Rachel Griffith, Stephen Redding and John Van Reenen

Measuring the cost effectiveness of an R&D tax credit for the UK

Abstract

This paper investigates the economic impact of the government's proposed new UK R&D tax credit. We measure the benefit of the credit by the effect on value added in the short and long_run. This is simulated from existing econometric estimates of the tax_price elasticity of R&D and the effect of R&D on productivity. For the latter we allow R&D to have an effect on technology transfer (catching up with the technological frontier) as well as innovation (pushing the frontier forward). We then compare the increase in value added to the likely exchequor costs of the program under a number of scenarios. In the long run the increase in GDP far outweighs the costs of the tax credit. The short run effect is far smaller with value-added only exceeding cost if R&D grows at or below the rate of inflation.

Keywords: Growth, Innovation, R&D, Tax Credit, Total Factor Productivity (TFP)
JEL Classification: H20, O32, O47

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1 Introduction

R&D tax credits are again on the policy agenda. In his March 2001 Budget the Chancellor announced his intention to extend the R&D tax credit for small and medium sized enterprises to larger firms in the following budget and issued a consultative document on how it should be implemented. In this paper we consider what impact such a policy is likely to have on UK productivity and growth.

One of the main justifications for government subsidies to R&D is the belief that social rates of return are in excess of private rates of return. Firms' decisions to undertake R&D are based on their private return to R&D. These are generally thought to be lower than the return to society as a whole. This means that we have under-investment in R&D. In order to achieve the optimal level of R&D investment government policy should aim to bring private incentives in line with the social rate of return.

The main reason why the social rate of return is believed to be higher than the private return is because the knowledge generated from R&D "spills over" from the inventor to other firms.[1] Once invented an idea can be imitated by others (it is non-rivalrous and only partially excludable), although intellectual property protection and delays in the dissemination of new ideas enable the innovator to appropriate a share of the rents from a new idea. Knowledge is also 'tacit' in nature: it takes time and effort to explain new ideas to others and to codify inventions in manuals and textbooks.[2] This means that imitation is not costless and R&D activity may be important for understanding the discoveries of others. Mansfield *et al.* (1981) present evidence of substantial costs of imitation (on average, 65% of innovation costs), while the average length of time for imitation is found to be 70% of

[1] Note that the 'social rate of return' to R&D in this literature refers to the private rate of return plus any externalities.

[2] For informal discussions of the tacit nature of knowledge, see David (1992) and Rosenberg (1982).

that taken for innovation. Recent theoretical research has emphasized the idea that R&D not only leads to innovation, but also enhances one's ability to imitate.[3] This second role is often termed the 'second face of R&D.' Empirical evidence lends support to these ideas.

In this paper we consider the implications of the two faces of R&D for the analysis of public policies that seek to stimulate private-sector R&D activity. The policy we consider is an R&D tax credit of the form set out in the Treasury's 2001 Consultative Document. The paper is structured as follows. Section 2 outlines the idea that R&D plays a dual role in both innovation and imitation in a simple analytical framework. Section 3 looks at the impact and cost effectiveness of introducing an R&D tax credit in the UK. We do this in several stages - (1) estimating the fall in the user cost of R&D for a typical firm, (2) using the change in the user cost to estimate the change in R&D, (3) estimating the impact of the change in R&D on TFP, (4) examining the exchequer cost of the policy. The appendix provides a more technical description of the model and approach. A final section summarises and offers some concluding remarks. Unsurprisingly we find that in the short run the exchequer costs will probably outweigh the increase in GDP. More interestingly, we find that the long-run effect on GDP easily outweighs the likely costs under a range of scenarios.

2 An Analytical Framework: The Two Faces of R&D

A large empirical literature has sought to estimate the rate of return to R&D. In general the empirical literature finds the social rates of return to R&D substantially above private rates of return. These findings are summarised by Griliches (1992), *"In spite of (many) difficulties, there has been a significant number of reasonably well-done studies, all pointing*

[3] See, for example, Aghion and Howitt (1998), Cohen and Levinthal (1989), Grossman and Helpman (1991), Neary and Leahy (1999), and Segerstrom (1991).

in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates."

The private rate of return can be estimated by looking at the impact of a firm's own R&D on the firm's output. Estimates of the private rate of return to R&D are obtained using US firm level data in Griliches (1992). The estimated elasticity of output with respect to R&D is around 0.07. This says that for a 10% increase in R&D expenditure there will be a bit less than a 1% increase in output (0.7%) holding other factors constant. The elasticity of output with respect to R&D is related to the rate of return to R&D as

elasticity of output with respect to R&D = (rate of return to R&D)*(R&D stock/output).

The R&D stock to output ratio in the US was estimated to be around 26%. This implies a rate of return of around 27% (=.07/.26) for R&D. Hall (1996) summarises empirical work in this area and reports that estimates of private rates of return to R&D cluster around 10% to 15% though can be as high as 30% in some studies.

What about estimates of the social rate of return to R&D? Care must be taken in interpreting estimates of the social rate of return to R&D. Ideas can spill over between firms in the same industry, across industries and across countries. Production function estimates using firm level data, where R&D in other firms is included in the regression, attempt to capture the social rate of return to firms' R&D (often within the industry).[4] Regressions of industry level productivity against industry-level R&D seek to capture the social rate of return to the industry, but not spillovers to other industries (unless other industry R&D has been incorporated in some way). Similarly, production function estimates conducted at the national level capture within country spillovers, but not those between countries.

[4] The critical problem here is in constructing the "knowledge weighting matrix" that links the R&D conducted by one firm to the productivity of the recipient firms. Using information contained in patent technology classes has proven relatively successful here (see Jaffe, 1986, for an early example or Bransetter, 1996, for a more recent case).

In addition, an important part of innovative output is the introduction of new goods and there are considerable difficulties that arise in measuring the value and benefit of these new goods.[5]

Cameron (1996a) and Jones and Williams (1998) summarize existing empirical estimates of R&D's social rate of return to R&D from the empirical literature on R&D and productivity. Many studies have been undertaken using US data and are typically for manufacturing industries. Estimates of the social rate of return to own-industry R&D include 21%-76% in Griliches and Lichtenberg (1984b), 24%-73% in Schankerman (1981), and 29-43% in Scherer (1982), (1984). Once we take into account that R&D conducted in one industry may have an impact on productivity in other industries (e.g. downstream industries), the estimated social rate of return to R&D rises further and can be as high as 100%. Jones and Williams (1998) show how estimates of R&D's social rate of return from industry-level data can be incorporated into a macroeconomic model of endogenous innovation and growth. They find that estimates actually provide a lower bound to R&D's true social rate of return once one takes into account the dynamic general equilibrium effects emphasized in the endogenous growth literature.

