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Is a Higher Rate of R&D Tax Credit a Panacea for Low Levels of R&D in Disadvantaged Regions?

(Richard Harris[1a], Qian Cher Li [a] and Mary Trainor[b])

[a] *Department of Economics, University of Glasgow, G12 8RT, U.K.*

[b] *School of Management and Economics, Queen's University Belfast, BT7 1NN, U.K.*

Abstract

This paper studies the impact of R&D spending on output as well as forecasting the impact of a regionally enhanced R&D tax credit on the 'user cost' (or price) of R&D expenditure and subsequently the demand for R&D. The example we use of a 'disadvantaged' region is Northern Ireland (partly because it has the lowest levels of R&D spending in the UK, and partly because the necessary data is available for this region). We find that in the long run, R&D spending has a mostly positive impact on output across various manufacturing industries. In addition, plants with a zero R&D stock experience significant one-off negative productivity effects. As to the adjustment of R&D in response to changes in the 'user cost', our results suggest a rather slow adjustment over time, and a long-run own-price elasticity of around −1.4 for Northern Ireland. We also find that to have a major impact on R&D spending in the Province, the

[1] Corresponding author. *Tel.*: +44 (0)1413304672; *fax*: +44 (0)1413301880. *E-mail address:* r.harris@lbss.gla.ac.uk

R&D tax credit would need to be increased substantially; this would be expensive in terms of the net exchequer cost.

JEL codes: L25; R11; R38

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I. Introduction

The expansion of the global economy and the role of technology as a key driver of globalisation have meant that the promotion of science and innovation is now a central tenant of UK industrial strategy (HM Treasury, 2004). Although the importance of R&D investment for innovation and subsequent economic growth has long been acknowledged (see below), there is concern in policy circles about the low levels of business investment by firms in R&D activities particularly at the regional level. Compared with other OECD and EU countries the UK has failed to improve its relative position as regards such investment. Business expenditure on R&D as a proportion of GDP remains below the OECD average and has been declining relative to other OECD countries – in 2003 the UK was ranked 12th whereas in 1993 it was ranked in 8th position (OECD, 2005). An alternative source of information on investment in R&D is provided by the 2005 EU Scoreboard data (EU, 2006). These data show investment in R&D by the top 1 000 EU companies and places the UK 11th out of 15 countries in terms of R&D intensity (investment as a proportion of net sales) and 8th out of 15 when measured as investment per employee. When the analysis is extended to incorporate the top 1 000 non-EU firms in 26 OECD countries[2] these rankings drop to 19th and 15th respectively.

There are a number of benefits from increasing R&D in local, regional and national economies. These include the likely increased level of innovation (both product and process) that would accompany such an increase in the R&D stock, plus an overall increase in firm level capabilities and absorptive capacity, which will have additional positive impacts on productivity through firms being better placed to internalise knowledge from outside the company (e.g. foreign technology transfers). This would increase the ability of firms to benefit more from globalisation as the literature generally shows that increased R&D, linked to greater absorptive capacity, is also associated with greater exposure to internationalisation (as R&D/absorptive capacity reduce entry barriers into international markets) – see Harris and Li (2008) for a review of the literature and empirical evidence of nexus between firm's internationalisation, R&D/ innovation activities, and absorptive capacity. Increased R&D by plants in disadvantaged regions, leading to greater innovation, absorptive capacity, and internationalisation, is likely to create a virtuous circle of further positive impacts on R&D, and therefore a movement upward in the growth path of the region's economy.

The decline in international rankings has occurred despite the efforts of government to provide incentives for firms either to initiate R&D activities or to expand the range of developmental activities that they undertake. If one takes the view that increasing R&D activities at the regional level is directly linked with national interests and certain regions lag behind in terms of R&D investment, then supporting these regions to become more involved in R&D will be to the benefit of the national interest. Following on from this, the question as to the type of policy instrument that is appropriate to

[2] Data on Iceland, Mexico, New Zealand and Turkey was either missing or applied to one firm only.

support R&D at the regional level has to be addressed. There are two main ways in which government can directly influence the level of R&D spending within firms - by directly subsidising such expenditures through grants (and/or loans) or by offering fiscal incentives. Historically in the UK, government has resorted to grant-based schemes, such as national schemes like SMART and SPUR,[3] or regional schemes like R&D grants in Northern Ireland (since 1977) through the operation of Selective Financial Assistance (see Harris et al., 2002). However, in 2000, government introduced a fiscal incentive in the form of a R&D tax credit for SMEs and extended the scheme in 2002 to include large companies. The tax credit is additional to traditional monetary-based inducements, and the rates are uniform across the UK.

The literature that considers the effectiveness of government grants to increase private sector R&D reaches very mixed conclusions. Partly this reflects a concern that direct subsidisation of R&D may have a high deadweight component (as firms free-ride on such subsidies); it also reflects the fact that many government schemes are aimed at longer-term outcomes (including pre-commercialisation R&D spending), rather than projects that generate near-term profits (which are more receptive to fiscal incentives, as discussed below). Thus Busom (2000) for Spain, Lach (2002) for Israel, Czarnitzki and Frier (2002) for Germany, and Kaiser (2004) for Denmark, all report negative (or insignificant) links between R&D subsidies and private R&D expenditures at the firm level. Moreover, surveys by David et al. (2000), Klette et al. (2000) and Harhoff and Fier (2002) also report a wide array of evaluations results.

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[3]That is the Small Firm Merit Awards for Research and Technology programme and Support for Products Under Research programme. See Harris and Robinson (2001, Chapter 3) for a detailed discussion of these schemes.

In contrast, fiscal incentives allow government to finance a portion of the R&D undertaken by firms that qualify automatically through the tax system; and it is argued that they are more likely to favour projects that generate near-term profits. The use of fiscal incentives, such as tax allowances, deferrals or most preferably, tax credits, has become increasingly popular in a number of countries (OECD, 2003), although it has a relatively long history in Canada (back to the early 1960's) and at both the federal and state level in the U.S.[4] There is a broad agreement that tax incentives stimulate R&D (see Hall, 1993, Hines, 1994, and Mamuneas and Nadiri, 1996, for the U.S.; and Bloom et al., 2002, for 9 OECD countries; and also Hall and van Reenen, 2000, for a review of the evidence). For example, Wu (2005) has considered the effect of state R&D tax credits as well as public sector R&D subsidies in the U.S., finding that tax credits have stimulated private R&D spending but public sector R&D subsidies seem to have had no significant effect. Many of the studies covered find long-run R&D price elasticities of around unity, implying that a 10% decrease in the cost of R&D through tax incentives stimulated a 10% increase in the level of R&D in the long-run; however, short-run effects are much lower, implying that the demand for R&D responds very slowly over time to changes in its price.

The literature suggests that a tax credit policy will bring benefits at the national level but if it is applied at a uniform rate then there will be different effects across regions. In relation to R&D tax credit as a policy tool, Howells (2005) noted that "….it

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[4] R&D tax credits were first introduced at the federal level in 1981, followed closely by Minnesota and by 1996, 17 states offered R&D tax credits. It is argued in the U.S. that the state schemes are put into place to capture spillovers that only feature locally, based around clusters of R&D intensive industries which can then be encouraged to further grow through R&D tax credits that might induce inward investment of firms in these industries (see Hall and Wosinska, 1999, with respect to the Californian R&D tax credit scheme).

will be the successful core regions with high concentrations of R&D activity that will benefit most …By contrast, disadvantaged regions will benefit least from such a measure.”(p. 1225).

