

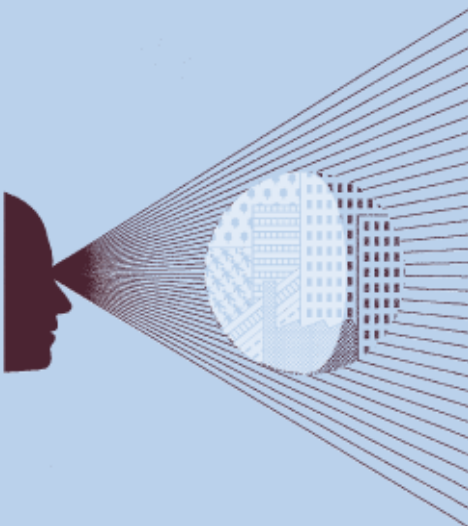
Feasibility study for potential econometric assessment of the impact of R&D tax credits on R&D expenditure

Literature review

**Prepared for
HM Revenue & Customs**

September 2006

HM Revenue & Customs Research Report 19



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1 Introduction

This literature review summarises previous studies that have analysed the impact of tax incentives for R&D on levels of R&D expenditure. The review focuses on the approaches that have been adopted by previous researchers and limitations of their methods, as well as a discussion of the results from previous studies. The review is intended as a technical paper aimed at research experts. However, brief definitions of the main terms are provided in the Appendix. From this review, valuable insights into the feasibility of undertaking an econometric analysis of R&D tax incentives in the UK have been gained, which are highlighted throughout.

As R&D tax incentives are relatively new in the UK, the majority of the empirical literature has been based on countries outside the UK, where the tax credit system is firmly established and recognised. As a result, this literature review incorporates studies that have used data from the UK, as well as research from other countries, notably the USA, where it has been considered that important parallels and implications can be drawn for any evaluation of the R&D tax credit system in the UK.

A review of the existing literature is important for assessing the feasibility of any econometric analysis of R&D tax incentives in the UK.

- The literature discusses empirical approaches to evaluate the impact of R&D tax incentives on R&D expenditure (section 2).
- The review identifies the datasets and the variables that should be considered in any econometric investigation in the UK (section 3).
- An evaluation of existing studies highlights methodological problems and issues associated with particular econometric techniques that will need to be considered (section 4).
- Empirical findings are presented that can form a basis on which to compare results obtained from any evaluation of the effectiveness of R&D tax incentives in the UK (section 5).

2 Empirical approaches

To evaluate the effectiveness of any R&D tax incentives scheme, the additional R&D expenditure that is undertaken by companies as a result of the scheme needs to be quantified, and the costs of such a scheme should be compared with the benefits accruing to society. However, there are difficulties associated with estimating the incremental amount of R&D expenditure that is undertaken by companies *directly* as a result of any tax incentives scheme, while controlling for other influences that could affect the level of R&D expenditure, such as macroeconomic growth. This would involve estimating the level of R&D expenditure that would have occurred, in the absence of such an R&D scheme.

This section discusses three common approaches that have been used to evaluate the impact of R&D tax incentives. In a review of empirical techniques, Hall (1995) has provided a summary of three main approaches that could be used to evaluate the effect of any R&D tax incentives scheme. These include:

- evaluation of the social return and the social cost from any R&D investment;
- estimation of the tax price responsiveness of R&D expenditure (price elasticity estimation);
- estimation of an R&D demand equation that allows for a shift parameter for the fiscal policy.

In the first of the above approaches, the effectiveness of any R&D tax incentives scheme is measured by comparing the return from any R&D expenditure with its cost. However, difficulties arise when trying to accurately estimate the return from R&D expenditure. As a result of these complications, several researchers have compared the incremental amount of R&D expenditure with the loss of tax revenue, arising from the introduction of an R&D tax incentives scheme.

As an alternative to the estimation of the social return and the social cost from any R&D investment, the level of R&D that would have occurred without any R&D tax incentives scheme would need to be accurately estimated, to evaluate the effectiveness of the tax incentives. However, as the counterfactual is never observed, the level of R&D without the tax credit would need to be inferred.

To overcome this problem, the response of R&D expenditure to tax incentives can be calculated, or an R&D demand equation with an indicator variable that captures the introduction of the tax incentives can be estimated. The estimated coefficient associated with the indicator variable will represent the response of R&D expenditure to the R&D tax incentives scheme. There are several econometric approaches that could be adopted to follow either of the above approaches, and these are outlined in greater detail in sections 2.2 and 2.3. The tax price responsiveness approach is often preferred on theoretical grounds, but there are difficulties associated with its practical implementation. In contrast, the indicator variable approach is easier to implement, as it avoids the need to estimate the actual level of the tax subsidy for each firm, although it may be less accurate.

The remainder of section 2 discusses the above approaches in greater detail, highlighting any methodological issues, which may have important implications for any econometric evaluation of R&D tax incentives undertaken in the UK.

2.1 Evaluation of the social return and cost

Hall (1995) suggests that, theoretically, the effectiveness of an R&D policy can be measured by quantifying the difference between the social return from expenditure on R&D and the

social cost of the investment. The social cost of investment in R&D captures the opportunity cost of using money in an alternative way—the projects that are foregone as a result of the government committing funds to finance the R&D tax incentives scheme. The social return represents the benefits to society that arise as a result of companies investing in R&D. It has been acknowledged that there are several complications associated with estimating the social return and the social cost from expenditure on R&D (which are discussed below); as such, few studies have adopted such an approach.

As part of an analysis of the impact of R&D on a country's rate of total factor productivity (TFP) growth, Griffith et al (2001a) suggest that to estimate the social rate of return, it is important to take into account three effects:

- the impact of R&D on growth in TFP;
- the potential for technological transfer;
- spillover effects from R&D expenditure.

However, Griffith et al (2001a) note that most studies do not capture all three effects, and as such, the social rate of return from R&D may not always be accurately estimated.

Griffith et al (2001a) illustrate that empirical evaluations may fail to adequately capture the ability for technological transfer. The authors suggest that many studies do not allow for the possibility that countries behind the technological frontier may catch up quickly if they invest heavily in R&D. As a consequence, the social rate of return to R&D may have been underestimated in previous studies. Griffith et al (2001a) present evidence showing that most studies that seek to quantify the social rate of return to R&D estimate a technological frontier based on levels of TFP, and fail to account for the potential for technological transfer.

The authors also acknowledge that empirical studies may fail to accurately estimate spillover effects from R&D expenditure, and as such may underestimate the social rate of return from R&D investment. Spillover effects can be defined as indirect or unexpected benefits that arise for other users from the uptake of R&D, such as the diffusion of knowledge through the development of technical skills. Griffith et al (2001a) suggest that to capture spillover effects, external rates of return to expenditure on R&D undertaken by other firms need to be estimated. The authors acknowledge that in practice it may be difficult to estimate the external rate of return, as levels of R&D undertaken by all firms in the same industry—total industry R&D expenditure—would need to be taken into account. It may be difficult to accurately quantify the impact of a company's R&D programme on the level of R&D undertaken by other firms in the industry.

As there are complications surrounding the estimation of the social return and the social cost of R&D expenditure, this approach is not commonly used. Instead, the incremental amount of R&D expenditure is often compared with the loss of tax revenue from an R&D tax incentives scheme. Dumagan (1995) adopts such an approach to evaluate the research and experimentation (R&E) tax credits system in the USA, concluding that approximately \$2 of R&E is induced per dollar of revenue loss.

Despite this approach being more frequently employed, Dumagan (1995) highlights several limitations: he notes that the full cost-effectiveness of an R&E tax credits scheme may be underestimated, as it may be difficult to account for tax revenues resulting from long-term improvements in company performance and firm spillover effects that enhance productivity and increase economic output. The author shows that studies in the USA in the early 1980s found evidence to suggest that the induced increase in R&E did not justify the credit's revenue cost. However, more recent studies conclude that the increase in R&E spending is greater than any foregone tax revenue.

2.2 Evaluation of the tax price responsiveness

Under this approach, an R&D demand equation is estimated that controls for the non-tax determinants of R&D, as well as the price (user cost) of R&D, which is included in the model to elicit the tax price responsiveness of R&D expenditure. Hall et al (2000) outline two measures of the price of R&D and the implications for the estimation. If the price variable includes the implicit subsidy given by the tax system to R&D, the response of R&D to tax incentives can be directly estimated. However, if the price variable does not contain a measure of the tax subsidy, the estimated response of R&D to a tax deduction would need to be inferred through an estimate of the price elasticity of R&D, combined with the known effective marginal R&D tax credit.

Several researchers, including Hall (1992), Bernstein and Nadiri (1988), Bloom et al (2000) and Bond et al (2003) have adopted similar approaches. Studies following the price elasticity approach have been summarised according to their econometric methods, which includes:

- structural models based on Euler equations;
- production functions;
- error correction models and other dynamic models;
- probability-based models, such as probit and tobit.

2.2.1 Structural models

To evaluate the impact of R&D tax incentives on the R&D investment of manufacturing firms, Hall (1992) adopts a Euler equation representation of R&D investment. The equation explains the level of R&D expenditure through the lagged sales to R&D capital ratio, the lagged R&D investment rate and its lagged square term, the tax price and its lagged value and year dummies. To control for any unexplained differences across firms that may be related to the explanatory variables and thus may bias the coefficients, Hall (1992) estimates the same specification expressed as first differences.

Despite Hall's (1992) finding that the results are not dependent on the chosen specification, Bloom et al (2000) suggest that estimating dynamic models based on Euler equations is unlikely to represent a robust approach. As a result, Bloom et al (2000) follow a different approach, by estimating a demand equation that is derived from a production function with a constant elasticity of substitution. The basic form of Bloom et al's (2000) model explains R&D by output and the user cost of R&D. Bloom et al's (2000) scepticism of structural models based on Euler equations is supported by Bond et al's (2003) claim that often coefficients are incorrectly signed and implausibly slow speeds of adjustment are obtained from econometric models derived from Euler equations. To assess the relationship between R&D investment in Britain and Germany and levels of cash flow, Bond et al (2003) adopt an error correction approach (which is outlined in section 2.2.3 below).

2.2.2 Production functions

Several authors, including Bernstein and Nadiri (1988), Mamuneas and Nadiri (1996) and Griffith et al (2001a) estimate the price elasticity of R&D expenditure through production functions. To evaluate the impact of R&D on productivity, Mamuneas and Nadiri (1996) augment a standard neoclassical production function to capture R&D financed by industry and the government as well as R&D that is performed within and outside the industry. The authors adopt a translog function to estimate the elasticity of company-financed R&D with respect to its own price and the cross-price elasticities of the other inputs with respect to the price of R&D, as well as the effect of tax incentives on the after-tax rental price of company-financed R&D.

Griffith et al (2001b) follow a similar approach to examine the impact that incremental R&D tax incentives may have on TFP growth in the UK and on value added in the manufacturing industry. The authors find evidence to suggest that there are significant lags between a

change in the user cost of R&D and levels of R&D expenditure, and a change in R&D and the subsequent increase in GDP. In contrast, Bernstein and Nadiri (1988) determine that the R&D adjustment parameter is not significant when a production function is estimated on pooled data to explain the determinants and the relationship between labour, physical capital and R&D. However, when the production function is estimated separately for each industry, the authors report that the estimate of the cost of adjustment associated with R&D is significant. The authors find that it takes companies longer to adjust R&D expenditure to the desired level, compared with the time taken for stocks of physical capital to adjust.