Another way in which the existing industry-level literature may underestimate both the private and social rate of return to R&D is by assuming that imitation is costless. Knowledge is 'tacit' in nature: it takes time and effort to explain new ideas to others and to codify inventions in manuals and textbooks. This means that imitation can itself be costly. Recent work has emphasized the fact that R&D not only leads to innovation, but also enhances one's ability to imitate. Many of the benefits to this second role of R&D activity may be internalised by firms, and the externalities from R&D-based imitation might in

[5] There are a large number of other caveats to the approach of aggregating to capture externalities. These are discussed in some detail in various chapters of Griliches (1998).

themselves be less than those from innovation. However, in a world where imitation is no longer costless, the knowledge spillovers emphasized in the innovation literature are now dependent on other firms undertaking R&D activity.

Griffith, Redding and Van Reenen (2000) present an empirical framework in which innovation and technology transfer provide two potential sources of productivity growth for countries behind the technological frontier. The rate of return to R&D is composed of an effect on productivity through innovation and an effect through increased potential for imitation. A country's distance from the technological frontier is used as a direct measure of the potential for technology transfer, where the frontier is defined for each industry as the country with the highest level of total factor productivity (TFP).[6]

More formally, we assume that value-added, Y, is produced with a standard neoclassical production technology,

$$Y_{it} = A_{it} F(K_{it}, L_{it}) \tag{1}$$

where i indexes countries, and t denotes time. A is an index of technical efficiency or TFP, L corresponds to labour input, and K denotes physical capital. The endogenous growth and empirical productivity literatures emphasize R&D-based innovation. Here, A_{it} is a function of R&D activity. In the conventional specification we have,[7]

$$\triangle \ln A_{it} = \rho \left(\frac{R}{Y}\right)_{it-1} + \gamma X_{it-1} + u_{it} \tag{2}$$

where $\rho = dY/dG$ is the social rate of return to R&D, X_{it-1} is a vector of control variables and u_{it} is an error term capturing stochastic determinants of TFP growth.[8] The arguments

[6] See Cameron (1996b) for an analysis along these lines of Japan and the United States and Cameron, Proudman, and Redding (1998) for an analysis of the United Kingdom and United States.

[7] See, in particular, Griliches (1980) and Griliches and Lichtenberg (1984a). The microeconomic rationale for this relationship is provided by the endogenous growth literature. See, for example, Aghion and Howitt (1992, 1998).

[8] There is a debate in the endogenous growth literature about whether the *level* of R&D activity can have

above suggest that the conventional specification needs to be augmented in order to allow for a second face of R&D in promoting technology transfer. Equation (2) becomes,

$$\triangle \ln A_{it} = \rho_1 \left(\tfrac{R}{Y}\right)_{it-1} + \underbrace{\beta \triangle \ln A_{Ft} - \delta_1 \ln \left(\frac{A_i}{A_F}\right)_{t-1}}_{\text{technology transfer}} \underbrace{-\delta_2 \left(\frac{R}{Y}\right)_{it-1} \ln \left(\frac{A_i}{A_F}\right)_{t-1}}_{\text{absorptive capacity}} + \gamma X_{it-1} + u_{ijt}. \tag{3}$$

Technology transfer is made up of two components. The presence of the first component, $\beta \triangle \ln A_{Ft}$, allows the contemporaneous rate of TFP growth in the frontier to have a direct effect on TFP growth in non-frontier countries. The second of these components, $\delta_1 \ln(A_i/A_F)$, allows for autonomous technology transfer independent of R&D activity. For non-frontier countries, relative TFP $\left(\ln (A_i/A_F)_{t-1}\right)$ is negative; the more negative relative TFP, the further a country lies behind the frontier, and the greater the potential for technology transfer. Therefore, with technology transfer, the estimated coefficient on relative TFP (δ_1) should be negative.

Absorptive capacity is captured by an interaction term that captures the second face of R&D. The more negative relative TFP, the further a country lies behind the frontier, and the greater the potential for R&D-based technology transfer. Therefore, if there is a second face of R&D, the estimated coefficient on the interaction term (δ_2) should be negative.

In steady-state equilibrium, TFP in a country i will grow at the same constant rate, equal to TFP growth in the frontier ($\triangle \ln A_i = \triangle \ln A_F$ for all i). The frontier will be whichever of the countries has the highest rate of TFP growth from innovation alone. All other countries will lie an equilibrium distance behind the constantly advancing frontier

permanent effects on the *rate of growth* of output (the 'scale effects' debate as in Jones (1995a), (1995b)). The conventional specification above exhibits such a scale effect, although it is straightforward to eliminate it by introducing diminishing returns to R&D.

such that TFP growth from innovation and technology transfer in a non-frontier country exactly equals TFP growth from innovation alone in the frontier.

The sum of the estimated coefficients on the R&D intensity in equation (3) is R&D's full social rate of return for an industry ($\rho \equiv \rho_1 - \delta_2 . \ln(A_i/A_F)_{it-1}$) and depends on both innovation and technology transfer. Our estimate of the social rate of return to R&D from innovation (ρ_1) is about 40%, which is broadly comparable with existing estimates of R&D's social rate of return using industry-level data. The existing estimates are largely for the United States, which is typically the frontier in our dataset. The rate of return to R&D in the US should therefore largely consist of a rate of return to innovation.

The full social rate of return to R&D depends upon how far a country lies behind the technological frontier. Griffith, Redding, and Van Reenen (2000) present empirical estimates. The relative level of TFP in the UK relative to the US in total manufacturing over the period 1974-90 was around 62.6%. The implied social rate of return to R&D (from both innovation and absorptive capacity) is around 90%. The social rate of return to R&D in the US is indeed due almost entirely to innovation (a total rate of return of 0.439 compare a rate of return from innovation of 0.433).