This paper investigates the use of tax credits to raise the level of R&D investment in a disadvantaged region (Northern Ireland[5]) and models the impact of applying differential rates. Given that panel micro-data is required to consider the relationships between R&D and productivity, as well as R&D and fiscal incentives, few (if any) studies have been undertaken at the sub-national level in the UK (or elsewhere). Moreover, Northern Ireland is an instructive case study in that business spending on R&D is relatively low compared to average spending in the UK as a whole. Data from the 2005 Community Innovation Survey shows that in terms of the amount spent on R&D per employee, the Northern Ireland figure was £766 per employee (or 39.4% of the UK level of expenditure per employee) for manufacturing and £140 per employee (or 21.6% of the UK level) for services.[6] Across all sectors, the CIS data shows that Northern Ireland spent £236 per employee on R&D compared to £921 per employee in the UK, or 25.6% of the UK level of expenditure. The next lowest spending region in the UK was the North East with spending of 51.5% of the average UK figure. Northern Ireland also has a long history of generous publicly-funded support for industry which has produced mixed results (Harris, 1991a; Harris and Trainor, 1995) and the agencies responsible for allocating support have a certain degree of autonomy that do not exist in

[5] Gross value added per head in Northern Ireland was only 80% of the UK average during the 1991-2003 period (with a standard deviation of 1.3% suggesting that there was little evidence of convergence).

[6] The other major source of information on R&D spending (the Business Enterprise R&D – or BERD – survey carried out annually in the UK) shows that in 2004 business R&D divided by gross value-added was 0.5% in Northern Ireland, compared to 1.2% for the UK (with both of these percentages well below the 3% of GDP target set by the Lisbon Agenda for the EU by 2010).

the national agencies. In addition, the use of the fiscal system to stimulate investment is currently under discussion in policy circles as politicians negotiate with the Treasury to agree a financial settlement to accompany an acceptable political agreement.

The next section describes the model that is estimated to determine the relationship between R&D and productivity. Section III discusses the dataset that was constructed for the estimation. Section IV discusses the impact of R&D on productivity before considering (in Section V) the impact of an enhanced R&D tax credit on productivity. The paper concludes with a discussion on the implications for policy and related issues.

II. The Model

The model that is used to estimate the impact of business R&D on firm-level productivity is based on the notion of the 'knowledge production function' as developed by Griliches (1980), whereby usually a simple Cobb-Douglas production function is extended to include the R&D capital stock (the firm's stock, and in some studies other firms' R&D stocks to capture spillover effects).[7] Wieser (2005) has recently provided an extensive review of this literature.

Starting with the following log-linear version of the augmented Cobb-Douglas production function:

$$y_{it} = \alpha + \beta_1 k_{it} + \beta_2 n_{it} + \beta_3 m_{it} + \beta_4 rd_{it} + \beta_5 ex\_rd_{it} + \lambda t + \upsilon_{it} \qquad (1)$$

[7] An alternative approach considers the 'two faces of R&D' concept introduced by Cohen and Levinthal (1989), whereby R&D has a direct and an indirect impact on TFP (e.g. Griffith et al. 2004; Cameron et al. 2005). We have not used this approach as we are not including frontier TFP estimates from outside Northern Ireland and thus not directly including 'catch-up' effects.

where lower case terms denote (natural) logarithms, y is output, k is capital stock, n is labour, m is intermediate inputs, rd is the stock of R&D, ex_rd is the stock of external R&D (to capture spillovers), t represents time (technical progress), and υ represents all other impacts (including panel data influences), for plant/firm i in year t. The primary interest when estimating Equation (1) is usually the size of the output elasticity associated with the stock of R&D (i.e. $\hat{\beta}_4$), together with the elasticity of output with respect to spillovers (i.e. $\hat{\beta}_5$). Some researchers have preferred to estimate (1) in dynamic form in order to 'net out' the influence of individual plant/firm fixed effects:

$$\Delta y_{it} = \lambda' + \beta_1' \Delta k_{it} + \beta_2' \Delta n_{it} + \beta_3' \Delta m_{it} + \beta_4' \Delta rd_{it} + \beta_5' \Delta ex\_rd_{it} + \Delta \upsilon_{it} \qquad (2)$$

but Equations (1) and (2) are not equivalent as the latter only allows for short-run impacts.[8] Moreover, many empirical versions of (2) substitute R&D spending per unit of sales for changes in the R&D stock:

$$\Delta y_{it} = \lambda' + \beta_1' \Delta k_{it} + \beta_2' \Delta n_{it} + \beta_3' \Delta m_{it} + \rho_1 (R/Y)_{it} + \rho_2 (EXR/Y)_{it} + \theta_{it} \qquad (3)$$

where R and EXR refer to (real) expenditures on R&D by the plant/firm and the spillover pool under consideration, respectively. The parameters ρ_1 and ρ_2 now represent the gross excess rate of return on (or marginal productivity of) internal and external R&D, rather than elasticities, since knowledge depreciation is not controlled for (see Schankerman, 1981).

Studies which have estimated (1) using either cross-section or panel data at the firm level include Griliches (1980), Schankerman (1981), Cuneo and Mairesse (1984), Griliches and Mairesse (1990), Griliches (1986, 1995), Jaffe (1986), Hall and Mairesse (1995), Cincera (1998), Smith et al. (2004), Tsai and Wang (2004), and Aiello and

[8] Equation (1) when estimated using a dynamic specification will encompass both long- and short-run impacts, where long-run effects cannot be recovered from Equation (2).

Cardamone (2005). These studies cover a number of countries and time periods. The overall mean value of the size of the output elasticity associated with the stock of R&D (i.e. $\hat{\beta}_4$) is around 0.12 (ranging from 0.01 to 0.29 across the studies). A recent study by Kafouros (2005) using firm-level UK data finds that the contribution of R&D to productivity over the 1989-2002 period was only 0.04 (i.e. a doubling of the R&D stock would have raised output by 4%). Studies which have estimated (2) include Griliches (1980), Cuneo and Mairesse (1984), Griliches and Mairesse (1983), Mairesse and Cuneo (1985), Hall and Mairesse (1995), and Cincera (1998). These studies also cover a number of countries and time periods. The overall mean value of the size of the output elasticity associated with the stock of R&D (i.e. $\hat{\beta}'_4$) is around 0.18 (ranging from 0.03 to 0.38 across the studies). Thus in general, short-run estimates tend to be rather higher than long-run estimates.

Studies that have estimated rates of return include Mansfield (1980), Link (1983), Griliches and Mairesse (1983, 1990), Odagiri (1983), Odagiri and Iwata (1986), Goto and Suzuki (1989), Hall and Mairesse (1995), and Cincera (1998). Covering a number of periods and countries, the overall mean value of the size of the rate of return associated with R&D spending (i.e. $\hat{\rho}_1$) is around 28.3 (ranging from 7.0 to 69.0 across the studies).

Firm level studies using similar models to that set out in Equations (1) and (2) that have estimated the impact of spillovers include Jaffe (1989), Antonelli (1994), Raut (1995), and Cincera (1998). Covering a number of periods and countries, the overall mean value of the size of the output elasticity associated with the external stock of R&D (i.e. $\hat{\beta}_5$ or $\hat{\beta}'_5$) is around 0.45 (ranging from -0.31 to 1.46 across the studies). This would imply that spillover effects associated with R&D are much larger on average than the direct benefits to a firm of its own R&D stock. However, there is much more variation across the studies that cover spillovers, suggesting that different methodologies, and the greater difficulties with accurately measuring spillover effects, render the measurement of spillovers as significantly more imprecise and open to bias. For example, some studies have found that the impact of the own firm's R&D stock was much higher than the effect on productivity of external R&D stocks (e.g. Aiello and Cardamone, 2005, report a ratio of 4.5:1, while this ratio in Tsai and Wang, 2004, is closer to 4:1).