2.2.3 Error correction models and other dynamic models

To evaluate the relationship between levels of cash flow and R&D investment in Britain between 1985 and 1994, Bond et al (2003) estimate an error correction model, using firm-level data on quoted companies obtained from Datastream. An error correction model allows both a long-run desired level of the accumulated stock of R&D, and flexible dynamics, to be specified. The model implicitly allows for the possibility that the actual R&D expenditure may not adjust immediately to the desired level. The authors explain the accumulated stock of R&D through levels of output, the user cost of capital and levels of cash flow net of R&D expenditure. Similar to the situation that is likely to exist when attempting to evaluate the impact of R&D tax incentives using data from companies' tax returns in the UK, Bond et al's (2003) dataset is characterised by a lack of time series data, despite a large number of panels; as such, Arellano and Bond's estimator is adopted.

Arellano and Bond's estimator overcomes some potential biases with dynamic panel data. If one or more lags of the dependent variable are included in the econometric model, the error will be correlated with the explanatory variables, which leads to a bias in the regression. Arellano and Bond (1991) proposed a solution where modelling in differences means it is possible to use lags as valid instruments. An instrument is a variable that is partially correlated with the endogenous explanatory variable, but is uncorrelated with the error from the model. As a result, Arellano and Bond's estimator overcomes the endogeneity in the econometric model.

Bloom et al (2000) adopt alternative specifications of dynamic econometric models, which are estimated on panel data. Current industry-funded R&D is explained through the previous level of R&D, output, the user cost of R&D capital, country fixed effects and time dummies. As the user cost of R&D may be endogenous, the authors instrument the user cost with the tax component of the user cost of R&D capital. In addition, Bloom et al (2000) estimate a dynamic specification expressed as first differences, where the ratio of industry-funded R&D to output is regressed on the lagged dependent variable and the tax component of the user cost of R&D capital.

2.2.4 Probability-based models

Several types of probability-based model are used to evaluate the effectiveness of R&D tax credit schemes. As part of their analysis described above, Bond et al (2003) estimate a probit model to evaluate whether firms are more likely to undertake R&D if the firms also have strong cash flow. The authors find that in Britain, firm size is associated with a greater probability of conducting R&D, and previous levels of cash flow are significantly correlated with the decision by firms to engage in R&D. Dagenais et al (1997) estimate a tobit model to explain the stock of R&D, allowing the tax price to influence both the level of R&D that is undertaken as well as the decision to conduct R&D.

2.3 R&D demand equation with a shift parameter for the fiscal policy

Under this approach, demand for R&D is modelled to be a function of previous levels of R&D, past output and other control variables, such as cash flow and other financial variables. An indicator variable is included in the model to account for the presence of the R&D tax credit—the magnitude of the coefficient associated with this variable will represent the

implied response of R&D expenditure to the tax credit. Examples of this approach include McCutchen (1992), Irwin and Klenow (1994), Lerner (1996) and Branstetter and Sakakibara (1997). Their findings are summarised according to the generic specification of their econometric models, which includes:

- static and dynamic models;
- probability-based models;
- other estimation techniques, such as two-stage least squares.

2.3.1 Static models

Lerner (1996) adopts the shift parameter approach to evaluate the effect of the Small Business Innovation Research (SBIR) programme on levels of sales and employment. The author estimates static regressions to explain employment and sales with an indicator variable to indicate whether the firm received SBIR funding, measures of the extent of venture capital activity in the local area, interactions between the indicator variable and venture capital activity as well as other control variables, such as the age of the firm, the industry ratio of R&D to sales and the industry market to book ratio.

2.3.2 Dynamic models

Irwin and Klenow (1994) estimate a dynamic model—a lagged dependent variable model—to evaluate the impact on firms' R&D expenditure, profitability, investment and productivity from joining an R&D consortium (Sematech) between US semiconductor manufacturers and the US government. The model incorporates an indicator variable, which equals unity if the firm is a member of the research consortium. Irwin and Klenow's (1994) sample, on which the dynamic econometric model is estimated, includes both members and non-members of the research consortium. As such, the authors only evaluate the impact of Sematech on members relative to non-members. Irwin and Klenow (1994) acknowledge that it is possible that Sematech may have affected the level of R&D that is undertaken by non-members, and as a result, year effects are included in the model in an attempt to capture the impact on non-members.

A further limitation with the analysis arises because firms' expected R&D intensity is likely to influence its decision to join Sematech, and as such, these firms are not a random group. This concern is supported by Branstetter and Sakakibara's (1997) suggestion that firms participating in research consortiums are more R&D-intensive compared with non-participants. Branstetter and Sakakibara (1997) find that even after controlling for this issue, frequent participation in R&D consortia has a positive impact on research expenditure and productivity. The authors' approach is described in section 2.3.4 below.

McCutchen (1992) follows a similar approach to explain levels of R&D intensity among pharmaceutical firms through the 'success' of previous R&D (sales of new chemical entities as a ratio of R&D expenditure), an index of diversification (sales of prescriptions), cash-flow margins and firms' sales expressed as a percentage of total industry sales. McCutchen (1992) notes that the indicator variable is likely to be highly correlated with the value of the tax credit; as such, this approach is not an exact way of measuring the tax credit, as other factors may cause a change in research intensity.

2.3.3 Probability-based models

Lerner (1996) estimates a tobit model to complement the analysis from the static model (described above), as the dependent variable—levels of sales or employment—will always be strictly positive. The author finds that results from the tobit model are similar to those obtained from the estimation of the static model. As an additional test of robustness, Lerner (1996) employs a two-stage Heckman regression to evaluate the impact of SBIR funding. Under this approach, the first regression examines whether the firm is likely to remain in the

market over the sample period, while the second-stage regression assesses the extent of the firm's growth.

2.3.4 Other estimation techniques

Branstetter and Sakakibara (1997) adopt an alternative estimation technique—two-stage least squares—to evaluate the effect of Japanese government-sponsored research consortium on firms' productivity. As panel data fixed effects estimation may give biased results in the presence of measurement error, the authors adopt two-stage least squares, to obtain consistent estimates. In the first stage, exogenous and lagged endogenous variables (such as previous levels of participation and firm-level R&D spending) are used to predict the number of research consortia with which a firm will be involved during the year. In the second-stage regression, the propensity of the firm to undertake patents is explained by the predicted level of intensity of participation in research consortia (from the first-stage regression), firm-level R&D spending and industry-specific dummies.

2.4 Additional tests

The procedures described above represent the most common methods that are adopted by researchers when evaluating the effectiveness of R&D tax incentives. The selection of the method by which to analyse the impact of R&D tax incentives in the UK will depend on the characteristics of the matched dataset, particularly the availability of time series data. However, in addition to the approaches described above, the tests that are described below should be considered.

- *Tests for cointegration*—these look at whether a long-run relationship exists between two or more data series. Bloom et al (2000) note that real R&D expenditure and output are highly persistent series; as such, the authors test for cointegration between these series.
- *Causality tests*—these are used to tentatively infer the direction of any relationship between two or more variables. Hall et al (1998) adopt Granger causality tests to evaluate differences in the dynamics between R&D and investment in countries with different institutional structures for corporate governance and finance. The authors evaluate whether cash flow determines the firm's future level of R&D, when controls are made for past R&D behaviour over the sample.

2.4.1 Analysis of survey data

The econometric methods described above relate to revealed-preference data; however, methods to analyse survey data should also be considered. Lattimore (1997) estimates a probit model, based on survey data, to explain whether the R&D tax concession affects firms' decisions to undertake R&D. The probit model includes a set of industry dummies, firm size, the proportion of incremental R&D, the payback period of a representative R&D project, tax loss status and dividend payout status.

2.5 Limitations with the empirical approaches

This section outlines limitations of the price elasticity estimation and the shift parameter approaches that have not yet been discussed herein. It is important that any econometric investigation considers these issues.

2.5.1 Price elasticity estimation

Price elasticity estimation is often preferable to estimating R&D demand equations on theoretical grounds since it may be more accurate, as the response to a change in the price of R&D is estimated directly. However, there are substantial problems with its practical

application, particularly in a panel data context, as the cost of R&D varies through time and across firms. Available R&D price deflators, such as the GDP deflator, only have significant variation across time and may not be sufficiently advanced to take into account industry-specific responses to R&D tax incentives. Branstetter and Sakakibara (1997) also note that available price deflators do not take into account improvements in quality over time.

However, Becker and Pain (2003) overcome these problems by using industry-specific value-added price deflators. Becker and Pain (2003) note that gross value-added deflators could be obtained from the Office for National Statistics. However, the authors do not include a direct source where deflators relating to industry prices of R&D could be obtained. As such, the availability of value-added price deflators would need to be investigated further if the price elasticity approach was to be considered in any future econometric investigation.

An additional problem, highlighted by Hall (2000), may arise as it is possible that firms may choose the amount of R&D at the same time as their tax price. In this situation, an alternative estimation procedure to ordinary least squares would need to be used to estimate the price elasticity. This would require instrumental variables estimation, which may lead to complications in finding appropriate instruments for the endogenous variables. Since a similar concern may be associated with the shift parameter approach, this issue is discussed in further detail in section 4.

2.5.2 Shift parameter approach

The shift parameter approach avoids the need to estimate the actual level of the tax credit subsidy for each firm. However, this approach may not accurately estimate the impact of the tax credit, as firms may face different levels of the credit over time. If the availability of the credit varies over time, and if other factors that increase R&D spending, such as economic growth, are not included in the regression, spurious conclusions about the effectiveness of the tax credit could be obtained. Dumagan (1995) suggests that the coefficient on the indicator variable may capture other influences excluded from the model. As a test of the robustness of the results, Berger (1993) examines whether the coefficient on the credit indicator captures omitted variables that could lead firms to increase their level of R&D expenditure, and as such, could lead to biased results.

This section has provided an overview of the methods that have been commonly adopted when evaluating the impact of R&D tax incentives. Before discussing methodological issues, common to both approaches, the following section summarises the datasets on which previous researchers have based their analyses. It is important to consider the variables that have been incorporated into previous econometric studies of R&D tax incentives, to avoid problems that may arise from failure to incorporate significant drivers of R&D expenditure into the econometric model (ie, omitted variable bias).

3 Datasets and variables

It is important that the properties of the dataset, on which any econometric analysis will be based, are thoroughly analysed before any evaluation of R&D tax incentives is undertaken. When sufficient data becomes available, the future econometric analysis of R&D tax incentives in the UK will be based on HMRC's dataset, combined with external sources. HMRC's dataset includes all claims submitted for R&D tax credits or enhanced expenditure by companies in the UK, since the tax incentives schemes were introduced from 2000 and 2002 for the SME and the large companies' scheme respectively. The dataset is based at the level of the company, and includes annual data on variables relating to R&D expenditure and other financial variables that are obtained from companies' tax returns, such as turnover and profits.

HMRC's database contains information on applications for R&D tax incentives that were submitted, rather than those applications that were approved. The robustness of any evaluation of the effectiveness of R&D tax incentives would be improved if the analysis were to be based only on those applications that were approved.¹ Previous researchers, such as Poot et al (2003) have overcome this issue by assuming that any applications submitted are approved. McCutchen (1992) also assumes that all reported R&D expenditure qualifies for the tax credit, although the author acknowledges that this will overstate the revenue loss to the government as some R&D may not qualify.