One important conclusion from the analysis in that paper is that many existing studies, in so far as they are based on US data (a country which is typically the frontier), will tend to underestimate the social rate of return to R&D. In non-frontier countries, there is the potential for R&D to generate TFP growth from both innovation and technology transfer. This conclusion receives independent support from Eaton *et al.* (1998), who calibrate a computable general equilibrium model of endogenous innovation and growth to economy-wide data from 21 OECD countries. With the exception of Portugal, research productivity in all other OECD countries is found to be higher than in the U.S.

This raises the question why many non-frontier countries do not undertake more R&D. One answer may be that there are larger differences between private and social rates of return in these countries. If some of the technology transfer induced by R&D activity takes the form of an externality it will not be internalised by private sector agents. The explanation provided by Eaton *et al.* (1998) is that research incentives are lower due to smaller market size. Market failures such as underdevelopment of financial markets and government policies may also act as barriers to R&D investment.

A second conclusion is that a distinction needs to be drawn between the social rate of return to R&D at the *national* and *supra-national* levels. In the theoretical model presented above, an increase in R&D in the frontier raises the steady-state rate of TFP growth in *all other countries.* In steady-state, TFP in all countries grows at the same rate, equal to TFP growth in the frontier. Thus, although *national* social rates of return to R&D are higher in non-frontier countries, there is an important *supra-national* externality to R&D undertaken in the frontier.

3 Policy Analysis

One of the policy implications of finding social rates of return in excess of private is that it would be welfare-improving to stimulate more R&D in the private sector. How should a policy-maker seek to do this? Tax incentives seem a natural policy tool for a market-oriented government wanting to increase R&D expenditures. Firms decide where and how to spend their R&D rather than have it determined through a bureaucratic central authority. The policy instrument is targeted closely at the source of the market failure. Many countries have turned to fiscal incentives for R&D, often involving substantial sums of taxpayers' money.[9]

What impact would we expect the introduction of an R&D tax credit in the UK to have?

We consider the impact that an incremental R&D tax credit would have on UK TFP growth and value-added in the context of the model laid out above. Our estimates relate to UK manufacturing only, but as this represents around 80% of UK R&D this should give a fairly complete picture. In order to answer the question of how cost effective a tax credit would be we need to specify:

- how the tax credit will change the price (user cost) of R&D;
- how R&D expenditure will respond to a change in its price;
- how TFP will respond to a change in R&D expenditure;
- how manufacturing value-added will respond to a change in TFP;
- how much the tax credit will cost the Inland Revenue.

We draw on estimates from our econometric work to provide answers to the first four of these questions. The fifth, on revenue costs, we estimated from aggregate data. In order to answer the question of whether an R&D tax credit is cost-effective, we need to estimate how much it will cost the Inland Revenue. Note that this is not the same as evaluating whether the policy is welfare improving. We do not consider potential deadweight welfare costs from any distortionary taxation used to finance the R&D tax credit. We also do not consider the opportunity cost of the funds allocated to the R&D tax credit, which could be spent on other areas of government expenditure. However, a necessary (though not

[9] See, for example, the discussions in Griffith, Sandler and Van Reenen (1995), Gravelle (1999), Hall (1993), Klette, Moen and Griliches (1999), Mansfield (1986), and US Government (1989).

sufficient) condition for the tax credit to be welfare improving is that the social surplus it generates is greater than the direct monetary cost. Moreover, a comparison of the increase in value-added as a result of the policy with its monetary cost constitutes an important part of a wider welfare evaluation.

We estimate what will be the immediate impact, and what the effects will be in the long-run. This is an important distinction as there are significant adjustment lags between a change in the user cost and R&D expenditure and the change in R&D and the subsequent increase in GDP. The details of how we do our calculations are sketched out here. A technical appendix provides the gory detail. While our analysis accounts for many features of R&D tax credit design and the ways in which firms are likely to respond to the introduction of a tax credit, there are a number of assumptions that we make in the interests of tractability. In particular, we assume that the accumulation of physical and human capital are unaffected by the tax credit; we do not consider the welfare costs that may arise from additional distortionary taxation used to finance the tax credit; we also do not consider the returns to alternative possible uses of the funds allocated to the tax credit.

3.1 The Impact of an R&D Tax Credit on the Price of R&D

The impact that an R&D tax credit has on the price of R&D depends on the precise details of its design. We consider a credit that is designed as proposed in the 2001 Consultative Document. The main features of this are that it is an incremental credit on a two-year rolling average base, the base is indexed by inflation and the credit is implemented as a deduction to corporate tax at a 50% rate.[10]

[10] The consultative document also proposes many other details, one important one is using a credit bank whereby firms carry forward a "shadow" negative credit. The impact of this is not considered here as it does not affect the user cost in our model firm. However, it would greatly affect the dispersion of marginal rates faced by different firms. See Bloom, Griffith and Klemm (2001).

We use estimates of the user cost of R&D and the own price elasticity of R&D from Bloom, Griffith and Van Reenen (2001) and Bloom, Griffith and Klemm (2001). We assume that only R&D performed in the UK is eligible for the tax credit. The impact of the credit on the price of R&D is measured by comparing the user cost of R&D in the absence of the credit with the user cost including the credit (see Appendix). The value of the tax credit to a firm receiving it depends upon the time path of the firm's R&D expenditure. We calculate the user cost for a 'model firm' where R&D is always expected to increase by at least the rate of inflation and where the firm is never in a tax exhausted position.[11] We assume that the real interest rate (and also the firm's discount rate) is 10% and that inflation is 5%.

The user cost combines a measure of the net present value of the tax credit with information about other features of the tax system to tell us about how the tax credit changes the price of investing an additional pound of R&D. The proposed tax credit yields a change in the user cost of 1.9% (i.e. the user cost of R&D capital has declined from about 0.386 to 0.379). The figure of 1.9% is considerably lower than the statutory rate of 50%. This is for a number of reasons. The three main features effecting the user cost are:

- it is implemented as a deduction, this means that the equivalent rate as a tax credit is 15%, (the statutory tax rate is 30%, so the value of a 50% deduction is 30%*50%=15%).