As stated at the beginning of this section, our approach to modelling is to try to capture the impact of business R&D on firm-level productivity using the 'knowledge production function' approach, with non-pecuniary spillover effects measured via the R&D stocks of *other* firms. There is a large literature on the role played by such non-pecuniary factors; for example, the 'innovation systems' approach (e.g. Cooke, 1997) argues that all aspects of the regional *system* affect the ability to exploit external knowledge such that the institutional environment acts directly as a generator of collective synergies and externalities (cf. Dosi et al., 1988; Freeman and Soete, 1997). So whereas earlier work was focused on spillovers between firms, the systems approach emphasises the (face-to-face) connections between individuals. Knowledge diffusion primarily emerges by means of social contacts, and social networks can play a key role.[9] As argued by Putnam (2000), this results in social capital, based on relationships of trust in the reciprocity of shared knowledge, which increases the flow of knowledge within the social network and boosts "localized knowledge spillovers" (Feldman, 1999). The emphasis is on "untraded interdependencies" (Storper, 1997) between economic agents, including firms that are 'deep' or 'thick' in some regions, 'thin' or 'shallow' in others

[9] This is particularly emphasised in studies of industrial districts (e.g. Piore and Sabel, 1984; Garnsey and Connon-Brookes, 1993; Saxenian, 1994; Gottardi, 1996).

(Lawson, 1999). Our difficulty with taking into account this broader approach is that most of the evidence supporting the existence and importance of such systems is case-study based[10] and thus does not lend itself easily to econometric analysis. Attempts to test its applicability more widely (e.g. Crescenzi, 2005) are usually forced to use general, inadequate proxies and the results do not necessarily support or reject the relevance of the approach.[11]

III. The Data

The dataset used in this study has been constructed from merging the BERD[12] and ARD[13] data for the period 1998-2003. The unit of measurement for the ARD is that of

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[10] In addition, it is largely descriptive often amounting to the mapping of the innovation system (e.g. Figure 2 in Cooke et al., 2003) and then 'informed' discussion of the strength of linkages and where the system is weakest.

[11] Crescenzi (*op. cit.*) states: "… the need for a feasible specification of the innovative process, which inevitably implies some simplistic assumptions, must not hide the complexity of the real world as represented by the systems approach". Effectively, he argues that the results need to be seen through the 'lens' of the systems approach, rather than his model providing any evidence for/against it.

[12] The Business Enterprise Research and Development annual data can be linked to the ARD at the level of the establishment (or reporting unit). Note, we include both intra- and extra-mural spending from the BERD data. Thus in-house R&D and R&D undertaken by another firm are both included for the beneficiary concerned.

[13] The Annual Respondents Database basically comprises financial information collected by the ONS, including information on sales, purchases of inputs, ownership, location, etc. Capital stock estimates at the plant level have been computed (and updated) based on Harris and Drinkwater (2000). Importantly, the financial data are weighted to obtain estimates that are representative of the population of UK establishments/plants.

the plant (i.e. local unit). Total capital expenditure data for each manufacturing plant (1998-2003) was disaggregated into the share spent on plant and machinery, converted to real prices, and then linked to historic plant level real expenditure on plant and machinery for manufacturing covering 1970-1998.[14] The 1970-1998 data were available from a previous study (Harris et al., 2002), and the full 1970-2003 information (together with pre-1970 benchmark data) was used to calculate the plant and machinery capital stock for each plant based on the methods set out in Harris and Drinkwater (2000) and Harris (2005).

BERD data for 1993-2003 contained information on R&D spending in Northern Ireland, which made possible the calculation of an R&D capital stock for each plant.[15] The depreciation rates used to calculate the R&D capital stock were taken from Bloom et al. (2002), and four assets were used (with different depreciation rates) which then added together to give the total R&D stock. These four assets are (with the depreciation rates included in parentheses): intra-mural current spending (30% p.a.); plant &

[14] Data for non-manufacturing in the ARD is only available from 1997 and therefore only manufacturing plants can be analysed using plant and machinery capital stock information. Note, during 1998-2003, manufacturing accounted for 82% of the total R&D capital stock in Northern Ireland.

[15] Note, nominal R&D spending is converted to real spending using the implied GDP deflator (which is the standard approach in the UK, as no separate deflator for R&D is available). This may lead to some overestimation of the growth of the real knowledge stock, as the R&D inflation is likely to be relatively higher. Also, for multi-plant firms the R&D stock calculated from BERD can cover more than one plant located in Northern Ireland (GB plants are not included) as BERD data refers to reporting units (which are usually sub-groupings of the firm). Here, we allocated the stock back to each plant based on the relative shares of employment of each plant in total employment for the reporting unit (i.e. larger plants get a larger ‘share’ of the R&D stock). The number of multi-plant reporting units where we resorted to this ‘allocation’ approach is small, so we do not expect any major impact on our reported results.

machinery R&D spending (12.64% p.a.); spending on buildings (3.61% p.a.); and extra-mural spending (assumed 30% p.a.). Since on average 90% of R&D spending in Northern Ireland was current spending, then using data from 1993 to calculate the 1998-2003 capital stock is sufficient given the service life of such assets. Much longer time series are needed for plant & machinery and buildings R&D investment in order to be able to accurately measure the stock of such assets, but since they only accounted for some 10% of spending, the R&D stock as measured here is assumed to be adequate.

Having obtained estimates of R&D capital stock for plants in operation during 1998-2003, this data was then merged with the manufacturing ARD database described above to form the merged BERD-ARD to be used in this study.

IV. Productivity Impact of R&D

Firstly, we consider the impact of R&D spending on output from the supply-side, by estimating the 'knowledge' production function (cf. Equation (1) above) using Northern Ireland 1998-2003 plant level data for different industries. Note, the R&D stock for each plant was entered in log-form, and therefore this variable had to be entered as (1 + R&D stock).[16] To account for any bias from converting the R&D stock in this way, a separate dummy variable was entered (denoted 'No R&D') which took on a value of 1 if the plant's R&D stock equalled zero. Separate equations were estimated for each industry covered, and the 'knowledge' production function was enhanced to include other aspects of total factor productivity. These additional TFP effects included the age of the plant; location of the plant in terms of a sub-regional breakdown of Northern

[16] Thus, plants with a zero R&D stock returned a value of zero using the variable *ln* (1 + R&D stock).

Ireland; ownership of the plant (including GB-owned plants); whether the plant was a single-plant enterprise; and whether it was an SME.

We employed two approaches to incorporate spillovers from R&D: one measure (designated NI R&D and designed to pick up local intra-industry spillovers) comprised the sum of R&D stocks for Northern Ireland plants in the same 2-digit industry group, and the other (labelled UK R&D and designed to cover UK-wide intra-industry spillovers) comprising the UK R&D stock in the same 2-digit industry. The definition of industry group differed for these two measures because of the differences in industrial structure (including which sectors undertook R&D) between the Province and the UK, and data availability (e.g. the UK data is based on the industry sub-groups used in the published Business Monitor MA14 reports for the UK). Neither of these measures is ideal, and we have tried other approaches such as calculating R&D stocks for Northern Ireland for each 2-digit sector sub-divided into 5 major sub-regions (based on travel-to-work areas). The latter measure recognises more explicitly the likely decay of external technological information with distance[17], but it proves no more significant in the results that follow and is therefore dropped in favour of the Province-wide measure. Rather than spillovers accruing to all plants, we have also experimented by entering the relevant spillover measures multiplied by a plant's R&D stock (e.g. *ln* (NI R&D) × R&D stock can be used instead of the *ln* (NI R&D) measure). This potentially allows the absorption of external R&D to be proportionate to the amount of accumulated R&D in the plant, with the expectation that plants that have a larger own R&D stock have a

[17] See for instance, Caniels (2000); Verspagen and Schoenmakers (2004); Cantwell and Piscitello (2005).

greater ability to internalise any spillovers from external R&D that takes place in the same industry and/or location.[18]

With respect to other factors impacting on firm's output, a regional dimension is added to this model, as there is a growing body of literature (referred to in Section II) on regional innovation systems underpinned by the role of knowledge (tacit knowledge in particular) and the notion of the 'learning region' (Cooke and Morgan, 1994; Howells, 2002; Oughton et al., 2002; Cooke et al., 2003; Asheim and Gertler, 2005). Moreover, ownership characteristics have also been taken into account, as they have previously been found to be very important in determining firm's R&D activities in Northern Ireland (Harris, 1991b; Harris and Trainor, 1995). This augmented production function is estimated for 11 distinct industries, as the variation in technological characteristics amongst different sectors has been well-documented in existing studies (e.g. Frenkel et al., 2001; Shefer and Frenkel, 2005).