Ideally, the panel dataset would also be balanced—consecutive years' data for the same companies would be available over time. Empirical investigations have predominantly been based on annual data, and the datasets have varied in size, ranging from a minimum of around four years to a maximum of around 15 years. Although it will depend on the unique properties of the dataset, the robustness of any econometric analysis would be likely to improve as the availability of consecutive data for the same companies increases over time.

The ideal dataset would include information on levels of R&D expenditure, such as the extent of the R&D tax subsidy. Potential explanatory variables would need to capture information specific to the individual companies that could explain levels of R&D expenditure, such as turnover, profits, employment in R&D, and sources of R&D expenditure. However, it is also important that factors external to the company, such as the state of the macroeconomy, are taken into account. In the UK, data on R&D is available from companies' tax returns. External sources, such as the Office of National Statistics' (ONS) Business Enterprise R&D survey, could be used to provide more detailed information about companies' R&D expenditure, such as the split between civil and defence R&D expenditure, and information specific to companies, such as turnover and profits. Any remaining accounting information that is required, which is not available from the tax returns could be collected from the FAME database. Macroeconomic variables, such as interest rates, GDP and price indices could be obtained from the ONS.

The remainder of section 3 discusses the variables used by previous researchers, when evaluating the effectiveness of R&D tax incentives. This can provide insights into the selection of variables for any future econometric investigation in the UK.

¹ If it was possible to identify those claims, which had been submitted but had not been approved, this may provide a useful counterfactual dataset. However, the feasibility of this approach would depend on the size of the dataset, and it may be likely that this dataset would be too small to facilitate any analysis.

3.1 The nature of the dataset

Griffith et al (2003) have suggested that it may not be appropriate to base an evaluation of R&D tax incentives on data at the industry level. At this level, it will not be possible to capture differences between firms, and as such, any estimates that are obtained could be biased. For example, if the industry-level dataset comprises firms that are highly productive, estimates of the impact of any R&D scheme could be biased upwards, as these firms are more likely to invest in R&D. Lattimore (1997) reports results from an econometric evaluation of R&D tax incentives based on aggregate data. In this study, the total amount of R&D expenditure of companies that registered for the tax incentives was explained with a time trend, an intercept and slope dummy, as well as GDP. The author notes that the estimate of the impact of tax incentives on R&D could capture the effect of changes in the domestic economy, as well as the introduction of the tax incentives. It is also likely that an evaluation of tax incentives based on aggregate data would yield results that differ from evaluations based on firm-level data, as no controls can be made for differences between firms in the former case.

This suggests that evaluation work should be based on disaggregated data at the level of the firm, rather than aggregate data at industry level. If data is available for a sufficient number of firms over a sufficiently long time period, econometric techniques could be used to control for differences between firms, provided that these do not vary with time.²

As any future econometric analysis of the R&D tax incentive scheme in the UK is likely to be based at the firm level, this overcomes the limitations associated with studies that evaluate the effectiveness of R&D tax incentives at an industry level. The availability of firm-level panel data is particularly important, given that Hall (1995) noted:

the absence of good econometric studies using what appears to be the most appropriate dataset: the individual corporate tax returns used by Altshuler (1988).

However, even though any future econometric analysis in the UK would ideally be based on a panel data approach, it is important to consider whether it is valid to pool the data in this way. This is particularly important given that Becker and Hall (2004) found that there are significant differences between factors determining R&D investment in high- and low-tech industries. The authors propose that government funding is a significant driver of investment in R&D in low-tech industries, but not in high-tech industries. This suggests that pooled coefficients from a dataset comprising companies from both low-tech and high-tech industries may not provide a reliable estimate of individual industry effects. This implies that it may be more appropriate to estimate separate panel data models for the low-tech and high-tech industries.

Only a small number of empirical studies have not been based on panel data. Lattimore (1997) used results from a survey of registrants of R&D tax incentives in 1992 to estimate the response of R&D expenditure to the introduction of tax incentives through probability-based models, such as the probit model. The survey sampled all registrants of tax incentives, although, potential biases with the survey were noted, including:

- some firms may answer the survey strategically, and may pretend that the tax incentives have had a greater impact on R&D expenditure than has actually occurred, in an attempt to ensure that they receive the same level of tax incentives in subsequent years;
- the respondent answering the survey (on the firm's behalf) may be unaware of the R&D tax concessions;

² If a fixed-effects panel data model is estimated, a separate constant is added for each cross-sectional unit, which controls for inherent differences between the cross-sectional units, provided these do not vary with time.

- firms may change their level of R&D in response to the behaviour of other firms, which could be unrelated to the tax incentives for R&D.

Jaffe (1984) used company cross-sectional data to examine the importance of market conditions and exogenous technological conditions in determining the allocation of resources to R&D and the growth of productivity. The cross-sectional models were estimated for the year where R&D was reported for the greatest number of firms—1976. The author estimated a cross-sectional regression that explained R&D expenditure with sales, capital stock, the sales-weighted average market share and the pool of spilled research that was potentially available to the firm. Jaffe (1984) also estimated a cross-sectional model explaining average patent applications with R&D and the pool of spilled research potentially available to the company. It was found that a 10 per cent increase in the R&D of all firms would increase total patents by around 17 per cent—7 per cent from the impact of the company’s own R&D on their own level of patents and 10 per cent from the collective effect on the increased pool of R&D.

Cross-sectional regressions only provide a snapshot of the relationship between R&D and its drivers, such as tax incentives, at a certain point in time. As companies may take time to adjust their R&D programme to tax incentives—for example, it takes time for a new research laboratory to be built—it is important to consider the response of companies to tax incentives through time. This suggests it would be more appropriate to base any future evaluation of R&D tax incentives on either time-series or panel data. Panel data would be preferred to time-series data, as this would enable the *aggregate* response of R&D expenditure to the introduction of tax incentives to be estimated directly. If the evaluation of R&D tax incentives were based on time-series data, this would only enable firm-specific effects of R&D tax incentives to be estimated. Even though firm-specific factors would be included in the model, it is likely that the estimated impact of tax incentives would differ significantly between companies. Hence, any evaluation of R&D tax incentives is likely to yield more robust results if it is based on a panel dataset.

3.2 Dependent variable

This section considers the dependent variables that have been used in previous empirical studies. There appears to be a reasonable consensus in the empirical literature regarding the definition of the dependent variable. Among studies that have assessed the effectiveness of R&D tax incentives, alternative definitions of the dependent variable are outlined below.

- *The rate of R&D investment or levels of R&D expenditure*—Poot et al (2003) proxy R&D expenditure with R&D labour costs, expressed as a fraction of total sales volume.
- *The level of R&D intensity*—the ratio of R&D expenditure to output or sales, as adopted by Berger (1993) and Irwin and Klenow (1994).

As the R&D tax incentive schemes in the UK have been introduced with the broad objective of promoting R&D expenditure by business, in any future econometric analysis, it may be more appropriate to define the dependent variable as the level of R&D expenditure, rather than the level of R&D intensity.

3.3 Explanatory factors

There is greater variation in the literature regarding the choice of explanatory variables. Before any econometric analysis is undertaken, the degree of correlation between the potential explanatory variables in the model would need to be assessed. Ideally, there would be a low level of correlation between the variables in an econometric model. The following list identifies those explanatory factors that have been included in empirical studies that evaluate the effectiveness of R&D tax incentives.

- *Lagged rate of R&D investment (and its squared term)*—there is widespread agreement that the current rate of R&D is strongly related to its history. Hall (1992) finds that this is the most significant predictor of R&D investment. The number of lagged terms that can be included in the econometric model will depend on the size and the nature of the dataset. If panel data is available, additional lagged terms can be incorporated into the econometric model that may not be feasible in a pure time series dataset, as a result of degrees of freedom restrictions. A review of the range of lagged R&D terms considered by empirical researchers is provided in section 3.3.1 below.
- *Own and external R&D*—Jaffe (1984) includes a term interacting own and external R&D, which allows the size and the direction of spillover effects to depend on the level of R&D that the firm undertakes. Berger (1993) includes a measure of industry R&D, as individual firms' R&D is likely to be influenced by the level of R&D undertaken by its rivals.
- *The lagged tax price (user cost) or an indicator variable set equal to unity if the firm received tax relief*—this will depend on which estimation approach is adopted.
- *Measure of innovation*—when analysing the impact of the introduction of legislation in the Netherlands to promote R&D, Poot et al (2003) proxies innovation from any R&D investment with the ratio at the industry level of the sales volume of new products to total sales volume.

Firm-specific characteristics

- *Factors specific to the firm or industry*—eg, the turnover of the company and the size of the market, which could be measured by the level of sales or value-added output. Poot et al (2003) incorporate a measure of the size of the firm in the regression, as a positive relationship between R&D expenditure and the size of the firm is expected, while Irwin and Klenow (1994) also include a measure of the age of the firm. In any evaluation of R&D tax incentives, it is important to control for factors, such as turnover, which could explain changes in the levels of R&D expenditure that are not related to the introduction of the tax incentives.
- *Firm's internal cash flow*—Becker and Pain (2003) suggest that capital market imperfections may lead firms to not be able to attract sufficient funds to finance R&D. This hypothesis supports Bond et al's (2003) conclusion that a higher debt to capital ratio prevents UK firms from investing in R&D in the following period. Canberra's (Australia) Department of Tourism (2005) note that the most frequently reported constraint to undertaking R&D investment is financial, with no significant variation by company size. While Becker and Pain (2003) highlight mixed evidence to suggest that a measure of the firm's internal cash flow may not be a significant driver of levels of R&D expenditure. Instead, the authors suggest that current and lagged values of the sales to R&D capital ratio could proxy future revenue expectations. Berger (1993) incorporates sales into the econometric model as a predictor of future sales that are expected to arise from the R&D investment.
- *Skilled labour endowments and measures to proxy geographical location*—Becker and Pain (2003) suggest that firms' stock of human capital and its geographical distance from universities or research centres may explain levels of R&D expenditure. Becker and Pain (2003) incorporate a measure of the number of scientists and engineers in the industry, relative to the total employment in the industry. However, Becker and Hall (2004) comment that these variables may be highly correlated with actual levels of R&D investment, and as such, endogeneity problems may arise.
- *The firm's ownership status*—this relates to the ownership of the company—whether it is listed or private—and whether it is UK or foreign-owned, and if the company belongs to a parent firm in a foreign country.

Market structure

- *Market concentration as measured by the Herfindahl index or the level of import penetration*—Becker and Pain (2003) suggest that greater competition may minimise incentives to innovate, because firms are less able to extract any economic rents arising from the investment. Alternatively, R&D may be used to counter increased competition to maintain market shares.
- *Proxies for different financial conditions and macroeconomic policies*—Berger (1993) incorporates real gross national product.

Other explanatory variables

- *Time dummies to control for omitted variables, whose impact varies over time but not across members of the panel*—this could control for industry-wide cycles. Hall (1992) includes year-specific effects in the model, which captures events such as technological advancements in the R&D-intensive industries in the 1980s.