- the tax credit is paid on incremental R&D, with the increment defined with respect to a 2-year rolling average base. This means that the firm receives a credit on the additional R&D it does over the average of the past two years. When a firm does more R&D in one year this earns them a credit in that year, but it also reduces the value of the credit to them in the next year by increasing their base.

[11] These are reasonable assumptions for many large firms. Bloom, Griffith and Klemm (2001) use data on a sample of 138 UK quoted firms to obtain estimates of the impact the various credits will have on the price of firms' R&D and thus look at heterogeneity in user costs across firms.

- the credit is paid on the increase in *real* R&D, that is the base is indexed by inflation, the 2001 Consultative Document proposes using the Retail Price Index (RPI).

Although a fall of under 2% seems small, it is relatively large by Britain's historical standards. The tax component of the R&D user cost in the UK has varied by only 0.1 percentage points between any two years from 1979 to 1997.

3.2 The Response of R&D Expenditure to a Change in its Price

We use estimates of how R&D expenditure will respond to changes in its tax price from Bloom, Griffith and Van Reenen (2001).[12] The results in that paper suggest that the own price impact elasticity is around 0.12 and the long-run elasticity is around 0.86. This means that a 10% change in the price of R&D will lead to an immediate increase of 1.2% in R&D intensity and a 8.6% increase in the long run (see Appendix for details). In order to estimate the amount of new R&D that is done in response to a change in the tax price we assume that the cost of capital calculated above gives a good approximation of the average cost of capital faced by firms.

Table 1 shows the change in the user cost and our estimates of the resulting change in R&D intensity. The immediate or impact effect is to increase the R&D intensity by 0.23%, and the long-run effect is 1.6%. To gives some idea of the size of this change, over the period 1973 to 1997 the annualised growth rate in the R&D intensity was 1.0% (there is considerable annual variation from -7% to 16%). The impact of reducing the user cost of R&D by 1.9% would thus increase the growth rate by around a quarter of its usually annual growth rate. This is quite a large effect.

[12] See Hall and Van Reenen (1999) for a survey of the empirical evidence on the effectiveness of R&D tax credits.

Table 1: Impact of the R&D tax credit on the price and amount of R&D

Change in user cost of R&D	-1.9% (from 0.386 to 0.379)
Increase in R&D intensity, $\%\Delta R/Y$	
impact	0.23%
long-run	1.6%
Initial Level of R&D intensity (without tax credit)	5.7%
Implied R&D intensity with tax credit:	
impact	5.713%
long-run	5.791%

Notes: $\%\Delta(R/Y) = \log(R/Y)_t - \log(R/Y)_0$, where t is period under consideration and 0 denotes the base period. See Appendices A1 and A2 for details

3.3 The Response of TFP and Value-added to a Change in R&D Intensity

First, we analyse the effects of the tax credit when R&D only affects innovation. This is a special case of the model above, where R&D has no effect on the propensity to imitate (in the context of equation (3) this means $\delta_2 = 0$). This corresponds to the conventional specification with 'one face' of R&D and provides a useful benchmark for our results. In this case, total manufacturing TFP growth is given by equation (2), and the increase in R&D intensity following the tax credit raises TFP growth in both the short and long-run. The estimated R&D innovation coefficient in Griffith, Redding, and Van Reenen (2000) is 0.433. The percentage increase in TFP growth following the tax credit is therefore 0.433 times the original level of the R&D intensity times the percentage increase in R&D intensity due to the tax credit. That is, an effect of $0.433 \times 0.057 = 0.025$ times the percentage increase in R&D intensity (see Appendix), where the short and long-run values for the latter are evaluated in Table 1 above.

Second, in line with recent empirical evidence, we allow for R&D to affect both innovation and imitation. This is the general case where there are 'two faces' of R&D and $\delta_2 \neq 0$.

In this case, total manufacturing TFP growth is given by equation (3). The implications of the tax credit for TFP growth are now different between the short-run and the long-run or steady-state. In the short-run, the increase in the R&D intensity following the tax credit raises TFP growth through both rates of innovation and imitation. In the long-run, assuming that the tax credit does not result in a change in technological leadership, the increase in the R&D intensity can have no effect on UK TFP growth. In steady-state, UK TFP growth from both innovation and imitation must equal the (unchanged) rate of TFP growth in the frontier from innovation alone. Since the increase in the R&D intensity following the tax credit raises both innovation and imitation for a given size of the technological gap, something must adjust in order for this steady-state equilibrium condition to hold. The variable that adjusts is the size of the technological gap: higher levels of UK TFP relative to the frontier imply a smaller potential for imitation. The adjustment process is as follows. The short-run increase in TFP growth following the introduction of the tax credit results in a progressively higher level of relative TFP which reduces the potential for imitation until TFP growth in the UK from innovation and imitation again equals TFP growth in the frontier from innovation alone. The steady-state effect of the R&D tax credit is to lead to a higher steady-state level of relative TFP. Note that steady-state TFP growth will always be higher in a model where R&D promotes imitation as well as innovation: TFP growth in the UK is no longer constrained by domestic rates of innovation, but can benefit from spillovers from a more rapid rate of innovation in the frontier.

With two faces of R&D, the short-run effect of the increase in the R&D intensity due to the tax credit depends on the initial level of relative TFP. The further a country initially lies behind the technological frontier, the greater the potential for R&D-based imitation. For our main estimates we use a value of 0.85 for the UK; this says that TFP levels in the UK are initially 85% of what they are in the US. We consider how the effects of the R&D tax credit changes with different sizes of this productivity gap. As shown in Table 2, these values imply that the short-run percentage change in TFP growth following the introduction of the tax credit is 3.4% of the percentage increase in R&D (see Appendix). When we consider only the direct impact of R&D (the first row) the immediate impact of the R&D tax credit is to increase the growth rate of TFP by 0.0056%, and in the long-run by about a third of a percent. Once we take into account the second face of R&D the immediate impact increases to 0.0077%. Thus, the short-run effect on rates of TFP growth when we consider the two faces of R&D (innovation and imitation) is about a third again as much as when R&D only affects innovation. In the final row we show how the increase in the TFP growth rate varies with the relative TFP gap. If we assume an initial gap of 75% then the increase in the growth rate is higher at 0.0093%.