All the variables used to estimate Equation (1) are set out in Table A.1 (in the Appendix). We have estimated this equation using (stepwise) panel data methods and a more general specification than just fixed effects. That is, the error term in Equation (1) comprises three elements:

$$\upsilon_{it} = \eta_i + t_t + e_{it} \qquad (5)$$

with η_i affecting all observations for cross-section unit *i*; t_t affects all units for time period *t*; and e_{it} affects only unit *i* during period *t*. If e_{it} is serially correlated such that:

$$e_{it} = \rho e_{it-1} + u_{it} \qquad (6)$$

[18] We also experimented using the R&D stocks of industry groups to which the plant did not belong, to allow for cross-sector spillovers (weighting these using UK I-O data), but the results were insignificant.

where u_{it} is uncorrelated with any other part of the model, and $|\rho| < 1$, then Equation (1) can be transformed into a dynamic form involving first-order lags of the variables and a well behaved error term (see Griffith, 1999, Equations 6-8).

To allow for potential endogeneity of the plant & machinery capital stock, employment, (real) intermediary inputs and R&D, it is appropriate to use the General Method of Moments (GMM) systems approach available in DPD98 (Arellano and Bond, 1998), since this is sufficiently flexible to allow for both endogenous regressors (through the use of appropriate instruments involving lagged values – in levels and first differences – of the potentially endogenous variables in the model) and a first-order autoregressive error term.

The full results for each of 11 industry groups are presented in Table A.2 (in the appendix). In terms of model diagnostics, the results show that the instruments used are appropriate (cf. the Sargan (χ^2) test of over-identifying restrictions), and there is no evidence of second-order autocorrelation.[19] In addition, since statistically insignificant regressors have been dropped from each model, it is important to note that the test that the slope coefficients for omitted variables are jointly equal to zero cannot be rejected.

[19] Tests for the first-differenced residuals are reported here, thus there should be evidence of significant negative first-order serial correlation and no evidence of second-order serial correlation in the differenced residuals.

Table 1: Long-run estimates of Equation (1) for Northern Ireland Industry Groups, 1998-2003 (dependent variable: *ln* real gross output)

Industry (SIC)	Food & drink (15)		Textiles (17)		Clothing (18)		Chemicals (24)		Rubber & plastics (25)		Non-metallic minerals (26)	
	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value
ln $capital_t$	0.119	2.76	0.134	2.35	0.180	3.59	0.209	2.50	0.131	2.76	0.091	1.88
ln $employment_t$	0.135	2.09	0.279	6.51	0.433	7.94	0.433	13.59	0.268	2.16	0.340	2.71
ln intermediary $inputs_t$	0.947	64.33	0.712	18.26	0.712	12.18	0.591	18.83	0.668	33.27	0.782	7.37
ln Age_t	0.097	2.28	-0.106	-3.27	–	–	–	–	–	–	–	–
ln $R\&D_t$	0.166	2.78	–	–	0.026	2.27	0.077	1.65	0.031	2.13	0.041	2.16
No R&D	-0.460	-3.07	–	–	–	–	-0.073	-3.01	-0.204	-2.25	–	–
North/North West	–	–	0.111	3.14	–	–	0.160	1.19	–	–	–	–
South	–	–	–	–	–	–	–	–	–	–	–	–
West	–	–	–	–	–	–	–	–	–	–	–	–
Mid-Ulster	–	–	–	–	–	–	–	–	–	–	–	–
US-owned	–	–	0.530	2.26	–	–	–	–	-0.261	-2.86	–	–
GB-owned	–	–	–	–	-0.213	-1.42	–	–	–	–	–	–
Single plant	0.201	3.80	–	–	0.349	2.01	–	–	–	–	–	–
SME	-0.121	-2.42	–	–	–	–	–	–	–	–	–	–
ln $(NI\ R\&D)_t$	–	–	–	–	–	–	-0.114	-4.81	–	–	–	–
ln $(UK\ R\&D)_t \times R\&D_t$	–	–	–	–	–	–	–	–	–	–	–	–
ln $(UK\ R\&D)_t$	–	–	–	–	–	–	–	–	–	–	–	–

See Table A.2 for details. Note all variables were entered for each industry sub-group, with non-significant regressors then omitted.

Table 1 (cont.)

	Fabricated metals (28)		Machinery & equipment (29)		Electrical & precision (30-33)		Motor vehicles & other transport (34-35)		Other manufacturing	
	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value
ln $capital_t$	0.187	3.15	0.167	12.00	0.316	5.19	0.382	9.13	0.165	2.72
ln $employment_t$	0.571	9.97	0.396	21.01	0.421	8.13	0.285	5.81	0.245	10.60
ln intermediary $inputs_t$	0.558	43.54	0.452	17.00	0.262	2.78	0.285	5.47	0.713	42.99
ln Age_t	–	–	-0.185	-7.47	–	–	–	–	–	–
ln $R\&D_t$	0.028	3.85	0.029	1.72	0.131	2.53	0.047	5.84	0.054	1.62
No R&D	–	–	-0.035	-3.16	-0.145	-2.63	-0.132	-8.11	-0.232	-1.72
North/North West	–	–	–	–	–	–	–	–	-0.081	-4.28
South	–	–	–	–	–	–	–	–	-0.061	-3.04
West	–	–	–	–	–	–	–	–	-0.053	-2.74
Mid-Ulster	–	–	–	–	–	–	–	–	-0.058	-3.24
US-owned	–	–	0.235	1.89	–	–	–	–	–	–
GB-owned	–	–	0.190	2.09	–	–	–	–	–	–
Single plant	–	–	–	–	–	–	–	–	–	–
SME	–	–	–	–	–	–	–	–	-0.154	-4.64
ln (NI $R\&D)_t$	–	–	–	–	–	–	–	–	–	–
ln (UK $R\&D)_t \times R\&D_t$	–	–	0.002	2.16	–	–	–	–	0.012	4.71
ln (UK $R\&D)_t$	–	–	–	–	–	–	0.085	2.84	–	–

Since we are more interested in the steady-state (i.e. equilibrium, long-run) results, these are presented in Table 1[20]. The key variables in this study are the impact of the R&D stock and R&D spillovers on output. The R&D stock had a positive impact on output in every industry except the Textiles sector; the result of a 10% increase in the R&D stock ranged from a 0.3% increase in output in Clothing through to a 1.7% increase in the Food & Drink sector. In addition, plants with a zero R&D stock experienced significant one-off negative productivity effects, ranging from –7% in Chemicals to –37% in Food & Drink[21] (although there was no significant effect in the Textiles, Clothing, Non-metallic Minerals, and Fabricated Metals sectors).

Spillover effects were largely absent.[22] In the Chemicals sector a 10% increase in the Northern Ireland R&D stock for that sector *reduced* plant level productivity by some 1.1%, suggesting that spillover effects were negative. This could possibly be explained by a tendency for Northern Ireland plants in this sector to 'free-ride' on the back of other firms R&D; or more generally, by the low absorptive capacity among firms in Northern Ireland, in terms of learning and assimilating externally acquired knowledge, which is documented in Harris et al. (2006). There was a very small (but significant) positive spillover from UK R&D in the Machinery & Equipment sector, but this benefited only those plants in the Province that had matching levels of absorptive capacity. In Motor Vehicles & Other Transport, a 10% increase in the UK

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[20] The short-run (i.e. dynamic) results in Table A.2 show that when there are changes in the right-hand-side variables in the model, gross output adjusts relatively fast over time to a new steady-state. Output adjustment in the Rubber & Plastic sector takes about 1.15 years, while adjustment in the Electrical & precision sector takes just under 2 years. Here the speed of adjustment is calculated as $1/[1 - \hat{\beta}$ (*ln* gross output$_{t-1}$)].