3.3.1 Review of lag structures

The specification of the lag structures adopted in empirical studies are discussed in this section, to provide an insight into the minimum number of years of data that is required for a robust econometric evaluation of R&D tax incentives in the UK. The specification of the lag structure will be influenced by the time series availability of data. For example, if annual data is only available for companies over a four-year period, only a maximum of three lags can be included in the panel-data econometric model. A review of the literature has shown that most empirical studies have restricted the lag structure in the econometric model, regardless of whether the dataset contains four or ten years of data. The approaches and the specification of the lag structure of models that are based on a limited availability of time series data will be discussed, before reviewing the specification of econometric models that are based on larger datasets.

McCutchen (1992) uses a panel dataset containing annual data for four years on 20 pharmaceutical companies, to evaluate the impact of the introduction of R&D tax incentives on research intensity. McCutchen (1992) restricts the specification of the lag structure by including a maximum lag of two years in the econometric models. Levels of R&D intensity are explained through a measure of past R&D success—the ratio of sales to R&D expenditure from two years ago, the cash-flow margin—the ratio of cash flow to sales from two years ago—and the ratio of current pharmaceutical sales to current total sales.

Similarly to McCutchen (1992), Hines (1993) evaluates the effectiveness of R&D tax incentives using a panel dataset with a limited availability of time series data. The dataset comprises annual firm-level data from Compustat on 40 multinationals between 1984 and 1989. As a result of the limited data, Hines (1993) estimates a static model to explain the stock of R&D with domestic and foreign tax prices, companies' level of foreign sales and firm and year dummies. Hall (1992) uses annual firm-level data on around 1,000 R&D performing firms from the Compustat database, with at least four years of continuous data between 1977 and 1991. The author includes a maximum lag of one year in the econometric model. The sales to R&D capital ratio is explained by its lagged value from one year ago, the one year lag (and the squared lag) of the R&D investment rate, the current and one year lag of the R&D tax price, as well as year dummies.

Even those empirical studies that are based on datasets with a greater availability of time series data adopt restricted lag structures. Bloom et al (2000) have access to annual firm-level data between 1979 and 1997, but only specify a maximum lag of one year. R&D investment is explained through the one-year lag of R&D investment and the ratio of R&D expenditure to output, as well as the current user cost of R&D and output.

This suggests that in any future econometric evaluation of the effectiveness of R&D tax incentives in the UK, the lag structure of the econometric models would need to be restricted,

as a result of data limitations. The review of the literature has shown that it may be most appropriate to estimate dynamic models. Static models may lead to biased results, as these models fail to capture any dynamic processes, and implicitly assume that the long run is reached instantaneously. To ensure the robustness of any future econometric analysis, consecutive data would need to be available for the same companies over time, to accurately identify any changes in R&D behaviour as a result of R&D tax incentives. The datasets used in empirical studies have varied in size, from around 4–15 years. The review of the literature has shown that a minimum of around five years of consecutive data for the same companies over time would be required, to estimate the effectiveness of R&D tax incentives. However, the robustness of any econometric assessment would increase with the availability of greater time series data and cross-sectional data.

3.4 Availability of data

There has been a limited discussion in the literature about possible approaches that could be adopted when the availability of data is restricted. In cases where data is limited, researchers have simulated the impact of tax incentives on R&D expenditure using results from previous studies. Griffith et al (2001b) used existing econometric estimates of the tax price elasticity of R&D and the effect of R&D on productivity to evaluate the impact of R&D tax incentives on R&D expenditure. For example, the authors used previous estimates of the response of R&D expenditure to changes in the tax price of R&D and the relationship between the size of the R&D tax credit and the productivity gap—the gap between the current position of a firm or country from the technological frontier. Bloom et al (1996) simulated the impact of tax incentives on revenue and investment for a sample of R&D performing companies in Australia, Canada, France and the USA. Previous estimates of the price elasticity of R&D were used to estimate the expected amount of new R&D expenditure that would be generated by the R&D tax incentives.

Even though interesting insights can be gained by simulating the impact of tax incentives on R&D expenditure, it is likely that this approach would yield different results compared with evaluations that are based on actual data. As the R&D tax incentives system in the UK is not as firmly established compared with other countries, such as Canada and the USA, identifying studies that can be used to accurately simulate the impact of the UK tax incentives schemes may be complicated. In particular, it is likely that the user cost elasticity of R&D expenditure will be different in the UK, compared with other countries, as a result of cross-country differences in the schemes and the tax system.

4 Methodological issues

This literature review has discussed various approaches to examining the effectiveness of R&D tax incentives and has summarised measures of both the dependent and independent variables. However, it is vital that any methodological issues that have been highlighted by previous researchers are considered before any econometric analysis is undertaken. The issues discussed in this section are common to both the tax price and the shift parameter approach. However, cases where these limitations will have greater implications for the feasibility of adopting a particular approach are highlighted.

An explanation of modelling terms can be found in Appendix 2.

4.1 Causality

When modelling R&D expenditure it is not always clear in which direction the causality flows. For example, while the level of turnover may affect the level of R&D expenditure, it is also conceivable that the level of R&D expenditure influences a firm's turnover. Bloom et al (2000) suggest that the company's R&D investment choice is likely to be influenced by government policies; however, government behaviour may also affect the amount of R&D undertaken by companies. This may arise if governments are inclined to introduce R&D tax incentives when R&D expenditure is exceptionally low. This would bias the results of any econometric analysis, and could lead the effectiveness of the fiscal measures to be underestimated. However, without explicitly modelling government behaviour, it may be difficult to overcome this problem.

Hines (1993) notes that this issue of causality is not dependent on the approach that is adopted—it is associated with both the tax price elasticity and shift parameter approaches. Hines (1993) illustrates that the level of R&D investment and the tax price faced by companies may be chosen simultaneously, which could cause the coefficients associated with the user cost of R&D to be biased upwards. This problem may also arise if the shift parameter approach is adopted, as the company's shareholders are likely to be able to influence the firm's characteristics, such as turnover, profits and sales at the same time as the future level of R&D spending is decided.

As a result of causality concerns, many researchers including Hall (1992), Hines (1993), Bloom et al (2000) and Griffith et al (2003) adopt an instrumental variables approach. Instrumental variables estimation requires that 'instruments' for the endogenous variables are found which can be used to replace the endogenous explanatory factors and mitigate the issue of causality. These variables must be partially correlated with the endogenous explanatory variables, but should be uncorrelated with the error from the econometric model. Often data limitations restrict the ability to use the instrumental variables approach, as it may be difficult to find variables that could act as appropriate instruments.

Hall (1992) and Hines (1993) use the instrumental variables approach described above, and instrument the endogenous variables through their own lagged values. In particular, Hall (1992) uses the values of the explanatory variables lagged twice and three times as well as the lagged tax status and lagged growth rates in R&D and sales as instruments. This is similar to the approach adopted by Bloom et al (2000), where current output is instrumented with lagged output and the user cost of R&D is instrumented with the tax component of the user cost of R&D capital. If an econometric analysis of R&D tax incentives in the UK was to be undertaken based on the annual data from companies' tax returns, the time series element of the dataset is likely to be limited, as the SME and the large companies' scheme were only introduced in 2000 and 2002 respectively. As a result, using lagged values of the

endogenous variables as instruments would severely reduce the available degrees of freedom, which would therefore risk further limiting the scope of the econometric analysis of the UK schemes.

However, there are other techniques that have been adopted by researchers, which could be used to reduce any bias that is introduced as a result of this issue of causality. For example, Irwin and Klenow (1994) instrument membership of an R&D consortium—Sematech—through a measure that captures the size of the firm—the book value of assets. However, the authors find that the instrument is not particularly powerful, as the standard errors increase sharply.

Bond et al (2003) adopt an alternative approach, applying an estimator developed by Arellano and Bond, to control for the endogeneity of current levels of the explanatory variables, as well as the presence of unobserved firm-specific effects. This has been outlined in section 2.2.3 above. In contrast, Branstetter and Sakakibara (1997) employ two-stage least squares to overcome any simultaneity concerns. The authors note that when evaluating the impact of participation in research consortia on productivity, it is possible that research productivity may determine participation in research consortia. As a result, they follow the two-stage least squares approach. In the first stage, exogenous and lagged endogenous variables are used to predict the number of research consortia with which a given firm will be involved during a particular year. Subsequently, in the second stage, the measure of participation is instrumented with the predicted values from the first-stage regression.

4.2 High adjustment costs

Several authors, such as Bernstein and Nadiri (1988), have documented the high adjustment costs associated with any expenditure on R&D. Companies undertaking R&D face significant development costs associated with their investment, as a result of the long-term nature of any R&D investment projects. As factors of production are costly to adjust, it will take companies time to respond to the introduction of any R&D tax incentives, implying that the firm's investment in R&D may not be particularly sensitive to R&D tax incentive schemes. However, this may also occur as a result of the risk and uncertainty surrounding long-term returns to R&D investment deterring investment.

Hall (1992) has suggested that the presence of high adjustment costs can be identified by the lower variance of the firm's R&D expenditure relative to the firm's level of ordinary investment expenditure. This will imply that R&D demand will not be particularly sensitive to changes in prices; as such, temporary tax changes will be unlikely to have a large impact. Hall (1992) notes that as a result of high adjustment costs for R&D, frequent alterations to the tax system will reduce any incentive effects of a tax subsidy for R&D.

Hall et al (2000) suggests that large adjustment costs for R&D will be reflected in a large value for the lagged dependent variable, and as a result, permanent changes to the R&D tax credit programme will not be felt instantaneously. This view is supported by McCutchen's (1992) observation that savings as a result of productivity improvements by firms will take time to emerge, and Lerner's (1998) suggestion that it is important to assess the long-term impact of any tax relief for R&D.

The presence of adjustment costs suggests that it may be appropriate to estimate a dynamic econometric model, as any conclusions drawn from a static model may be biased. However, Hall (1992) reports evidence to suggest that the high correlation of R&D spending over time may complicate this estimation, particularly the identification of any long-run effects. As high adjustment costs suggest that R&D expenditure at the firm level will have a low variance, this will make it more difficult to identify any long-term impacts. For example, it is likely that any assessment of whether levels of R&D expenditure one or two years ago are a more significant driver of current levels of R&D will be less accurate. The large expected size of

the coefficient on the lagged R&D expenditure term, suggest that it will be more difficult to identify the influence of the other explanatory variables on current levels of R&D.

4.3 The choice of the control group

In any econometric evaluation of the effectiveness of R&D tax incentives, the impact of the tax credits will be overestimated if the dataset is composed solely of those firms that receive the tax credit. Therefore, the level of R&D expenditure that would have occurred, in the absence of any R&D tax incentives, needs to be estimated. One approach to estimating the counterfactual would be to define a control group of firms, which may not receive the R&D tax incentives, but have similar characteristics to those firms that do.

4.3.1 Definition of the control group

Irwin and Klenow (1996) and Lerner (1998) use the outcome of non-supported firms to represent the performance of the supported firms in the absence of any support. However, the authors note that this is only a crude approach, as the performance of the non-supported firms may differ substantially from the performance of the supported firms in the absence of any support. Also, this approach assumes there are no spillover effects of the R&D scheme on the non-supported firms.

In contrast to Irwin and Klenow (1996) and Lerner (1998), the control group in Brown et al's (1995) analysis comprises those firms with rejected applications. A possible approach suggested by HMRC would be to define the control group by using information from companies, before the tax incentives scheme was introduced that have subsequently claimed R&D tax credits. In practice, it may be difficult to implement this approach, as it may be difficult to control for external factors that affect the firm's performance, which have changed over time.