Table 2: Percentage increase in TFP growth, $\triangle \ln A_{it}^{C} - \triangle \ln A_{it}$

	impact	long-run
Innovation effect	0.0056%	0.32%
Innovation and imitation effect (UK TFP initially 85% of frontier)	0.0077%	-
Innovation and imitation effect (UK TFP initially 75% of frontier)	0.0093%	-

In the Appendix, we show how the model presented above may be solved for the effect of the R&D tax credit on steady-state levels of relative TFP when there are two faces of R&D. This steady-state effect is independent of the initial level of relative TFP. Our estimates also depend on the rate of TFP growth in the US (which is the frontier country). We use a value of 1.5%, which is the average rate of growth over the past two decades. We also consider how sensitive the estimates are to using alternative values. Table 3 presents the implied effect of the tax credit on steady-state equilibrium levels of relative TFP. Since this refers to an effect on levels of relative TFP, while Table 2 was concerned with rates of growth, it is hard to directly compare these numbers. We show below how both sets of figures may be made comparable by examining the implied increase in manufacturing value-added.

Table 3: Percentage increase in relative TFP in long-run steady state

	$\ln(A_{it}^C/A_{Ft}) - \ln(A_{it}/A_{Ft})$
Innovation and Imitation effect (UK TFP initially 85% of frontier)	0.43%

To do so, we employ a standard growth accounting decomposition which suggests that the rate of growth of output equals TFP growth plus the weighted growth of factor inputs (see Appendix). The effect of the R&D tax credit on manufacturing value-added in the year after it is introduced is simply the short-run increase in TFP growth from Table 2 times the initial level of manufacturing value-added. This is shown in the column headed "impact" in Table 4 for the one face of R&D and two faces of R&D models using manufacturing value-added in 1999 (using the 1999 value for manufacturing value-added of £155bn as the initial value). When R&D only affects innovation (the one face model), the long-run effect of the tax credit is a permanently higher rate of TFP growth in each subsequent year. As shown in the Appendix, this may be converted into an effect on manufacturing value-added in any given year by multiplying the annual increase in TFP growth by the initial level of manufacturing value-added at the beginning of that year. The final column of Table 4 reports the implied effect on manufacturing value-added in 1999. When R&D affects both innovation and imitation (the two faces model), the long-run effect is a permanently higher level of TFP relative to the frontier, where the frontier is constantly advancing at a rate greater than UK-based rates of innovation. Again as shown in the Appendix, this may be converted into an effect on manufacturing value-added in any given year by multiplying the increase in steady-state levels of relative TFP growth by the initial level of manufacturing value-added at the beginning of that year. The third column of Table 4 reports the implied effect on manufacturing value-added in 1999. The effect is larger than in the one face model, because R&D raises manufacturing value-added by enhancing both innovation and imitation.

Table 4: Increase in manufacturing value-added, £m

	impact	long-run
Innovation effect	8.7	491.9
Innovation and imitation effect	11.9	670.1

3.4 The Cost Effectiveness of an R&D Tax Credit

How much is such a policy likely to cost? In order to answer this question we need to know what the real growth rate of R&D would be in the absence of the tax credit. Since we do not know this we calculate it for a range of real growth rates between 0% (R&D grows at the same rate as the RPI) to 5%. Over the period 1973 to 1997 the annualised real growth rate in R&D was 0.8%. It varied substantially year to year from -6.0% to 17%. In the last five years it has been ranged from -1% (1994-95) to 3.9% (1998-99). We thus consider the likely counterfactual rate of growth to be towards the lower growth rates shown in the first few rows of the table.

The Inland Revenue (IR) has to pay 15% on every £ of incremental R&D. Incremental R&D is defined as the amount of R&D done today minus the average amount done in the past two years, indexed for inflation. This means that, even if firms had not responded at all to the credit the IR would have had to pay out 15% of the increase in real R&D. This means that the revenue cost depends mostly on the growth rate in R&D. Therefore, we calculate estimates of the revenue cost for different assumed growth rates. The first column in Table 5 shows the amount of R&D that would be defined as incremental under the rules of the proposed tax credit (under the assumption that the credit had no impact on R&D spending). The second column shows the amount of credit the IR would have to pay out on this R&D. This is one form of deadweight loss from such a credit.

The IR would also have to pay out a credit on new R&D that resulted from the credit. Manufacturing business enterprise research and development (BERD) was £8,782m in 1999. From the estimate of the impact effect of the R&D tax credit in Table 1, this means that the immediate effect of the R&D tax credit will be to raise R&D spending by £19.9m which will cost the IR £3m a year as shown in column (3). In column (4) we add this number to the figure in column (2), which yields an estimate of the immediate revenue cost of the tax credit, taking into account both the incremental growth in R&D that would have occurred without the tax credit and new R&D due to the policy intervention. Combining the long-run response of R&D to the tax credit from Table 1 with the 1999 figure for manufacturing BERD above implies a long-run increase in R&D of £142.5m which will cost the IR £21.4m per year. In column (5), we add this number to the figure in column (2) to get an estimate of the long-run revenue cost of the credit. It should be noted that these revenue costs are very approximate. They do not take into account any of the complexities of taxation at the firm level.

Table 5: Revenue cost in £m

(1)	(2)	(3)	(4)	(5)
Real growth rate in R&D (in the absence of the credit)	Incremental R&D without credit	Credit paid on incremental R&D without credit (from (2))	Credit paid on incremental R&D with credit (impact effect)	Credit paid on incremental R&D with credit (long-run effect)
0%	0	0	3	21.4
1%	130	19.5	22.5	40.9
2%	257	38.5	41.5	60.0
3%	380	57.0	60.0	78.4
4%	500	75.0	78.0	96.4
5%	617	92.6	95.6	114

In Table 6 we calculate the cost effectiveness of the proposed tax credit using the estimates of the increase in manufacturing value-added from Table 4 and the estimates of revenue cost from Table 5. The cost effectiveness is simply additional value-added divided by revenue cost. In the first two columns we use the increase in value-added implied by the model of TFP where R&D only has a direct affect through increasing the rate of innovation. Here we see that only if R&D does not grow above the rate of inflation (in the absence of the credit) is the tax credit cost effective in the short-run. This is because with higher growth rates the deadweight of the tax credit is greater. A similar picture arises looking at the model in which R&D also contributes to TFP growth by enhancing imitation, although the cost-effectiveness ratios are higher.