[21] The impact of dummy variables is obtained as $e^{\hat{\beta}} - 1$.

[22] An alternative explanation could be that our attempts to measure spillover effects were too crude, but lack of data prevented a more sophisticated approach.

R&D stock resulted in a 0.9% increase in productivity through spillovers, and in Other Manufacturing, plants with absorptive capacity also experienced a 0.1% increase in productivity for a 10% increase in the UK R&D stock relevant to this sector.

With regard to the impact of the other variables in Equation (1), returns-to-scale (obtained by summing the output elasticities across factor inputs) were greater than 1 in all sectors; 'age' effects were not very important overall (although older plants in the Textiles and Machinery & Equipment sectors experienced lower productivity the older the plant vintage); location effects were mostly absent (with location in the North/North West imparting some positive effects for the Textiles and Chemicals sectors, while Other Manufacturing had lower productivity outside of the benchmark sub-region of Belfast); being US-owned had a significant positive productivity effect in the Textiles and Machinery & Equipment sectors (resulting in *cet. par*. between 26-70% higher output levels) but a negative impact in Rubber & Plastics (23% lower productivity); GB-owned plants did worse in the Clothing sector but better in Machinery & Equipment; single plant enterprises had higher productivity in Food & Drink and Clothing; and SMEs had lower productivity in Food & Drink, and Other Manufacturing.

V. Impact of R&D Tax Credit on Productivity

Having found that the R&D stock impacts positively on output in Northern Ireland manufacturing, we now consider the impact of an enhanced R&D tax credit on the 'user cost' (or price) of R&D expenditure and then the relationship between the 'user cost' and the demand for R&D (see Equation (7) below).[23] This will help to establish

[23] A brief introduction to the R&D tax credit scheme in Northern Ireland is available in the appendix.

how firms respond to any change in the cost of undertaking R&D through a reduction in its price.

Following Bloom et al. (2002, Equation 2.10) and Griffith et al. (2001, Equation A.6), it is possible to measure the own-price elasticity of R&D (ϕ) with respect to its price based on:[24]

$$\ln RD_{it} = \theta \ln RD_{it-1} - \phi \ln p_{it} + \alpha \ln Y_{it} + \varepsilon_{it} \qquad (7)$$

where i refers to plant and t refers to year; RD is the stock of R&D; Y is output; p is the 'user cost' of R&D; and ε captures other effects (including panel data influences).

The 'user cost' (or price) of R&D to a firm is defined as:

$$p_{it} = \sum_{j=1}^{3} \omega_{jt} \frac{1-(A_{ijt}^{c} + A_{ijt}^{d})}{1-\tau_{it}} (r_{it} + \delta_{j}) \qquad (8)$$

where j refers to the three assets covered (qualifying current expenditure, and spending on land & buildings and on plant & machinery); ω refers to the relative amount spent on each asset; τ is the corporation tax rate on profits; A^{c} is the net present value of the tax credit (which as Bloom et al., 2002, show is simply equal to the tax credit rate, τ^{c}, when a volume based scheme is used)[25]; A^{d} is the net present

[24] This equation can be derived from a CES production function which includes *RD* as an additional factor input. Note, many empirical models substitute R&D spending for the stock variable, *RD*, on the grounds that they do not have adequate measures of the stock. If R&D spending is used, it is presumed that in the steady-state *RD* is proportional to the flow of R&D investment (i.e. in equilibrium ΔRD = 0, thus net R&D spending equals δ′RD, where δ is the R&D stock depreciation rate). This is clearly an approximation, and estimating (7) using *RD* is preferable when data permits.

[25] Tax credit schemes can cover all expenditure in a given year (and thus subsidise not just marginal spending – which can be argued to be an expensive approach since a tax credit scheme is presumably wanting to boost marginal R&D spending), or only incremental spending. How the base is calculated when incremental spending only is covered (and whether the credit is capped – as in France) will impact on how the net present value of the credit is calculated. See Bloom et al. (op cit.) and Bloom et al. (2001) for details.

value of tax depreciation allowances (for straight-line depreciation $A^d = \tau\phi$, where ϕ is the value of the depreciation allowance on qualifying capital expenditures); r is the internal rate of return to the firm (in common with others we assume this to be a 0.1, or 10%); δ is the economic deprecation rate; and ω refers to the proportion of R&D spending for plant i in year t that is spent on asset j.

The values used in this study to calculate the ‘user cost’ (in Equation (8)) are set out in the appendix. We estimate that the introduction of 50% R&D tax credits in 2001 for SME’s reduced the ‘user cost’ for this sub-group of firms by 8.9% (in 2002 the scheme was extended to larger firms at the rate of a 25% credit, which lowered the ‘user cost’ of R&D by 9.7%[26]). To measure the impact of the ‘user cost’ of R&D (i.e. the price) on the demand for R&D, we have estimated Equation (7) using our matched BERD-ARD data for Northern Ireland manufacturing covering the 1998-2003 period. The estimation procedure is similar to that employed in estimating the production model (Equation (1)); that is, the DPD system GMM panel estimator. R&D, the user cost and output are treated as potentially endogenous and are instrumented using lagged values – in levels and first differences – of each variable (all other variables in the model are predetermined and form their own instruments).[27]

[26] Larger firms benefited more since their corporation tax rate was 1½ times higher.

[27] As pointed out by a referee, plants with a zero R&D stock (omitted from this demand model) may react differently to changes in the ‘user cost’ of R&D vis-à-vis those with a positive stock and thus sample selection potentially may bias the estimate of ϕ. Hence we have tried an ‘ad hoc’ approach whereby we estimate a first-stage probit with a R&D dummy (coded 1 if R&D > 0; and 0 if R&D = 0), regressed on size, industry, location, age, and ownership variables; we calculate the first-stage predicted values of the probability of having a non-zero R&D stock, with the second stage estimation of our demand for *ln* R&D equation also including the sample selectivity correction term from the first-stage model. We find that including this term actually has little impact on the estimated value of ϕ obtained.

Table 2: Demand for R&D in Northern Ireland manufacturing, 1998-2003

	Short-run model		Long-run model	
	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value
ln R&D stock$_{t-1}$	0.846	79.62	–	–
ln user cost$_t$	-0.528	-6.11	-1.365	-3.18
ln user cost$_{t-1}$	0.317	3.44	–	–
ln gross output$_t$	0.045	2.95	0.291	2.68
—”— × Food & drink (15)	0.083	3.38	0.537	3.21
—”— × Chemicals (24)	0.192	4.90	1.242	4.55
—”— × Rubber & plastics (25)	0.098	2.37	0.633	2.25
—”— × Fabricated metals (28)	0.093	2.18	0.604	2.13
—”— × Machinery & equipment (29)	0.083	2.28	0.539	2.19
—”— × Electrical & precision (30-33)	0.134	4.88	0.865	4.49
—”— × Motors & other transport (34-35)	0.085	2.64	0.553	2.56
constant	-0.431	-4.98	-2.791	-5.08
Restricted (β= 0) χ^2 (P-value)	19.10	[0.209]		
Sargan test χ^2 (P-value)	19.04	[0.122]		
AR(1) (P-value)	-3.99	[0.001]		
AR(2) (P-value)	0.55	[0.582]		
R^2	0.98			
No. of observations	2,063			
No. of units	563			
instruments	Δt−1, t−2			

Note year dummies were included but are not reported.

The results from estimating the dynamic version of Equation (7), covering all industries but allowing the impact of output to vary by (2-digit) industry, are presented in Table 2.[28] In terms of model diagnostics, the results show that the instruments used are appropriate (cf. the Sargan (χ^2) test of over-identifying restrictions), and there is no evidence of second-order autocorrelation. In addition, the test that the slope coefficients for the composite dummies for those industries not shown are equal to zero cannot be rejected.