4.3.2 Spillover effects

Klette et al (2000) note that benefits from any R&D programme could spill over to non-supported firms, complicating the identification of an appropriate control group, with the problem becoming more acute as the level of aggregation increases. Klette et al (2000) suggest that bias could be introduced in two different ways:

- the impact of the R&D programme will be underestimated if the non-supported firms benefit from spillovers from the R&D undertaken by the supported firms;
- the impact of the R&D programme will be overestimated if the performance of the non-supported firms deteriorates as a result of the R&D undertaken by the supported firms.

As a result of the above issues, Klette et al (2000) note that it is important to measure the magnitude of any spillover effects. Becker and Hall (2004) investigate whether there are spillover effects on private-industry R&D that arise from country-wide university R&D in the UK. To test for spillover effects, Becker and Hall (2004) pool coefficients from a panel data model of R&D in the UK manufacturing industry, and test for common trends in the variation of R&D expenditure. The authors find evidence of spillovers from economy-wide university research to private industry R&D, although this is only significant for the low- and medium-tech industries.

4.3.3 Selection bias

The identification of an appropriate control group is closely related to the issue of self-selection bias. Klette et al (2000) suggest that neither firms receiving support nor those that do not receive support are a random sample, as there is the possibility of selection bias in the funding process. Lattimore (1997) suggests that firms with low levels of expected future R&D will not register for the R&D tax concession, and as a result, failure to take account of sample selection bias could lead to an upward bias in the coefficient estimates. However, it is

also important to consider Altshuler's (1988) suggestion that firms that do not file for a tax credit do not necessarily have zero levels of qualified research expenditure. Possible ways in which to minimise the selection bias are outlined in sections 4.3.4 and 4.3.5, and include:

- panel data and fixed effects;
- the difference-in-differences approach.

4.3.4 The fixed effects approach to mitigating selection bias

Irwin and Klenow (1994) seek to mitigate the problem of self-selection bias through the use of a panel data approach based on fixed effects. In this context, the fixed effects will represent firm-specific constants that cannot be observed, and which also do not change over time. Under the fixed effects approach to modelling panel data, the firm-specific constants are correlated with the explanatory variables.

If it is assumed that the supported firms are not randomly selected, and their selection depends on characteristics of the firm that do not vary through time, the use of a fixed-effects panel regression estimation technique will be unlikely to lead to a biased estimate of the impact of the tax relief.

4.3.5 The difference-in-differences approach to mitigating selection bias

For dealing with potential selection bias, Klette et al (2000) suggest a difference-in-differences approach. If data is available before and after companies have successfully claimed R&D tax credits, the average impact of the R&D tax incentives on the supported firms can be measured through the use of the difference-in-differences approach. This is illustrated in Equation 4.1 below. The estimator is defined by the difference between the average change in the performance of the supported companies (Y^s) before and after the R&D scheme was introduced, and the change in the performance of the non-supported companies (Y^n) over the same period.

Equation 4.1

$$\beta = (Y_{t1}^s - Y_{t0}^s) - (Y_{t1}^n - Y_{t0}^n)$$

$$\beta = (\Delta Y^s) - (\Delta Y^n)$$

Klette et al (2000) illustrate potential biases that could affect the difference-in-differences estimator. A downward bias may be introduced if R&D support is only targeted at firms that are performing particularly poorly. In this situation, the performance of the non-supported firms will not represent the performance that the supported firms would have achieved, if they had not been supported. As a result, the difference-in-differences estimator will underestimate the impact of R&D support on the supported forms. Conversely, Klette et al (2000) show that an upward bias could also be introduced, if firms only submit claims for R&D tax credits when they have discovered particularly promising R&D projects that are likely to generate above-average performance growth in subsequent years. In this case, the difference-in-differences estimator will overestimate the impact of R&D support on the performance of the supported firms.

However, Klette et al (2000) suggest that it is possible that the bias can be minimised, by incorporating variables reflecting the pre-programme performance of firms into the model. This will control for pre-event shocks that could influence the probability of a scheme being accepted. However, Heckman et al (1998) conclude that the difference-in-differences approach will only be reliable when firms (or countries) are comparable, and can lead to misleading results if firms are not adequately 'matched'.

4.4 Relabelling expenditure on R&D

Hall et al (2000) discusses the relabelling problem—estimates of the response of R&D to tax credits may be overestimated when a tax relief is introduced for a particular activity, as firms are incentivised to reallocate expenditure in their accounts, to maximise the amount of qualifying R&D. Eisner et al (1984) report evidence to suggest that as firms become more familiar with the tax relief system, this problem may intensify.

Hall et al (2000) suggests that this issue will be minimised if the impact of the R&D tax incentives is estimated from price elasticities, which do not incorporate a measure of the tax subsidy. If the responsiveness of R&D to tax incentives is estimated through the ordinary price of R&D, rather than the tax price of R&D, the potential for the relabelling of expenditure on R&D to affect the results will be minimised. However, Hall et al (2000) notes that whether firms will respond to the tax incentive in the way that is implied by the price elasticity and the estimated credit rate is uncertain. Poot et al (2003) address any relabelling concerns by assuming that projects arising as a result of relabelling are not given approval—the authors assume that all project applications are valid.

4.5 Substitution

A concern related to the relabelling issue—the substitution problem—is discussed by Poot et al (2003). Substitution arises when a proportion of R&D funding is spent on internal R&D labour costs, to ensure that savings are made on the firms' internal financial budgets. Poot et al (2003) note that although substitution can have a detrimental impact on the effectiveness of any R&D scheme, it is difficult to detect in practice. As such, Poot et al (2003) do not alter their approach to control for this issue.

4.6 Stocks versus flows

Bloom et al (2000) and Griffith et al (2003) suggest that using a measure of the stock of R&D capital, rather than the flow of R&D, will lead to lower estimates of the impact of any R&D tax incentives. Bloom et al (2000) illustrate that there are difficulties associated with constructing an appropriate measure of the stock of R&D capital, particularly as the rate at which knowledge will depreciate cannot be accurately estimated.

4.7 Truncated distributions

Branstetter and Sakakibara (1997) highlight problems associated with applying linear regression models to cases where the dependent variable often equals zero, but is also continuously distributed over strictly positive values. For example, several firms may have no R&D expenditure, but firms that undertake R&D may report levels of expenditure that are distributed over a wide range of values. The distribution of R&D expenditure may be highly skewed—most firms will generate far less than the mean level of R&D expenditure in a given year.

A crude approach to overcome this problem is noted by Branstetter and Sakakibara (1997)—as the natural log of zero cannot be identified, the dependent variable for such observations can simply be set to zero. However, the authors acknowledge that such a crude approach could affect the results. As such, the authors experiment with models based on the poisson binomial distribution, although the authors find that the models give similar results to those obtained from the linear models. Alternatively, Poot et al (2003) estimate a tobit model, which takes into account those firms that receive the fiscal facility that reduces wage costs for R&D employees and those firms that did not receive any fiscal facility.

5 Empirical findings

This literature review has discussed common approaches used to evaluate the effectiveness of R&D tax incentives, and has highlighted limitations with these approaches that have important implications for any econometric analysis of the tax credits system in the UK. This section discusses results from previous studies, which can be used to form a basis on which to compare the findings from any empirical analysis in the UK. However, it should be noted that diversity between the approaches as well as differences in the tax credits system between countries and the time period of the analysis complicates any comparison of results over time and across countries.

Hall et al (2000) suggest that a low short-run elasticity to R&D tax credit has sometimes been incorrectly interpreted by researchers as implying that there is only evidence of a weak response of R&D spending to the tax credit, when in reality the policy had not had sufficient time to mature and for the long-run effect to become clear. Dagenais et al (1997) examine the effectiveness of R&D tax incentives using an unbalanced panel of 434 firms between 1975 and 1992 in Canada. The authors (1997) find that the long-run effect of the tax price on the amount of R&D undertaken is almost 20 times larger than the short-run effect; as such, it is vital to take into account the length of the sample that is used for the estimation. Dagenais et al (1997) do not provide any explicit information on the length of the short run, although the econometric specification included a lagged dependent variable. The authors note that attempts were made to specify a fully dynamic specification with finite lags and various lag structures, but this was not successful. Hall et al (2000) conclude that overall R&D tax incentives have a significantly positive effect on expenditure, although there is considerable variation in the findings of different studies.

Any econometric evaluation of the tax credit scheme in the UK is likely to be based on a restricted availability of time series data, and consequently, it may not be possible to estimate long-run responses to the tax credit scheme for some time.

5.1 Price elasticity approach

To evaluate the impact of R&D tax incentives on the R&D investment of manufacturing firms in the USA, Hall (1992) considers firms with at least four years of continuous data between 1977 and 1991. The author finds that the amount of additional R&D spending, as a result of the R&D tax incentives, is greater than the cost in foregone revenue, although it takes time for firms to fully adjust. As such, the author notes that expenditure on R&D is sensitive to financial incentives on the margin, although the response is reduced as a result of the long-term nature of R&D.

Hall (1992) finds that the length of the short run is approximately two years, while the majority of the long-run effects occur within four years. The short-run price elasticity of R&D varies between -0.8 per cent and -1.5 per cent, implying that an increase of 5 per cent in the R&D credit would lead to an increase in R&D expenditure between 8 per cent and 13 per cent after two years. Hall's (1992) long-run elasticity ranges between -2 per cent and -2.7 per cent, suggesting that a permanent R&D tax credit of 5 per cent would lead to a permanent increase in R&D expenditure between 10 per cent to 15 per cent, with the majority of the impact occurring in the first four years of the tax incentives. However, Hall (1992) acknowledges that it is possible that the long-run estimates are imprecise; therefore, the estimates should be viewed with caution.

Hall's (1992) estimates of the short- and long-run R&D price elasticities are higher than those obtained by Bloom et al (2000). Bloom et al (2000) use data from a sample of listed R&D

performing companies over the period between 1979 and 1994. Bloom et al (2000) find that short-run price elasticities range between -0.12 and -0.14 , and the respective long-run elasticities vary between -0.88 and -1.09 . The authors do not implicitly define the length of the short run. However, as the maximum lag is defined to be one year, this may suggest that the econometric model may fail to incorporate the full long-run response of R&D expenditure to the introduction of tax incentives.

Both Hall (1992) and Bloom et al's (2000) estimates contrast with those reported by Bernstein and Nadiri (1988), who estimate that the long-run price elasticity ranges between -0.4 and -0.5 for a sample of manufacturing firms. Bernstein and Nadiri's (1988) long-run elasticity is substantially lower than other estimates. This may be due to the selected sample of firms and the time period chosen for the analysis as well as the potentially weaker design of the tax credit. Bernstein and Nadiri (1988) estimate their econometric models over an earlier period, between 1959 and 1966, compared with other investigators. The authors do not define the length of the short and long run, and as such, an assessment of the time involved to reach the long run cannot be obtained. According to Becker and Pain (2003), the own-price elasticity of R&D rises over time, and as such, the authors' findings should be interpreted in conjunction with more recent studies.

5.2 Shift parameter approach

In the empirical literature, there appears to be a divergence among the results from studies that have adopted the shift parameter approach. Branstetter and Sakakibara (1997) report that if a firm participates in an additional R&D consortia per year, its total R&D spending will increase by approximately 2 per cent and its patenting per dollar—its research productivity—will increase by between 4 per cent and 8 per cent. In contrast, Lerner (1996) finds that the presence of a SBIR award only has a positive impact on levels of employment and sales for firms that receive venture capitalist funding. For firms that did not receive such funding, Lerner (1996) suggests that the presence of a SBIR award only has a small impact on levels of employment and sales.