In the long-run or steady state the credit is cost effective which ever model or growth rate we consider.

Table 6: Cost effectiveness

Real growth rate in R&D (in the absence of the credit)	Innovation		Innovation and Imitation	
	impact	long-run	impact	long-run
0%	2.90	23.01	3.97	31.35
1%	0.39	12.04	0.53	16.39
2%	0.21	8.22	0.29	11.19
3%	0.14	6.28	0.20	8.55
4%	0.11	5.10	0.15	6.95
5%	0.09	4.32	0.12	5.88

The upsurge in US productivity growth between 1995 and 2000 has stimulated a vigorous debate over whether there has been a structural shift in the growth of TFP associated with rapid computer-based technological change.[13] Since the US is generally the technological frontier, according to our model this will affect the long-run TFP growth rate of the UK economy (British TFP growth will also approach 2% p.a). What is more relevant to this paper, however, is that the impact of the UK R&D tax credit will vary depending on our assumptions regarding US TFP growth. In particular a faster TFP growth in the frontier is associated with a higher equilibrium TFP gap between the UK and the US. In this circumstance an extra pound of R&D is more valuable because it helps the UK to catch up more quickly with the US (the second face of R&D-based technology transfer becomes stronger).

Our baseline estimates assume that US TFP growth is 1.5%. If US TFP growth was higher at 2% then this would mean a long-run increase in valued-added of £710m rather than the £670.1m of Table 4. The two faces steady-state cost effectiveness for 2% real growth (for example) would be 11.8 (rather than 11.2 as shown in Table 5). If US TFP growth was 2.5% the equivalent numbers are: £750m and 12.5. So, although there are

[13] See Van Reenen (2001) for a discussion on the hard evidence over the "new economy".

additional benefits associated with R&D policy if there has been an increase in frontier steady state growth these are not huge.

4 Conclusion

In March 2001 the Chancellor of the Exchequer announced his intention to extend an R&D tax credit to large firms in his next budget. In this paper we have examined what is the likely impact of this policy and whether it will be cost effective. There is obviously a large degree of uncertainty surrounding these calculations, but we think it is a valuable exercise. Much progress has been made in recent years in examining the impact of fiscal incentives on R&D and on analysing the effect of R&D on growth. We use estimates from recent econometric work to simulate the effect of the proposed R&D policy based on the design contained in the Treasury's consultative document. Our model allows R&D to have a dual impact through its increase in the rate of innovation and through its "second face" of improving technology transfer. We find that the short-run effect of the R&D policy on manufacturing value-added is very limited when we assume that in the absence of the R&D tax credit the real rate of growth of R&D would be 1% or more). In this case the exchequer cost is greater than the extra output generated in the first year. This is due to the design of the credit (it is not very generous), the slow adjustment of R&D to changes in its price and the slow impact of R&D on long-run TFP. In the longer-run, however, the policy seems far more attractive and is cost-effective under a wide range of assumptions.

There are a number of important limitations to the paper. First, we have assumed that R&D is neutral with respect to other factors of production. Although this is a common assumption in the literature we are rather uneasy with it as there are likely to be complementarities between R&D and physical and human capital.[14] A more general analysis would take these into account. A corollary of non-neutrality is that the demand for R&D scientists is likely to rise as a result of the subsidy. To the extent that the labour supply of these highly skilled workers is fixed, much of the subsidy may be captured in the form of higher wages, at least in the short run.[15] In the longer-run labour supply will adapt but even the small gains we identify in the shorter run may be illusory.

A second limitation of the study is our focus on manufacturing. This is necessary because most of the existing estimates are based on data from this sector. Although it is true that 80% of R&D is conducted in manufacturing under 20% of people are actually employed in this sector. Since we do not focus on inter-industry spillovers (such as those from the manufacturing industries to the service industries) we may be underestimating the benefits of the R&D tax credit.

A third limitation is that we have not modelled the international dimension of R&D in any detail. Although we do allow for technology transfer across counties within industries we have not taken into account the effect of UK policy on other countries. On the positive side there are likely to be some spillovers from the UK to other nations (even in the terms of our model the UK is frontier in some industries). On the negative side, some of the additional UK R&D may come from multinationals simply relocating their R&D activity.[16] This is clearly a concern of the EU and an R&D tax policy may eventually be blocked because of these concerns over "state aid" rules.

Finally, and from a policy point of view the most problematic, is the issue of timing. We have focused on the impact effect and the long-run effect. We have not modelled the

[14] See, inter alia, Machin and Van Reenen (1998).
[15] See Goolsbee (1998) for evidence of this affect in the US.
[16] See Bloom and Griffith (2001) for evidence on this.

transition to steady state. This is due to the highly complex nature of the dynamics and our uncertainty over the various adjustment processes. Yet for a Chancellor with his eye on the electoral cycle the issue of exactly *when* the policy will become cost effective and start bridging the productivity gap is clearly important. We hope to address these concerns in future work.

Appendix

A Details of the Calculations

This appendix gives a technical explanation of our modelling strategy and calculations. Our aim is to provide sufficient detail to allow the reader to reproduce our calculations making alternative assumptions. Values used for key parameters are as follows:

Table A1 : Values of the Key Parameters

Real interest rate	10%
Statutory tax rate on corporate income	30%
Economic depreciation rate of R&D	28%
Manufacturing value-added	£155bn
Manufacturing BERD	£8,782m
R&D/Y in UK	0.057
R&D/Y in US	0.079
US TFP growth	1.5%
UK TFP relative to the US	85%
Net present value of existing depreciation allowances on R&D	28.7%

A.1 How Will an R&D Tax Credit Change the Price of R&D?

The standard methodology for measuring the impact of a tax credit on the price of investment is the user cost. This tells us what the impact of the tax credit would be on the price of investing an additional pound in R&D. Let i index countries and t index years. The impact of an R&D tax credit on the price of R&D can be summarised by a user cost of R&D of the following form.

$$p_{it} = \frac{\left(1 - \left(A_{it}^{c} + A_{it}^{d}\right)\right)}{\left(1 - \tau_{it}\right)} \left[r_{it} + \delta\right] \tag{4}$$

where A^c is the net present value of the tax credit, A^d is the net present value of tax depreciation allowances, τ is the statutory tax rate on corporate income, r is the real interest rate and δ is the economic depreciation rate. Bloom, Griffith and Van Reenen (2001) provide estimates of this for the G7 countries plus Australia and Spain for the period 1979-1997.