[28] Various modelling permutations were tried, including separate models for each industry and allowing the ‘user cost’ term to vary across industries. The results reported here were the ‘best’ obtained.

The short-run (i.e. dynamic) results show that when there are changes in the 'user cost' or output, the stock of R&D adjusts very slowly over time. Given the value of the lag of R&D stock, the results imply that full adjustment to the equilibrium takes about 6.5 years. In terms of the long-run (equilibrium) results, the own-price elasticity of R&D (ϕ) with respect to its price is found to be −1.36, which is not very different to a value of −1.088 reported by Bloom et al. (2002, Table 1) using UK data. Thus, taking the estimate of the Northern Ireland elasticity and the fall in the 'user cost' of around 11% associated with the introduction of enhanced tax credits (in 2001), this implies that (*cet. par*.) the long-run R&D stock should rise by 15% in the Province.[29] The short-run impact is much smaller (only about a 2.3% rise p.a. assuming nothing else changes).

The long-run elasticity of R&D with respect to output demand is low (at 0.291) for those industries not explicitly included in Table 2 (through composite dummy variables). The figure obtained for the UK by Bloom et al. (op cit.) was 1.083, which is comparable to the results we obtain for the Rubber & Plastics, Fabricated Metals, Machinery & Equipment, Electrical & Precision and Motors & Other Transport sectors. By contrast, we find that the output elasticity is much higher for the Chemicals sector (which is dominated by pharmaceuticals) where the long-run value obtained is 1.533 (i.e 0.291+ 1.242).

Having established how much output is increased by R&D spending (in Section IV), and how responsive such spending is to changes in the price of R&D, it is now possible to provide an overall assessment of whether there is a case for a higher rate of R&D tax credit in Northern Ireland. To determine whether an enhanced R&D tax credit would likely have a positive impact on economic activity (i.e. production), we

[29] This assumes that all eligible firms claim the tax credit and that there is no deadweight (the latter occurs when the increase in R&D is less than it would be if tax credits were fully incorporated into the 'user cost' term).

have used the results presented in Tables 1 and 2 to predict the outcome for the economy of the following overall scenario: an increase in the R&D tax credit for SMEs from the current 50% to 100% (and an increase for larger firms from 25% to 50%). These changes would lower the 'user cost' as at 2003 by 12.4% for all manufacturing plants (a 11.2% fall for larger firms and a 12.5% fall for SMEs).[30] Based on our results for the impact of the 'user cost' of R&D on the demand for R&D, in the long-run this would result in a rise in the demand for the R&D stock by nearly 16.9% (in the short-run the initial effect in year 1 would be an increase in demand of 2.6%). Of course, we are imposing no supply-side constraints on the ability of the economy to respond to such large increases in demand, and our results are based on the underlying assumption that the supply of qualified R&D workers would be sufficient to meet demand..

In terms of the output effect (i.e. the supply-side response) of this fall in the price of R&D, this could simply benefit those plants already doing R&D (i.e. the effect only comes through the *ln* R&D term in Table 1); alternatively, plants not undertaking R&D may now find it 'worthwhile' to carry out R&D. Evidence for this is harder to come by using the BERD-ARD dataset; however, Harris et al. (2006), show that during 1998-2000 in Northern Ireland manufacturing, the cost of finance was a barrier to undertaking R&D and that receiving public sector support had a significant effect on the likelihood of R&D being non-zero. Therefore, we amend our overall scenario and assume two variations in terms of the impact on productivity of a fall in the price of R&D: (i) only plants undertaking R&D benefit; and (ii) the fall in price induces an additional 10% of plants to start spending on R&D. Under (i), to calculate this impact

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[30] This is obtained using Equation (8) and the values set-out in the Appendix but with the A^c term changed to 0.5τ (larger firms) and 1.0τ (SME's) for 2003; the new values for the 'user cost' for 2003 are then compared to the original values to obtain the estimates of the fall in the user cost that would result from enhancing the tax credit. Note, despite the larger increase in the enhanced tax credit for SME's, they face a much lower corporation tax rate and thus the tax credit is 'worth' less.

for each plant we have simply multiplied gross output by the *ln* R&D parameter estimate in Table 1 and multiplied this result by 0.159 (i.e. the increase in R&D stock) and then added the result to actual gross output. Different industries have different effects given their different *ln* R&D parameter estimates. Under (ii), this impact is Scenario 1 plus multiplying gross output by the exponential of the 'No R&D' parameter estimate minus 1, and multiplying this result by 0.1 (reflecting 10% of plants benefit – here we have assumed for simplicity all plants benefit by 10% rather than trying to choose which 10% of plants now begin to spend on R&D). For example, the calculation for the Food & Drink sector is scenario 1 − gross output × $[e^{-0.46} - 1] \times 0.1$. Note the minus sign in this calculation reflects the fact that plants now no longer experience the negative impact of doing no R&D. This figure of 10% is fairly arbitrary but we think it is likely to be a strict upper limit.[31]

Table 3: Gross output in 2003 (2000 prices) in Northern Ireland manufacturing

Industry sector (SIC92)	Actual	Scenario 1[a]		Scenario 2[b]	
	£m	£m	% change	£m	% change
Food & drink (15)	2468.4	2537.7	2.7	2690.1	9.0
Textiles (17)	355.8	355.8	0.0	355.8	0.0
Clothing (18)	197.4	198.2	0.4	198.2	0.4
Chemicals (24)	506.0	512.6	1.3	516.2	2.0
Rubber & Plastics (25)	643.5	646.9	0.5	658.8	2.4
Other non-metallic minerals (26)	631.7	636.1	0.7	636.1	0.7
Fabricated Metals (28)	467.6	469.8	0.5	469.8	0.5
Machinery & Equipment (29)	657.4	660.7	0.5	662.9	0.8
Electrical & Precision (30-33)	1596.5	1631.9	2.2	1653.4	3.6
Motors & Other Transport (34-35)	915.7	923.0	0.8	934.3	2.0
Other Manufacturing n.e.s.	2117.4	2136.7	0.9	2180.6	3.0
Total	10557.3	10709.4	1.4	10956.1	3.8

[a] Increase in R&D tax credit to 100/50% (SMEs/large firms): only plants undertaking R&D benefit
[b] Increase in R&D tax credit to 100/50% (SMEs/large firms): extra 10% of plants undertake R&D as well

[31] As suggested by the referee, we have also estimated a first-stage probit with a R&D dummy (coded 1 if R&D > 0; and 0 if R&D = 0), regressed on the 'user cost' of R&D, size, industry, location, age, and ownership variables (see Footnote 27). We found the 'user cost' to not be a significant determinant of whether the R&D was non-zero or not, giving added weight to our assertion that we believe the 10% figure used is an upper limit.

The results of applying the two scenarios are presented in Table 3. If only those plants undertaking R&D were to increase their R&D stock, the increase in gross output would be around £152.1m (in 2000 prices), or 1.4%. If an additional 10% of plants also start to spend on R&D we estimate the total increase in output would be about £398.8m, or 3.8%. In terms of the cost to the Government of this exercise, if the R&D stock increases by 16.9% and we separate out this increase into large firms and SMEs, with an associated cost of 200% and 150% of this increase (multiplied by the corporation tax rate) being borne by the Exchequer, then based on the 2003 R&D stock as a baseline, we estimate that the increased public subsidy would be £17.3m (in 2001 prices). Note, only current (not capital) expenditure qualifies for a tax credit and thus we use the relevant proportions for 2003 (these are 89.8% and 88.6% for SME's and non-SME's, respectively). We also have assumed that only 80% of plants will apply for the R&D tax credit. Thus, to arrive at the figure quoted we multiply the 2003 R&D stock by 0.169 (for the increase due to lower user cost) and then by 2.0 for SME's (1.5 for non-SME's) to reflect the *total* tax credit paid on the increased R&D (i.e. the original initial allowance of 100% plus the existing enhanced credit plus the increase to the enhanced tax credit), and then by 0.19 for SME's (0.3 for non-SME's) to reflect the corporation tax liability of firms, and then by 0.898 (or 0.886) to reflect the proportion of R&D eligible for tax credit, and finally by 0.8 (as we assume only 80% of firms apply). If 100% take-up is assumed, the public subsidy would be £21.6m. Note also, there is no 'deadweight' in this model; we assume that any increase in the tax credit is fully incorporated into the 'user cost' and firms fully adjust by increasing their demand for R&D.