Irwin and Klenow (1994) find evidence of a positive effect of joining the research consortium Sematech on member firms' R&D intensity, although Sematech led to a reduction in total industry expenditure on R&D of around 9 per cent. The authors attribute this finding to a reduction in duplicated R&D among industry members, as Sematech aims to encourage the sharing of R&D within the consortium. McCutchen (1992) finds evidence of a strong response to the R&D tax credit among pharmaceutical firms, suggesting that the tax credit caused a \$2.7 billion increase in R&D expenditure between 1981 and 1985. The strong response is attributed to competition among pharmaceutical firms being primarily determined by levels of R&D expenditure, and as a result, incentives designed to encourage a rise in research intensity reinforces firms' motives to allocate additional resources to R&D.

The empirical studies that have adopted the shift parameter approach do not explicitly define the length of the short and long run. Under the shift parameter approach, it is more difficult to estimate the dynamic response of R&D expenditure to the introduction of tax incentives, as this would require the indicator variable to be lagged. This would affect the accuracy of any estimates of the length of the short run, as it is likely that the lagged indicator could capture other influences that may affect R&D expenditure that are not related to the introduction of R&D tax incentives, such as a decline in the country's macroeconomic performance.

6 Conclusions

This literature review has discussed common approaches that could be used to evaluate the effectiveness of R&D tax credit schemes, highlighting limitations associated with these approaches. This has important implications for any econometric evaluation of R&D tax incentives in the UK, and these issues should be considered in any future investigation. This review should be interpreted in conjunction with other papers highlighted throughout the literature review. The empirical literature has emphasised several important areas that should be considered in any future econometric analysis of R&D tax incentives in the UK.

- The empirical literature suggests that price elasticity estimation may lead to the most accurate estimates of the impact of any R&D tax credit scheme. However, the shift parameter approach may represent the most practical approach. The choice of method for future studies is likely to depend on the available data and its properties.
- The majority of econometric investigations of tax incentive schemes have been based on panel data. Since the R&D schemes in the UK were not introduced until 2000 at the earliest, at present, the availability of data over time for the same companies is limited, particularly for the smaller R&D performers. This would restrict the possibility of undertaking a robust econometric evaluation of the effectiveness of R&D tax incentives in the UK. As high adjustment costs are associated with any investment in R&D, this implies that companies cannot adjust their R&D expenditure instantaneously in response to any tax incentives. This suggests that dynamic rather than static econometric models should be estimated, to identify the long-run impact of R&D tax credits. This would require a greater amount of time series data than is currently available in the UK. If evaluation studies were to be based on cross-sectional data, this would fail to account for the dynamic effects of tax incentives, and hence, any estimates of the impact of R&D tax incentives on R&D expenditure are likely to be biased.
- To reduce the potential for bias in the estimation of the impact of R&D tax incentives on levels of R&D expenditure, the counterfactual—the level of R&D that would have occurred in the absence of any tax incentives—would need to be estimated. This could be achieved by identifying a control group of firms that do not claim R&D tax credits, but that have similar characteristics to the firms that do. The control group could comprise the unmatched firms, although the characteristics of these firms would need to be examined. The unmatched firms may represent genuine non-claimants; however, it is also possible that claims for R&D tax incentives may not have been recorded in companies' tax returns, and as such, these companies would not appear in HMRC's dataset. This suggests that the unmatched observations could include genuine claimants. An alternative (suggested by HMRC) would be to use data for those companies that have submitted claims for R&D tax incentives before the introduction of the tax incentives. However, controls would need to be made for the impact of external factors that could affect the firm's performance. An alternative control group could be composed of those firms that submitted claims for R&D tax incentives, which were rejected by HMRC.
- It is likely that in any future econometric study of the effectiveness of R&D tax incentives, issues of simultaneity and sample selection bias will arise. Although the nature of panel data will mean that through the use of a fixed-effects framework, the effect of these issues could be minimised. A difference-in-differences approach could be used to mitigate such issues, providing that variables are incorporated into the model to reflect the pre-programme performance of firms in the model. If more data was available for the same companies over time, a difference-in-differences approach could be used

in the UK. Alternatively, an instrumental variables approach could be used to account for simultaneity. However, as a result of likely data limitations, it may be difficult to follow an instrumental variables approach to account for the simultaneity. While an instrumental variables approach has many theoretical advantages, it is often difficult in practice to find a variable that is partially correlated with the endogenous explanatory variable, but is not correlated with the error term.

- Overall, very few studies have been based on data in the UK. The majority of studies focus on data in the USA, reporting overall evidence of a positive impact from the tax credits. However, given that long-run R&D price elasticities are often at least twice as large as any short-run impacts, it is important to assess the long-term impact of any tax relief for R&D. As features of the R&D tax credits scheme in the UK differ from the US system, the relationship between the short- and long-term effects in the UK may not be consistent with those in the USA. Empirical studies have shown that frequent changes to the tax incentives scheme will increase the time that is required for the effects to emerge. As such, the frequency of changes to the tax credit schemes would need to be taken into account when undertaking any econometric evaluation of tax credits in the UK.

Currently, in the UK, an insufficient amount of data is available for the *same* companies over time, and as such, it would not be possible at present to undertake a robust assessment of the impact of R&D tax incentives on levels of R&D expenditure. Previous econometric studies have been based on a panel dataset that includes a minimum of around four years of annual data for the same companies over time. As the SME and the large companies' schemes were not introduced in the UK until 2000 and 2002 respectively, it is currently too early to evaluate the effects of R&D tax credits on R&D expenditure. The available data is also biased towards the largest R&D spenders. This suggests that the impact of tax incentives on R&D expenditure could only be estimated for the large companies. Ideally, any econometric evaluation of R&D tax credits would be based on a dataset that includes both the larger and smaller R&D performers.

Empirical studies have been based on a minimum of around four years of data. If consecutive data for the same companies was available in the UK for around four years, and the companies were distributed across a wide range of industries, it may be possible to estimate the short-term impacts of the introduction of R&D tax incentives for the larger companies. However, as the restricted availability of time series data would prevent the dynamics from being fully specified, estimates of the short-run impacts of any R&D tax incentives may be biased. It is likely that around a minimum of ten years of data for the same companies from a range of industries over time would be required, to estimate the short- and long-run impacts simultaneously. However, the robustness of any procedure would increase, as greater time series data becomes available.

Appendix 1 Summary of empirical studies

Table A1.1 UK studies—summary of studies adopting the price elasticity approach

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
Britain	Griffith et al (2001b)	Simulates the possible effect of the proposed introduction of tax credits on R&D expenditure. R&D is assumed to have an effect on the rate of innovation and the ability for technological transfer	Uses results from studies between 1979 and 1996	Simulated data, based on previous econometric studies of the tax-price elasticity of R&D and the effect of R&D on productivity	Production function based on simulated data	Short-run effects of the R&D policy on value-added in the manufacturing industry is limited, with the cost to the exchequer exceeding the additional growth in output. This is attributed to the design of the policy and the slow adjustment of R&D to changes in its price
Britain	Griffith et al (2003)	Evaluates the impact of R&D on productivity in the British manufacturing industry and the extent of spillovers from R&D investment	1990–2000	UK firms listed on the London Stock Exchange. Data is obtained from Datastream, the annual Business Enterprise R&D Survey and the Annual Census of Production	Cobb Douglas production function	Private rates of return on R&D of around 5 per cent in excess of the rate of return on capital. Positive rates of return from external R&D within high-tech industries, but not within the low-tech sector
Britain and Germany	Bond et al (2003)	Evaluates the importance of levels of cash flow in determining investment in fixed capital and R&D in Britain and Germany	1985–94	Firm-level panel data. UK data is obtained from Datastream, which covers all quoted companies	Panel data based on Arellano Bond, difference-in-differences and probit models	Cash flow is an important driver of R&D investment in Britain, although it does not explain the level of R&D spending conditional on the R&D participation decision
Britain and seven other countries	Bloom et al (1996)	Describes the evolution of the tax treatment of investment in R&D, and simulates the impact of tax incentives in a select number of countries. Revenue and the first-round investment effects of the tax credits are simulated for Australia, Canada, France and the USA	1979–94	Sample of R&D performing firms from the UK stock market. Data on the amount of R&D undertaken and the tax liability is obtained from published accounts. The amount of R&D reported in the published accounts is assumed to represent the level of R&D undertaken by the firm in the absence of tax	Based on a simulated data approach	Considerable variation in the cost of R&D capital among countries, even after controlling for differences in inflation, depreciation and interest rates over time

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
UK and 8 other OECD countries	Bloom et al (2000)	The effect of fiscal incentives on R&D investment in nine OECD countries	1979– 97	Panel data—annual firm-level data. 165 observations from manufacturing firms in nine OECD countries. Only a maximum of 19 time series observations per country. The majority of the data is obtained from Pricewaterhouse Coopers, KPMG and the International Bureau of Fiscal Documentation. Data on R&D is obtained from the OECD's ANBERD database	Lagged dependent variable models and instrumental variables	Tax incentives are associated with increases in R&D intensity. A 10 per cent reduction in the cost of R&D leads to a 1 per cent rise in the level of R&D in the short run, and a 10 per cent increase in the long run

Source: Oxera.

Table A1.2 Outside the UK—summary of studies adopting the price elasticity approach

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
USA	Altshuler (1988)	A dynamic approach to examine incentive effects of the incremental research and experimentation credit. Uses an algorithm to estimate an effective rate of research and experimentation credit, which incorporates constraints on the use of the credit	1981 and 1984	Annual corporation tax returns—a subset of the Treasury's corporate tax model. Approximately 5,000 non-financial firms with assets exceeding \$10m in 1982. Does not include firms with less than \$10m, as these firms are not completely sampled	Algorithm-based approach	The incremental structure of the tax credits leads to effective credit rates that may be zero or negative. The author suggests that the introduction of a flat rate credit for research expenditure would lead to an increase in incentives
USA	Bernstein and Nadiri (1988)	The determinants and the relationship between labour, physical capital and R&D. The authors evaluate the extent to which output expansion leads to an increase in labour, physical capital and R&D. In addition, adjustment costs are estimated for physical and R&D capital	1959– 66	Firm-level data on 35 firms from the food, chemicals, primary metals and non-electrical machinery industries. Investment in R&D was obtained from Standard and Poor's, with the explanatory variables obtained from the Bureau of Labour Statistics and the President's Economic Report	Pooled data and individual time series models, based on an inverted production function	Marginal costs of adjustment—the time taken to adjust to the firm's desired level—are greater for R&D than for physical capital. The long-run net marginal value (marginal product) of R&D ranges from 20 per cent to 50 per cent of the short-run value. The long-run R&D price elasticity was found to be approximately -0.5 in all four industries
USA	Hall (1992)	The impact of the R&D tax credit on the R&D investment of manufacturing firms. Estimates the tax-price responsiveness of R&D spending during the 1980s	1980– 91	Annual firm level data on R&D performing firms from the Compustat database. Hall's (1992) analysis only considers those firms with at least four years of continuous data between 1977 and 1991, which represents approximately 1,000 firms per year. The database does not provide information on the proportion of R&D that qualifies for the tax credit and the firm's tax status. Hall (1992) also reports evidence to suggest that tax data on Compustat may not be consistent with Internal Revenue Service records	Structural Euler equation approach based on panel data	Reports a unit elastic short-run responsiveness of R&D to the after-tax price of undertaking R&D. The strong price response implies that the amount of additional R&D spending is greater than the cost of foregone tax revenue. The high correlation over time of R&D spending complicates the estimation of long-run effects
USA	Hines (1993)	Examines R&D expenditure, since a change in the tax legislation in 1986, which reduced the tax deductions US firms could claim for R&D expenditure incurred in the US. Evaluates differences in R&D expenditure since 1986 among two groups of US multinational firms—those with excess and deficit foreign tax credits	1984–89	Firm-level data from Compustat. The database covers 40 multinationals with excess or deficit foreign tax credits, experiencing no significant merger activity over the sample	Panel data, which incorporates fixed effects	US firms did not respond to the legislation by increasing the level of R&D performed abroad. This was attributed to the US tax law providing generous treatment of R&D performed in the US for use abroad by firms with excess foreign tax credits. The own price elasticity was found to vary between -1.2 and -1.8