The net present value of the credit, A^d, will depend on the precise design. The fact that the credit is on incremental expenditure means that, by tying the amount of credit given to the past levels of spending, the value of the credit is reduced. This is because, by spending an extra pound today the firm earns a credit today, but it also reduces the amount of credit it will get in the future. In addition, the fact that the credit is implemented as a deduction means that it is worth the credit rate, c, times the statutory rate, τ. The proposal is also for the base to be indexed by inflation. The net present value of this tax credit is given by the formula

$$A_t^d = c\tau \left[1 - \frac{1}{k} \sum_{i=1}^{k} \frac{(1+\pi)}{(1+r)^i} \right] \tag{5}$$

where we have assumed that R&D grows by at least the rate of inflation in every year, c is the nominal credit rate, π is the inflation rate, r is the firm's discount rate (the real interest rate) and k is the number of years over which the moving-average base is calculated.[17] The credit proposed in the 2001 Consultative document has a two year moving average base, R&D will be indexed by the RPI and is proposed that it will be implemented as a deduction at the rate of 50%. This means that the rate of credit is $c = 0.5 * 0.3 = 0.15$, and we assume that inflation is 5% and the real interest rate is 10%. The net present value of the proposed tax credit is thus

$$A_t^d = 0.15 * [1 - 0.5 * 0.955 - 0.5 * 0.868] \tag{6}$$

$$= 0.013 \tag{7}$$

Using the other parameters set out in Table A.1 this gives a user cost without the tax credit of

$$p_{it} = \frac{(1 - (0 + 0.287))}{(1 - 0.3)} [0.1 + 0.28] = 0.386 \tag{8}$$

and with the tax credit of

$$p_{it} = \frac{(1 - (0.013 + 0.287))}{(1 - 0.3)} [0.1 + 0.28] = 0.379 \tag{9}$$

which gives a change of 1.9% in the user cost of R&D as a result of the R&D tax credit.

[17] See Bloom, Griffith and Klemm (2001), Eisner et al (1984) and Hall (1993).

A.2 How Will R&D Expenditure Respond to a Change in its Price?

An equation for the effect of the price (generally measured as a user cost defined in equation (4) above) on the R&D intensity is given by

$$\ln\left(\frac{R}{Y}\right)_{it} = \theta \ln\left(\frac{R}{Y}\right)_{it-1} - \phi\ln(p_{it}) + \eta_i + S_t + \omega_{it} \tag{10}$$

where R is R&D, Y is value-added, η captures country specific characteristics and S captures common macro shocks. Bloom, Griffith and Van Reenen (2001) estimate such a model using data on a panel of countries and obtain estimates of $\theta = 0.86$ and $\phi = 0.12$ (see Bloom, Griffith and Van Reenen (2001), Table I, Column 4).

Consider the effect of a permanent R&D tax credit that reduces the user cost of capital by $z\%$ in a non-frontier country. The instantaneous effect on the R&D intensity is given by

$$\triangle\ln(R/Y)_{ij} = \phi z\% \ = 0.12z\%. \tag{11}$$

The long-run percentage change in the R&D intensity following the introduction of an R&D tax credit that reduces the user cost of capital by $z\,\%$ is

$$\triangle\ln(R/Y)_i = \left(\frac{\phi}{1-\theta}\right) z\,\% \equiv \Lambda\ \% = \frac{0.12}{0.14} z\,\% = 0.86z\,\%. \tag{12}$$

Equations (8) and (9) suggest that the proposed tax credit will change the user cost by 1.9 percentage points. Plugging this in to equations (11) and (12) yield predictions that the R&D intensity will increase by 0.23% immediately and by 1.6% in the long-run.

A.3 How Will TFP Respond to a Change in R&D Expenditure?

We begin by analysing the effects of the R&D tax credit when R&D only influences TFP growth through the rate of innovation (i.e. there is no effect on the ability to imitate). In this case, total manufacturing TFP growth is given by the empirical version of equation (2)

$$\triangle\ln\widetilde{A}_{it} = \rho\left(\frac{R}{Y}\right)_{ijt-1} + \psi_i + T_t + \varepsilon_{it} \tag{13}$$

where the tilde denotes that we only consider R&D's effect on innovation. ρ gives an estimate of the rate of return on R&D, ψ_i is a fixed effect that controls for unobserved heterogeneity across countries in the determinants of TFP growth, T_t is a vector of time dummies controlling for common macroeconomic shocks, and ε_{it} is a serially uncorrelated error. Griffith, Redding and Van Reenen (2001) obtain an estimate of $\widehat{\rho} = 0.433$. We also use the fact that in the UK, total manufacturing value-added in 1999 was £155bn and Business Enterprise R&D Expenditure (BERD) was £8.78bn.[18] This yields an R&D intensity of 0.057. Plugging these into (13) yields

$$\triangle \ln \widetilde{A}_{it} = 0.025 + \psi_i + T_t + \varepsilon_{it}.$$

With a tax credit we have

$$\begin{aligned}\triangle \ln \widetilde{A}_{it}^{C} &= 0.433 \times \left(\tfrac{R}{Y}\right)_{it} \times (1 + \%\Delta R/Y) + \psi_i + T_t + \varepsilon_{it} \\ &= 0.025\,(1 + \%\Delta R/Y) + \psi_i + T_t + \varepsilon_{it}\end{aligned}$$

where the superscript C indicates the adoption of the R&D tax credit, and $\%\Delta R/Y$ is the increase in R&D intensity measured from (11) or (12). The implied change in TFP growth following the tax credit is thus

$$\triangle \ln \widetilde{A}_{it}^{C} - \triangle \ln \widetilde{A}_{it} = 0.025\,(\%\Delta R/Y)\,. \tag{16}$$

From our calculations above we know that the impact effect of the tax credit is to increase R&D by 0.23% so this gives us an immediate increase in TFP growth of 0.0056%. Note that, because the equation for TFP growth is linear (rather than log linear) in the R&D intensity, the effect of the R&D tax credit on TFP growth depends on the level of the R&D intensity.

