448
	(0.1990)	(0.1933)	(0.1043)	(0.1389)	(0.1971)	(0.0919)	(0.1240)	(0.1754)	(0.1496)	(0.1262)	(0.1714)
Employment growth	14.3678	13.5873	14.0105	10.0131	14.3902	4.7905	13.7963	12.6128	5.9443	11.9219	11.9392
	(15.0884)	(15.2965)	(12.2107)	(9.8362)	(15.0884)	(7.4568)	(15.3477)	(14.3142)	(10.3104)	(13.1110)	(14.0483)
Constant	2.8862**	2.8846**	3.1980**	3.2536**	2.8516**	1.7212*	2.9045**	2.4619*	2.1797*	2.5243**	2.6310**
	(1.1626)	(1.0893)	(1.3507)	(1.2987)	(1.1295)	(0.7728)	(1.2081)	(1.1245)	(1.1655)	(0.8635)	(1.1170)
Observations	100	100	100	100	100	100	100	100	100	100	100
Number of industry_code	11	11	11	11	11	11	11	11	11	11	11
number of instruments	8	9	9	9	8	9	9	9	9	9	9
AR2 p-value	0.208	0.197	0.111	0.181	0.204	0.0523	0.176	0.171	0.103	0.152	0.170
Hansen p-value	0.0554	0.139	0.204	0.150	0.0473	0.255	0.136	0.202	0.184	0.189	0.270

Source: Oxford Economics

Figure 138: Panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

Sector	Agriculture, Forestry and Fishing	Mining & Quarrying	Manufacturing	Utilities	Construction	Transportation & Storage	Trade	Information & Communication	Financial & Real Estate	Professional, Scientific & Technical Activities	Others
	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)
VARIABLES	Dynamic Panel - 15-A	Dynamic Panel - 15-B	Dynamic Panel - 15-C	Dynamic Panel - 15-D	Dynamic Panel - 15-E	Dynamic Panel - 15-F	Dynamic Panel - 15-G	Dynamic Panel - 15-H	Dynamic Panel - 15-J	Dynamic Panel - 15-M	Dynamic Panel - 15-O
Private BERD (logs)	0.5188***	0.5203***	0.4369*	0.4763***	0.5188***	0.5643**	0.4997***	0.5188***	0.5425**	0.6186***	0.4876**
	(0.1491)	(0.1476)	(0.2091)	(0.1221)	(0.1495)	(0.1821)	(0.1430)	(0.1491)	(0.1645)	(0.1452)	(0.1492)
Public BERD (logs)	0.4030**	0.4009**	0.3412**	0.4661***	0.4054**	0.3833*	0.4378**	0.4030**	0.3626**	0.4340**	0.4166**
	(0.1561)	(0.1519)	(0.1272)	(0.1387)	(0.1582)	(0.1677)	(0.1687)	(0.1561)	(0.1489)	(0.1300)	(0.1759)
Sector-specific leverage	0.0000	-8.0892*	0.3064	-0.2222*	11.4309**	-0.3146	-0.2861	0.0000	0.1131*	-0.0871	0.4943*
	(0.0000)	(4.0253)	(0.4070)	(0.1153)	(4.3512)	(0.3686)	(0.2191)	(0.0000)	(0.0563)	(0.1320)	(0.2575)
Interest rates	-0.3919	-0.3941	-0.2863	-0.6460	-0.3912	-0.4012	-0.4887	-0.3919	-0.5417	-0.5243	-0.4057
	(0.3214)	(0.3207)	(0.2382)	(0.3494)	(0.3225)	(0.2512)	(0.3270)	(0.3214)	(0.3345)	(0.3496)	(0.3526)
Capital stock change	17.8374	17.6595	14.8315	31.9066	17.7160	13.1698	22.2779	17.8374	33.6778	25.4073	22.0329
	(20.0934)	(19.8535)	(15.4779)	(18.9799)	(20.1173)	(17.0856)	(21.0705)	(20.0934)	(21.2326)	(23.8655)	(23.4013)
Constant	2.8504**	2.8501**	2.8117*	3.6481**	2.8652**	2.8539**	3.1943**	2.8504**	3.0801**	2.6091*	2.9504**
	(1.1208)	(1.1230)	(1.2383)	(1.2474)	(1.1237)	(1.2333)	(1.1563)	(1.1208)	(1.1959)	(1.2053)	(1.1735)
Observations	73	73	73	73	73	73	73	73	73	73	73
Number of industry_code	9	9	9	9	9	9	9	9	9	9	9
number of instruments	7	8	9	9	8	9	9	7	9	9	9
AR2 p-value	0.0404	0.0384	0.0286	0.0417	0.0413	0.0439	0.0506	0.0404	0.0778	0.0459	0.0607
Hansen p-value	0.0403	0.183	0.149	0.211	0.113	0.274	0.243	0.0403	0.220	0.180	0.220