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
USA	Mamuneas and Nadiri (1996)	Evaluates the effect on growth and productivity of publicly funded R&D within industries (internal R&D) and the effects of publicly-funded R&D performed in other industries and non-profit institutions (external R&D)	1956–88	Annual firm-level data on 12 manufacturing industries. Data was obtained from a variety of sources, including Research and Development in Industry, the Federal Funds for Research and Development, Historical Statistics and Statistical Abstracts of the USA	Dynamic production model	Publicly financed R&D was found to crowd out private R&D in low-tech industries. The incremental R&D tax credit had a significant impact on privately funded investment
Australia	Lattimore (1997)	Analyses the sensitivity of firms to the R&D tax incentives. Estimates a probit model to determine whether there are factors, which might explain whether a firm would be responsive to a tax concession. Additionally, a tobit model was estimated to explain the extent of firms' response to the tax concessions	1997	The Bureau of Industry Economics survey of tax concession registrants in 1992. The survey sampled all registrants. However, the author has acknowledged some limitations with the survey. Potential biases include the possibility that firms may answer the survey strategically and there may be difficulties capturing the effects of R&D that is undertaken by a firm as a result of rivals' behaviour	Probit model and several alternative specifications of the tobit model	Firms with longer payback periods or those firms that were subsidiaries were unlikely to respond to any R&D incentives. Firms who were exporters or consistent R&D performers were more likely to respond to any tax incentive. The author found a strong relationship between the responsiveness of firms to R&D and observable firm characteristics

Source: Oxera.

Table A1.3 UK studies—summary of studies adopting the shift parameter approach

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
UK	Becker and Pain (2003)	Estimate a model of R&D expenditure in an attempt to explain the UK's comparatively poor R&D performance in the 1990s. R&D expenditure is explained by market size, the proportion of R&D funded by government, the proportion of R&D undertaken by foreign firms, a measure of import penetration and employment in R&D relative to total industry employment	1993–2000	Panel data on 11 broad manufacturing industry groups. Data on R&D was obtained from the Office for National Statistics. The study focuses on the manufacturing industry, as the majority of business sector expenditure on R&D occurs in the manufacturing sector	Panel data, assuming fixed-effects and using instrumental variables estimation.	Weak output growth, declining levels of government funding for private industry and the appreciation of the exchange rate explained the UK's relatively low level of R&D investment over the period. The authors found that a 1 per cent rise in output leads to a 0.7 per cent to 1.1 per cent increase in the volume of R&D that is undertaken

Source: Oxera.

Table A1.4 Outside the UK—summary of studies adopting the shift parameter approach

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
USA	McCutchen (1992)	Response of different types of firm within the pharmaceutical industry to the R&D tax credit. Four categories of firms were formed depending on levels of research intensity and the relative cash-flow margin	1982–85	20 firms were divided into four strategic groups, depending on the ratio for 1973 to 1974 for the relative cash-flow margin (the ratio of cash flow to sales) and research intensity (the ratio of R&D to sales). As the grouping of firms depended on their relative values in 1973 and 1974, the author avoided created any simultaneity with the dependent variable. The data on R&D, total sales, pharmaceutical sales and cash flow was obtained from annual reports	Pooled ordinary least squares	The tax credit led to an increase in R&D expenditure and contributed towards increased competitive R&D spending among firms in the pharmaceutical industry. Evidence to suggest that 1.6 per cent of the R&D performed between 1982 and 1985 was directly attributable to the tax credit
USA	Berger (1993)	Evaluates the impact of the R&D tax credit on the level of R&D expenditure, and estimates the magnitude of the implicit tax created by the credit	1976–89	Firm-level data with the manufacturing industry is obtained from the Compustat database. The sub-sample of firms that are unable to use the credit are clustered within the industrial machinery, computer equipment, electronics and measuring equipment industries. The sub-sample of firms that are able to use the credit are clustered within the food, chemicals, petroleum, computer equipment and electronics industries	Time series analysis—individual firm's regressions as well as pooled regressions, based on fixed effects	Tax-incentives were found to encourage increased R&D investment. On average, credit usability was found to lead to an increase in the R&D to sales ratio by 2.9 per cent relative to the median level before the tax credit was introduced in 1981
USA	Irwin and Klenow (1994)	Evaluation of the Sematech programme, which was designed to enhance the development of technology in the manufacturing industry	1970–92	Panel data—annual firm-level data for both members and non-members of Sematech	Lagged dependent variable model, using weighted least squares	The Sematech programme caused a reduction in overall levels of R&D expenditure, as a result of a reduction in duplicated R&D expenditure
USA	Lerner (1998)	The impact of the public venture capital initiative—the SBIR programme	1983–95	Panel data on participants and non-participants of the SBIR programme—approximately half the sample received one or more awards from the programme, while the other half were matching firms constructed to resemble the awardees as closely as possible. The database was obtained from the US General Accounting Office	Regressions based on ordinary least squares and tobit specifications	Firms receiving assistance from the research programme grew faster than comparable firms that did not receive any awards. However, the positive effects of the programme were confined to those firms in areas with substantial venture capital activity

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
Japan	Branstetter and Sakakibara (1997)	Impact of participation in government sponsored research consortia on research expenditure and productivity	1983–89	Firm-level data—approximately 230 firms with 140 firms participating in at least one consortium. The sample is divided into non-participants, occasional participants and frequent participants, as measured by levels of involvement in R&D consortia	Panel data using fixed effects and a two-stage least squares approach	Frequent participation in R&D consortia has a positive impact on research expenditure and productivity. If a firm participated in an additional project per year, the authors estimated that the firm's total R&D spending would increase by approximately 2 per cent and its research productivity (as measured by the ratio of its patenting per dollar) by between 4 per cent and 8 per cent

Source: Oxera.

Table A1.5 UK studies—summary of studies estimating an R&D demand equation

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
UK and another 11 OECD countries	Griffith et al (2001a)	Evaluates whether R&D has a direct impact on a country's rate of total factor productivity growth (innovation) and whether TFP growth depends on a country's distance from the frontier (technological transfer)	1974–90	The main source of data is the OECD International Sectoral Database, which for the UK, has been combined with data from the ONS' Business Enterprise Survey	Technological frontier estimated using panel data, based on fixed effects	R&D has a significant impact on rates of innovation and technological transfer. Human capital is a significant driver of innovation and technological transfer, while international trade has little impact on productivity. R&D's full social rate of return varies with a country's distance from the technological frontier
UK and 15 other OECD countries	Guellec and Pottelsberge (2001)	Investigates long-term effects of R&D on multifactor productivity growth. The analysis focuses on the contribution of business-generated technology to productivity growth, the importance of spillovers from any R&D investment and the contribution of government and university research to productivity growth	1980–98	Annual panel data on 16 OECD countries, with data on multi-factor productivity obtained from the OECD's database	Error correction model based on the Cobb–Douglas production function	An increase of 1 per cent in business R&D was found to generate an additional 0.13 per cent in productivity growth. This effect was found to be greater in countries with a higher rate of business R&D, and lower in those countries where the share of defence-related government funding was lower
Britain	Griffith et al (2003)	Estimates both private and social rates of return to R&D	1990–2000	Firm-level accounting data from two alternative sources. One sample is based on publicly available accounting data for those firms that are listed on the London Stock Exchange for at least five years between 1990 and 2000. The second sample is comprised of data from the Annual Census of Production (ARD) and the Annual Business Enterprise (BERD) R&D survey	Cobb–Douglas production function, estimated using an instrumental variables approach	Based on publicly available accounting data, private rates of return to R&D of around 5 per cent in excess of the rate of return on capital were reported. The authors reported some evidence to suggest a positive return on external R&D within the high-tech industries, but not within the low-tech sector. However, the matched ARD and BERD data yields estimates of excess private rates of return of around 13–24 per cent
UK	Becker and Hall (2004)	Evaluation of whether it is valid to pool the determinants of industry-level R&D expenditure	1993–2000	Manufacturing industry-level data covering low (textiles, rubber, paper and publishing), medium (food and metals) and high-tech (chemicals, electrical machinery and transport equipment) sectors. Based on databases from the Office for National Statistics	Panel data based on fixed-effects, using the Arellano Bond estimator	Significant differences exist between the factors determining R&D investment in high-tech and low-tech industries. Government funding is only a significant driver of R&D in the low-tech sector. However, skilled and foreign R&D is only significant in high-tech industries

Source: Oxera.

Table A1.6 Studies outside the UK—summary of studies estimating an R&D demand equation

Country	Author (s) and year	Focus of study	Period of analysis	Datasets and sources	Main econometric methodology	Main findings
USA	Jaffe (1984)	Assessment of spillover effects from individual firms' research programmes	1976	Cross-sectional company-level data for 1976—the year when R&D was reported for the greatest number of firms. Firms with no patents between 1975 and 1977 were excluded from the analysis.	Cross-sectional analysis based on a Cobb Douglas production function	Firms located in areas where there is a high level of research by other firms undertake more R&D themselves, produce a greater number of patents per R&D dollar and experience faster improvements in their productivity. This result was found to be robust to changes in controls for industry and technological effects, such as sales and patent distributions. Report evidence to suggest that a 10 per cent increase in the R&D undertaken by all firms would lead to an increase in the total number of patents by 17 per cent
Netherlands	Poot et al (2003)	Analysis of the impact of the introduction of legislation in 1994 to promote R&D. The legislation provided a fiscal facility to reduce wage costs for R&D employees, by reducing wage tax and social insurance contributions	1996–98	Data from the Senter was linked to that from Central Bureau of Statistics. The Senter database covers all firms that made one or more applications for the fiscal facility over this period. While data on production statistics and background information, such as sales volume, employment and value added, was obtained from the Central Bureau of Statistics	Estimate a lagged dependent variable model using instrumental variables as well as tobit and Heckman models	Reports evidence to suggest that each € 1 of allowance under the scheme to promote R&D leads to additional expenditure on R&D of between €1.01 and €1.02 in the short term
USA, France and Japan	Hall et al (1998)	Examines causal relationships between sales and cash-flow and investment and R&D	1978–89	Panel data of scientific (high-tech) firms— 204, 156 and 221 firms for the US, France and Japan respectively. In France, data on R&D is obtained from a census of manufacturing firms. While for the US and Japan, the dataset on R&D is comprised of data from the filings of publicly traded firms	Panel data version of the vector autoregressive model	Investment and R&D are highly sensitive to cash flow and sales in the USA, compared with France and Japan. As such, both investment and R&D predict cash flow and sales positively in the USA, while the impact is more mixed in other countries

Source: Oxera.