Since gross value added minus labour costs was some 17.3% of gross output in the manufacturing sector of Northern Ireland in 2003, and SMEs accounted for about 26% of total GVA less labour costs, we can surmise that under scenario 1 the increased corporation tax bill from the increase in output would be about £7.2m (in 2000 prices).[32]

This suggests that such an increase in the enhanced R&D tax credit would be relatively expensive, but this would be to ignore the other likely benefits from increasing R&D that have not been taken into account (and which were mentioned in the introduction to this paper e.g. the likely increased level of innovation, an overall increase in absorptive capacity and an increased ability of firms to benefit more from globalisation).

The above exercise of increasing the R&D tax credit from 50% (25%) to 100% (50%) for SME's (large firms) would have a small impact on boosting R&D, and thus productivity. Thus, we provide results for some further simulations involving raising the R&D tax credit up to 300% for SME's (250% for larger firms) – see Table 4.[33]

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[32] Specially we take 17.3% of the increase in gross output (equals £26.5m) and allocate this 74/26 to large and small firms and apply the appropriate (30%/19%) corporation tax rates. Clearly, this is likely to be at the upper bound of any tax revenue from the increased gross output since we have not subtracted other costs from gross output (other than intermediate inputs and labour costs) to derive a figure for revenue that would be subject to corporation tax.

[33] An alternative of reducing corporation tax rates would actually increase the 'user cost' of R&D, as Equation (8) shows that with 100% depreciation allowances against R&D expenditure plus R&D tax credits after 2001, reducing τ would increase the numerator relative to the denominator with regard to $[1-(A^c-A^d)]/(1-\tau)$. If there were no R&D tax credits, reducing τ would be neutral; if depreciation allowances were abolished as well, then reducing τ does lower the 'user cost'. However, halving corporation tax rates (when depreciation allowances and tax credits are zero) in 2003 would have reduced the 'user cost' by slightly less than a doubling of the R&D tax credit (cf. Table 4 column 1), while the 'user cost' in 2002 would have been some 40% higher in the absence of depreciation allowances and tax credits.

Table 4: Impact of increasing R&D tax credit in Northern Ireland

	Rate of R&D tax credit for SME/large firms:				
	100/50%	150/100%	200/150%	250/200%	300/250%
Fall in 'user cost' (%)	12.4	25.5	38.6	51.7	64.8
Rise in R&D stock (%)	16.9	34.8	52.7	70.6	88.4
Increase in gross output (%)*:*					
Scenario 1	1.4	3.0	4.5	6.0	7.5
Scenario 2	3.8	5.3	6.8	8.3	9.9
Gross Exchequer cost (£m)[a]	17.3	46.9	88.1	141.0	205.5
Corporation Tax (£m)[a]	7.1	14.7	22.2	29.8	37.3
Net Exchequer cost (£m)[a]	10.1	32.2	65.9	111.2	168.2

[a] Based on scenario 1 that only plants with a non-zero R&D stock in 2003 benefit. See text for details

Note, we apply the same methodology as set out above; the results suggest that to have a significant effect on productivity (and hence output), a substantial increase in the R&D tax credit is necessary. Since the amount raised from increased corporation tax is significantly below the gross cost to the exchequer of financing the extra amount spent on R&D, the implications of a generous R&D tax credit are likely to be constrained in fiscal terms. However, the major constraint that would be faced is the unsustainable increase in the long-run R&D stock that results from a generous R&D tax credit scheme. It is unlikely that very large increases in the stock could be met without significantly increasing the supply-side provision of R&D facilities (especially personnel) in Northern Ireland.

VI. Conclusions

In this study, we have considered whether increasing R&D tax credits in disadvantaged regions would have a significant impact on both the R&D stock and productivity levels. We began by estimating the impact of R&D spending on output from the supply-side, by estimating 'knowledge' production functions for Northern Ireland (our case study region). It is found that in the steady-state, the R&D stock had a positive impact on output in every industry except the Textiles sector. In addition, plants with a zero R&D stock experienced significant one-off negative productivity effects, ranging from –7% in Chemicals to –37% in Food & Drink. Spillover effects were largely absent in Northern Ireland, and this may reflect (low) absorptive capacity levels in the Province, but also our imprecision in measuring such effects, and/or possibly that R&D is mostly appropriated internally by firms (given also that we include extra-mural R&D in our estimates of the R&D stock).[34] Furthermore, we have also analysed the impact of an additional enhanced R&D tax credit on the 'user cost' (or price) of R&D expenditure and subsequently on the demand for R&D, showing that in the long-run a 10% fall in the 'user cost' would result in a 13% increase in demand.

Assuming plants in Northern Ireland are able to meet any increase in demand for R&D (i.e. assuming away any supply-side constraints in the provision of R&D services in the Province) we have made use of various scenarios to provide an overall assessment of the impact of an increased R&D tax credit on productivity. Our results suggest that a doubling of the R&D tax credit would indeed increase productivity but the overall impact on productivity is small. Thus to have a significant effect on productivity (and hence output), a substantial increase in the R&D tax credit is necessary. Since the amount raised from increased corporation tax is significantly below the gross cost to the exchequer of financing the extra amount spent on R&D, the implications of a generous R&D tax credit are likely to be constrained in fiscal terms. However, the major constraint that would be faced is the unsustainable increase in the long-run R&D stock that results from a generous R&D tax credit scheme. It is unlikely that very large increases in the stock could be met without significantly

[34] If the appropriability argument contributes most to our findings (and other studies need to be done using data for other UK regions before stronger conclusions can be reached), this would have important implications on the literature that believes that spillover effects are large and have important policy implications – e.g. the 'innovations systems' literature (see, for example, Cooke et al., 2003).

increasing the supply-side provision of R&D facilities (especially personnel) in Northern Ireland. Currently, the Province does have a relatively high proportion of 18 year olds that go to University – some 14% above the UK average in 2004 based on UCAS data and population figures – with only London having a higher proportion (30% above the UK average), but nearly 30% of Northern Ireland students move outside the Province to take their degree and do not return (DFPNI, 2007, p. 50). In addition, Community Innovation Survey data covering 2002-2004 shows that some 9.6% of private sector employees in Northern Ireland were graduates (with some 43% of these being science or engineering graduates) compared to an significantly higher average in the Greater South East of England of 15.5% (of which 38% were scientists/engineers). Therefore, based on current data, it is likely that any substantial increase in the demand by firms to undertake (more) R&D will face a capacity constraint, although it is worth considering that when estimating the demand for R&D model (Equation 7) our results show that full adjustment to the equilibrium following changes in the 'user cost' of R&D takes about 6.5 years, giving more time for the supply of personnel to respond to increases in demand (assuming that steps are taken to increase the number of graduates, especially science and engineering graduates[35]). This is an area for more research, with associated important policy consequences that will need to be carefully assessed by the Northern Ireland Government.