Source: Oxford Economics

Figure 139: Panel regression methods using ONS data

Dependent variable: Private BERD (log). Monetary variables specified in GBP and deflated using CPI using the June 2018 dataset.

Sector	Agriculture, Forestry and Fishing	Mining & Quarrying	Manufacturing	Utilities	Construction	Transportation & Storage	Trade	Information & Communication	Financial & Real Estate	Professional, Scientific & Technical Activities	Others
	(51)	(52)	(53)	(54)	(55)	(56)	(57)	(58)	(59)	(60)	(61)
VARIABLES	Dynamic Panel - 16-A	Dynamic Panel - 16-B	Dynamic Panel - 16-C	Dynamic Panel - 16-D	Dynamic Panel - 16-E	Dynamic Panel - 16-F	Dynamic Panel - 16-G	Dynamic Panel - 16-H	Dynamic Panel - 16-J	Dynamic Panel - 16-M	Dynamic Panel - 16-O
Private BERD (logs)	0.3158	0.3255	0.2872	0.2510	0.3270	0.7443***	0.2612	0.4895*	0.4517	0.4276	0.3713
	(0.3703)	(0.3675)	(0.3543)	(0.3700)	(0.3490)	(0.1010)	(0.3958)	(0.2656)	(0.3571)	(0.2967)	(0.3685)
Public BERD (logs)	0.3595*	0.3520	0.2803	0.3864*	0.3483*	0.2230**	0.4097	0.3185*	0.2675	0.3627	0.3806*
	(0.1956)	(0.2010)	(0.1771)	(0.1891)	(0.1877)	(0.0731)	(0.2272)	(0.1510)	(0.1546)	(0.2173)	(0.1955)
Sector-specific leverage	-0.2583	0.2419	0.3758	-0.3364	19.6973*	-0.0854	-0.1920	-0.7470**	0.1128	-0.1162	-0.2407
	(0.2250)	(0.5912)	(0.3990)	(0.1925)	(9.6695)	(0.2388)	(0.1825)	(0.2391)	(0.1302)	(0.1485)	(0.1750)
Interest rates	-0.0243	-0.0257	-0.0840	-0.1036	-0.0354	-0.0908	0.0065	-0.0752	-0.0059	-0.0548	-0.0331
	(0.1609)	(0.1591)	(0.0955)	(0.1420)	(0.1581)	(0.0908)	(0.1208)	(0.1271)	(0.1326)	(0.1377)	(0.1440)
GFCF growth	1.6396	1.5168	1.0754	1.1913	1.2259	-0.1829	2.0740	-0.4893	1.3212	1.3880	2.1638
	(3.3000)	(3.4595)	(3.2199)	(3.6712)	(3.2727)	(1.9829)	(3.2300)	(2.4790)	(3.0691)	(3.3332)	(2.8348)
Constant	3.0755*	3.0404*	3.2832**	3.6674**	3.1128**	1.2452*	3.1641*	2.3899**	2.4341	2.5978*	2.7158*
	(1.4871)	(1.4513)	(1.4485)	(1.5398)	(1.3966)	(0.6651)	(1.5914)	(1.0725)	(1.4706)	(1.1714)	(1.4928)
Observations	100	100	100	100	100	100	100	100	100	100	100
Number of industry_code	11	11	11	11	11	11	11	11	11	11	11
number of instruments	8	9	9	9	8	9	9	9	9	9	9
AR2 p-value	0.263	0.239	0.145	0.405	0.200	0.0952	0.424	0.0521	0.118	0.168	0.279
Hansen p-value	0.120	0.234	0.220	0.214	0.122	0.231	0.423	0.301	0.229	0.217	0.241

Source: Oxford Economics

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