Appendix 2 Modelling terms

Term	Definition
Arellano Bond estimator	A type of an instrumental variables estimator that can be used in the dynamic panel data context
Binary choice modelling	Econometric model which models the probability of an event occurring (denoted by 0 or 1) as a function of one or more explanatory variables
Cobb–Douglas production function	A standard production function used to describe how much output the inputs (usually capital and labour) into a production process make
Data envelopment analysis	A non-parametric or mathematical programming approach to determine the best-practice production frontier
Difference in differences estimator	An approach that uses two cross-sectional datasets, collected before and after the occurrence of an event, to determine the effect on economic outcomes
Econometric modelling	Technique for expressing, estimating and testing statistical relationships between economic variables
Endogeneity	The presence of an endogenous explanatory variable. This is a variable that is correlated with the error term as a result of an omitted variable, measurement error or simultaneity—where the explanatory variable is determined jointly with the dependent variable.
Error correction model	An econometric model that allows both short- and long-run effects to be evaluated, which also contains an error correction term that works to correct any deviations in the actual values of series from their long run equilibrium
Euler equation	An equation describing the relationship between a variable that has different values in different time periods or states. Euler equations allow structural parameters to be estimated and the specification of the model to be tested
Generalised least squares	Ordinary least squares estimation technique, transformed to mitigate the effect of correlation in the error term over time
Granger causality tests	These tests can be used to suggest the direction of causality, where past values of one series— x_t —can be used to predict future values of another series— y_t —if past values of y_t are controlled for
Heckman regression	A two-stage regression approach that can mitigate the effect of self-selection bias.
Herfindahl index	Measure of industry concentration, which is calculated as the sum of the squared value of the market shares of all companies in the industry
Heterogeneity	Unobserved differences across firms that are constant over time
Instrumental variables	An approach that can be used to overcome problems introduced as a result of endogeneity in an econometric model. An instrumental variable is a variable that does not appear in the equation, but is uncorrelated with the error from the model and is partially correlated with the endogenous explanatory variable
Latent variable model	A model where the observed dependent variable is assumed to be a function of an unobserved variable
Logistic regression framework	Binary choice model, assuming that the probability of the binary outcome corresponds to a logistic cumulative distribution function
Ordinary least squares	Technique for estimating coefficients in a linear model by minimising the sum of the squared differences between the observed dependent data points and those predicted by the linear regression model
Panel data	Observations of the same sample of units at several different points in time
Parsimonious model	An econometric model which best describes the data with as few explanatory factors as possible
Poisson binomial distribution	A distribution which informs the researcher of the probability of n successes in N trials for a series which follows a Poisson process

Term	Definition
Probit modelling	Binary choice model, assuming that the probability of the binary outcome corresponds to a standard-normal cumulative distribution function
Production function	A function that expresses the relationship between an organisation's inputs and outputs
Productivity	A measure of a company's productive performance A simple measure of productivity (a single factor productivity measure) is often given by output (eg, turnover) per head (ie, number of employees)
Tobit model	A model for a dependent variable that takes the value of zero, but is continuously distributed over positive values
Total factor productivity	A measure of productivity which takes into account all factors of production—ie, capital, raw materials and labour
Translog production function	A more general production function compared with the Cobb–Douglas production function
Two stage least squares	An instrumental variables estimator where the instrumental variable is obtained as the fitted value from regressing the endogenous explanatory variable on all exogenous variables
Vector autoregression	A model for two or more series, where each variable is modelled as a function of past values of all variables
Weighted least squares	An estimator used to adjust for any bias that is introduced into the regression as a result of the variance of the error term, given the explanatory variables, not being constant

Bibliography

- Altschuler, R. (1988), 'A Dynamic Analysis of the Research and Experimentation Credit', *National Tax Journal* XLI 1989, pp.453–66.
([http://ntj.tax.org/wwtax/ntjrec.nsf/5A0C0247A873C2838525686C00686D08/\\$FILE/v41n4453.pdf](http://ntj.tax.org/wwtax/ntjrec.nsf/5A0C0247A873C2838525686C00686D08/$FILE/v41n4453.pdf))
- Arellano, M. and Bond, S. (1991), 'Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations', *Review of Economic Studies*, **58**, pp 277–97.
- Department of Industry, Tourism and Resources—Canberra (2005), 'The R&D Tax Concession—Impact on the Firm, Report on a Survey of 116 Firms', October.
- Becker, B. and Hall, S. (2004), 'Testing the Pooling Assumption in an Industry Panel of R&D Investment: What Do We Learn?', National Institute of Economic and Social Research.
- Becker, B. and Pain, N. (2003), 'What Determines Industrial R&D Expenditure in the UK?', National Institute of Economic and Social Research, March.
- Berger, P.G. (1993), 'Explicit and Implicit Tax Effects of the R&D Tax Credit', *Journal of Accounting Research*, **31**, pp.131–71.
- Bernstein, J., L. and Nadiri, M., I. (1988), 'Rates of Return on Physical and R&D Capital and Structure of Production Process: Cross Section and Time Series Evidence', National Bureau of Economic Research Working Paper, No. 2570.
- Bloom, N., Chennels, L., Griffith, R. and Van Reenen, J., (1996), 'How has Tax Affected the Changing Cost of R&D? Evidence from Eight Countries', Institute for Fiscal Studies, October.
- Bloom, N., Griffith, R. and van Reenen, J. (2000), 'Do R&D Tax Credits Work? Evidence from an International Panel of Countries 1979–1994', The Institute for Fiscal Studies, Working Paper Series No. W99/8.
- Bond, S., Harhoff, D. and van Reenen, J.(2003), 'Investment, R&D and Financial Constraints in Britain and Germany', The Institute for Fiscal Studies, Working Paper Series No. W99/5.
- Branstetter, L. and Sakakibara, M., (1997), 'Japanese Research Consortia: A Microeconomic Analysis of Industrial Policy', National Bureau of Economic Research, Working Paper No. 6066, June.
- Brown, M., Randall Curlee, T., Elliott, S. (1995), 'Evaluating Technology Innovation Programmes: the Use of Comparison Groups to Identify Impacts', *Research Policy*, **24**, pp.669–84.
- Dagenais, M., Mohnen, P. and Thierrien, P. (1997), 'Do Canadian Firms Respond to Fiscal Incentives to Research and Development?', Tilburg University Press.
(<http://www.cirano.qc.ca/pdf/publication/97s-34.pdf>)
- Department of Industry, Tourism and Resources (2005), 'The R&D Tax Concession—Impact on the Firm, Report on a Survey of 116 Firms', Canberra, October.
- Dumagan, J.C. (1995), 'Re-examining the Cost-Effectiveness of the Research and Experimentation Tax Credit', U.S. Department of Commerce, June.
(<https://www.esa.doc.gov/reports/re-examining.pdf>)
- Eisner, R., Albert, S. and Sullivan, M. (1984), 'The new incremental tax credit for R&D: incentive or disincentive?', *National Tax Journal*, **37**, pp. 171–185.
- Griffith, R., Redding, S. and Van Reenen, J. (2001a), 'Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Countries', Institute for Fiscal Studies, August.
- Griffith, R., Redding, S. and Van Reenen, J. (2001b), 'Measuring the Cost-effectiveness of an R&D Tax Credit for the UK', *Fiscal Studies*, **3**, pp.375–99.
- Griffith, R., Harrison, R. and Hawkins, M. (2003), 'Report on Estimating Private and Social Rates of Return to R&D using Matched ARD and BERD Micro Data', Institute for Fiscal Studies, January.

- Guellec, D. and Pottelsberge, B. (2001), 'R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries', OECD Economic Studies.
- Hall, B. (1995), 'Effectiveness of Research and Experimentation Tax Credits: Critical Literature Review and Research Design.' report prepared for the Office of Technology Assessment, Congress of the USA.
(<http://emlab.berkeley.edu/users/bhhall/papers/BHH95%20OTArtax.pdf>)
- Hall, B. (1992), 'R&D Tax Policy during the Eighties: Success or Failure?', National Bureau of Economic Research Working Paper, No. 4240.
- Hall, B. (1993), 'R&D Tax Policy during the Eighties: Success or Failure?', *Tax Policy and the Economy*, **7**, pp.1–36.
- Hall, B. (1995), 'Fiscal Policy Towards R&D in the United States: Recent Evidence', Presentation to the OECD, University of California and the National Bureau of Economic Research, January.
- Hall, B., Mairesse, J., and Branstetter, L. (1998), 'Does Cash Flow Cause Investment and R&D: An Exploration Using Panel Data for French, Japanese and USA Scientific Firms', National Bureau of Economic Research, April.
- Hall, B. and Reenen, J., V. (2000), 'How effective are fiscal incentives for R&D? A review of the evidence', *Research Policy*, **29**, pp.449–69.
- Heckman, J., Smith, J., Ichimura, H., and Todd, P., (1998), 'Characterizing Selection Bias Using Experimental Data', *Econometrica*, **66**, pp.1017–98.
- Hines, J.R. (1994), 'No Place like Home: Tax Incentives and the Location of R&D by American Multinationals', NBER Working paper no. 4574.
- Hines, J.R. (1993), 'On the Sensitivity of R&D to Delicate Tax Changes: the Behaviour of U.S. Multinationals in the 1980s in Giovannini, A., Hubbard, R.G., Slemrod, J., *Studies in International Taxation*, University of Chicago Press, Chicago, pp.149–94.
- Irwin, D., A. and Klenow, P., J. (1994), 'High Tech R&D Subsidies: Estimating the Effects of SEMATECH', National Bureau of Economic Research, Working Paper No. 4974, December.
- Jaffe, A.B. (1984), 'The Effects of Market Demand, Technological Opportunity and Research Spillovers on R&D Intensity and Productivity Growth', National Bureau of Economic Research, Working Paper No. 1432, August.
- Klette, T.J., Moen, J. and Griliches, Z. (2000), 'Do Subsidies to Commercial R&D Reduce Market Failures? Micro Econometric Evaluation Studies', *Research Policy*, **29**, pp.471–95.
- Lattimore, R. (1997), 'Research and Development Fiscal Incentives in Australia: Impacts and Policy Lessons', Industry Commission, Canberra, Australia, Chapter 7.
- Lerner, J. (1998), 'The Government as Venture Capitalist: the Long-run Impact of the SBIR Programme', Harvard University. Previously published as NBER (1996) working paper 5753.
- Lerner, J. (1996), 'The Government as Venture Capitalist: The Long-Run Impact of the SBIR Programme', National Bureau of Economic Research, Working Paper No. 5753.
- Mamuneas, T.P. and Nadiri, M.I. (1996), 'Public R&D Policies and Cost Behaviour of the US Manufacturing Industries', *Journal of Public Economics*, **63**, pp.57–81, December.
- McCutchen, W., W. (1992), 'Estimating the Impact of the R&D Tax Credit on Strategic Groups in the pharmaceutical Industry', The City University of New York, February.
- Poot, T., Hertog, P., Grosfeld, T. and Brouwer, E. (2003), 'Evaluation of a Major Dutch Tax Credit Scheme Aimed at Promoting R&D', Draft version 2.0, 22/4.

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