We now extend the analysis to allow R&D to also play a role in promoting imitation. In the absence of a tax credit TFP growth is given by equation (3). In the presence of a credit we have

$$\begin{aligned}\triangle \ln A_{ijt}^{C} = {} & \rho_1 \left(\tfrac{R}{Y}\right)_{it-1} (1 + \%\Delta R/Y) + \beta \triangle \ln A_{Ft} - \delta_1 \ln \left(\tfrac{A_i}{A_F}\right)_{t-1} \\ & - \delta_2 \left(\tfrac{R}{Y}\right)_{it-1} (1 + \%\Delta R/Y) \ln \left(\tfrac{A_i}{A_F}\right)_{t-1} + u_{it}.\end{aligned} \tag{17}$$

[18] Manufacturing valued-added is from Table 15.4 of Annual Abstract of Statistics, 1999. Manufacturing BERD is Table 5 in First Release 1999 and equals DLEP plus DLEX.

The difference between these two is given by

$$\triangle \ln A^C_{ijt} - \triangle \ln A_{ijt} = \left[\rho_1 \left(\frac{R}{Y}\right)_{it-1} - \delta_2 \left(\frac{R}{Y}\right)_{it-1} \ln\left(\frac{A_i}{A_F}\right)_{t-1}\right] (1 + \%\Delta R/Y) \,. \quad (18)$$

Griffith, Redding and Van Reenen (2001) estimate $\widehat{\rho}_1 = 0.433, \widehat{\beta} = 0.124, \widehat{\delta}_1 = 0.068, \widehat{\delta}_2 = 1.00$. We use the same initial value for the R&D intensity as above. The increase in the R&D intensity due to the tax credit will affect TFP growth through both rates of innovation and imitation. The second effect depends on a country's distance behind the technological frontier. We assume that TFP in the UK is 85% of the US.

Plugging in these estimates we get an implied change in TFP growth following the tax credit of

$$\triangle \ln A^C_{it} - \triangle \ln A_{it} = 0.034\,(\%\Delta R/Y)$$

With an immediate increase in R&D of 0.23% this gives us an immediate increase in TFP growth of 0.0065%. It is hard to interpret the magnitude of this number. We will show below how it may be converted into an effect of the R&D tax credit on manufacturing value-added. The long-run effect of the R&D tax credit on TFP growth is greater, as R&D gradually responds over time to the change in its user cost.

So far we have assumed that the UK's distance behind the technological frontier is fixed. However, the model above can also be used to solve for steady-state equilibrium levels of relative TFP.

Our model implies that the following first-order difference equation for the evolution of relative TFP

$$\begin{aligned} \triangle \ln \left(\tfrac{A_i}{A_F}\right)_t = \rho_1 \left(\left(\tfrac{R}{Y}\right)_{it-1} - \left(\tfrac{R}{Y}\right)_{Ft-1}\right) + \beta \triangle \ln A_{Ft} \\ - \left(\delta_1 + \delta_2 \left(\tfrac{R}{Y}\right)_{it-1}\right) \ln \left(\tfrac{A_i}{A_F}\right)_{t-1} \\ + (u_{it} - u_{Ft}) \end{aligned} \quad (20)$$

where $u_{it} = +\psi_i + T_t + \varepsilon_{it}$. In steady-state, TFP in all non-frontier countries is an equilibrium distance behind TFP in the frontier, such that all countries exhibit the same rate of TFP growth as the frontier. Steady-state equilibrium relative TFP is

$$\ln\left(\frac{A_i}{A_F}\right)_t^* = \frac{\psi_i + \rho_1\left(\frac{R}{Y}\right)_i^* + T_t - (1-\beta)\triangle\ln A_F^*}{\left(\delta_1 + \delta_2.\left(\frac{R}{Y}\right)_i^*\right)}. \tag{21}$$

Where * denotes the steady-state level of all variables. In steady-state, the increase in R&D will have no effect on the non-frontier's rate of TFP growth (unless it induces a change in the frontier country), but it will affect the steady-state level of relative TFP.

A.4 How Will Output Respond to a Change in TFP?

What is the immediate impact of an increase in TFP on levels of output? Here we use the fact that

$$\triangle\ln Y_{it} = \triangle\ln A_{it} + \left(\frac{\alpha_{it}+\alpha_{it-1}}{2}\right)\triangle\ln L_{it} - \left(1-\left(\frac{\alpha_{it}+\alpha_{it-1}}{2}\right)\right)\triangle\ln K_{it} \tag{22}$$

where Y denotes value-added in total manufacturing, and where the second and third terms on the right hand side are assumed to be invariant to the R&D tax credit. The change in output attributable to the R&D tax credit is

$$Y_{it}^C - Y_{it} = Y_{it}\left(\triangle\ln A_{it}^C - \triangle\ln A_{it}\right) \tag{23}$$

Equation (23) can be used for a cost-benefit analysis of the R&D tax credit based on its instantaneous effect.

To look at the steady-state impact we use the fact that

$$\ln\left(\frac{Y_i}{Y_F}\right)^* = \ln\left(\frac{A_i}{A_F}\right)^* + \ln\left(\frac{F(K_i,L_i)}{F(K_F,L_F)}\right)^* \tag{24}$$

where the second term on the right hand side is assumed to be invariant to the R&D tax credit. If we could observe actual steady-state output without the R&D tax credit, it would be straightforward to calculate the change in steady-state output attributable to the R&D tax credit

$$\ln\left(\frac{Y_i}{Y_F}\right)^{*C} - \ln\left(\frac{Y_i}{Y_F}\right)^* = \ln\left(\frac{Y_i}{Y_F}\right)^*\left[\ln\left(\frac{A_i}{A_F}\right)_t^{*C} - \ln\left(\frac{A_i}{A_F}\right)_t^*\right] \tag{25}$$

Where we again use the fact that equation (24) must hold as an accounting identity. However, since steady-state output in the frontier is unaffected by the R&D tax credit, equation (25) simplifies to

$$\ln Y_i^{*C} - \ln Y_i^* = \ln Y_i^* \left[\ln \left(\frac{A_i}{A_F} \right)_t^{*C} - \ln \left(\frac{A_i}{A_F} \right)_t^{*} \right] \tag{26}$$

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