In addition, there is a more fundamental issue that we have not considered in this paper, about whether an R&D tax credit on its own is the best approach to increasing R&D spending in a region like Northern Ireland. A fundamental issue is whether there are significant entry barriers to undertaking R&D in the Province, such that too few firms are engaged in this activity, leading to an overall lack of a 'culture' of undertaking R&D (and perhaps an overemphasis on producing goods and services that compete more on costs than quality). Put another way, it is possible that in addition to

[35] See Box 1.2 and par. 1.56 in the Varney Review (2007), which discusses how the Republic of Ireland responded to a lack of capacity in the 1970's with respect to engineering graduates.

facing a resource-gap (which an R&D tax credit may help to alleviate) there is a more fundamental capabilities-gap holding back firms in Northern Ireland. We have provided some initial evidence in Harris et al. (2006) that shows that this line of research is likely to provide some useful insights into why R&D activities are relatively underdeveloped, and that in isolation it is likely that R&D tax credits may not produce the desired results of significantly boosting R&D in a disadvantaged region like Northern Ireland, and consequently productivity levels. Thus future research needs to look in greater depth of the 'capabilities-gap' argument, taking a broader approach to the factors that are important (and perhaps underdeveloped) in determining the regional innovation system.

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Appendix

R&D Tax Credit Scheme in Northern Ireland

R&D tax credits were introduced in April 2000 for SMEs,[36] but were then extended to other companies in April 2002 (often called the 'Large Company' scheme). The scheme covers expenditure on staffing costs, materials used in the R&D (including since 2004 computer software, water, fuel and power), externally provided workers and in certain cases some of the costs of sub-contracted R&D.[37] That is, the scheme does not cover capital expenditure associated with R&D on land, building, plant and machinery.[38] The latter is covered by a 100% depreciation allowance on capital expenditure for 'scientific research'.

The current R&D tax credit scheme for SMEs is set at 50% of the above qualifying revenues when calculating taxable profits; for larger companies the amount is 25%. This is in addition to (but separate from) the basic 100% deduction for revenue expenditure on R&D that firms were already able to claim prior to the introduction of the R&D tax credit scheme. For SMEs making losses, they can sacrifice the tax loss from R&D (since they cannot obtain any relief from the standard tax credit scheme if they have no corporation tax liability) in exchange for a cash payment of 24p per £1 of qualifying expenditure.[39]

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[36] Defined as companies employing <250 employees and with annual turnover not greater than €40 million (or an annual balance sheet total not exceeding €27 million).

[37] Up to 2003, R&D expenditure needed to be at least £25,000 to qualify for credit; after the 2003 Budget this was reduced to £10,000 per year.

[38] Note, the majority of R&D spending in Northern Ireland (and the UK as a whole) is on non-capital spending, and most of it is intramural and therefore presumably qualifies for tax credits.

[39] It is claimed by Government that 90% of support for SMEs is claimed through this mechanism (see Supporting Growth in Innovation: Enhancing the R&D Tax Credit, HMSO, July 2005). This is an

User Cost of R&D

The values used in this study to cover the 'user cost' (Equation (8)) are as follows:

Corporation tax rates

- For SMEs: 0.21, in 1998; 0.2, between 1999 and 2001; 0.19, after 2001
- For larger firms: 0.31, in 1998; 0.3, after 1998

R&D tax credits

- For SME's: from 2001 these equalled 50% and thus A^c equals τ^c (=0.5τ); no separate role for the 'payable' scheme covering loss-making SME's is included here.
- For larger firms: from 2002, $A^c = 0.25\tau$ (25% tax credit)

Depreciation allowances

- For qualifying current expenditure, $A^d = \tau$ since firms were allowed a 100% deduction for revenue expenditure prior to the introduction of the R&D tax credit scheme; and we assume depreciation δ equals 0.3 (30%), following Bloom et al. (2002) – see also discussion in Section III.
- For R&D spending on plant and machinery, δ equals 0.1264 (12.64%), and ϕ equals 1 (100% first year allowance), thus $A^d = \tau$.
- For R&D spending on land and buildings, δ equals 0.0361 (3.61%), and ϕ equals 1 (100% first year allowance), thus $A^d = \tau$.

To obtain the overall 'user cost', the three assets (current spending, spending on plant & machinery, and spending on land & buildings) were weighted by their shares in total R&D spending. When a plant spent nothing on R&D in any one year, the average spending on each asset for the plant (over the 1998-2003 period) was used as a proxy in order to obtain the missing 'user cost' information for that year.

interesting figure as it implies (if take-up is high) that most SMEs who undertake qualifying R&D make losses.

Table A.1: Variable Definitions and Basic Descriptive Statistics

Variable	Definitions	Mean	Standard deviation
ln output	Real gross-output in plant *i* and time *t* (£m 2000 prices)	-1.274	1.769
ln capital	Plant & machinery capital stock for plant *i* in time *t* (source: Harris and Drinkwater, 2000, updated)	-4.602	3.264
ln employment	Current employment in plant *i* in year *t*	1.675	1.416
ln intermediate inputs	Real spending on intermediate inputs in plant *i* in year *t* (£m 2000 prices)	-1.875	1.880
ln age	Age of plant (*t* minus year opened +1) in years	1.258	0.934
ln R&D stock	1+ R&D stock in plant *i* and time *t* (£m 2001 prices)	-0.264	1.045
No R&D	Dummy coded 1 when plant *i* has zero R&D stock in year *t*	0.905	0.293
North/North West	Dummy coded 1 if plant located in Coleraine or Ballymena TTWA	0.115	0.319
South	Dummy coded 1 if plant located in Newry or Craigavon TTWA	0.189	0.392
West	Dummy coded 1 if plant located in Londonderry, Strabane, Enniskillen or Omagh TTWA	0.164	0.370
Mid-Ulster	Dummy coded 1 if plant located in Dungannon or Mid-Ulster TTWA	0.177	0.382
Old Commonwealth	Dummy coded 1 if plant *i* is owned at time *t* by either: Australian, New Zealand, South Africa, or Canada	0.001	0.032
Rep. of Ireland	Dummy coded 1 if plant *i* is Irish-owned at time *t*	0.012	0.109
SE Asia owned	Dummy coded 1 if plant *i* is SE Asian-owned at time *t*	0.002	0.040
US-owned	Dummy coded 1 if plant *i* is US-owned at time *t*	0.007	0.083
EU-owned	Dummy coded 1 if plant *i* is EU-owned at time *t*	0.006	0.075
GB-owned	Dummy coded 1 if plant *i* is GB-owned at time *t*	0.028	0.166
Single plant	Dummy coded 1 when plant *i* is a single plant in year *t*	0.896	0.305
SME	Single plant firms with less than 250 employees	0.887	0.317
ln (NI R&D)	R&D stock for 11 Northern Ireland industry groups in year *t*.[a]	2.543	0.988
ln (NI R&D) × R&D stock	R&D stock for 11 Northern Ireland industry groups in year *t* times R&D stock in plant *i* at time *t*	0.253	6.141
ln (UK R&D)	R&D stock for 21 UK industry groups in year *t*.[b]	5.818	1.184
ln (UK R&D) × R&D stock	R&D stock for 21 UK industry groups in year *t* times R&D stock in plant *i* at time *t*	0.479	10.394

[a] Obtained by summing across plants in each of the 11 industry groups modelled

[b] Obtained using real R&D spending in UK for 1993-2003 (separately for intramural and two types of capital assets), and using same perpetual inventory approach as used to obtain NI plant level data, in each of the 21 industry groups available in the Business Monitor MA14 published tables.

Note: year dummies were included in the model to take account of technical change and other temporal shocks.

Table A.2: Estimates of Equation (1) for Northern Ireland Industry Groups, 1998-2003: GMM System Estimator*
(dependent variable: *ln* real gross output)

	Food & drink (15)		Textiles (17)		Clothing (18)		Chemicals (24)		Rubber & plastics (25)		Non-metallic minerals (26)	
	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value
ln gross output$_{t-1}$	0.234	3.92	0.153	2.12	0.163	2.63	0.237	8.73	0.131	2.12	0.422	6.33
ln capital$_t$	0.091	2.97	0.114	2.06	0.151	3.00	0.160	2.88	0.114	2.85	0.053	2.23
ln capital$_{t-1}$	–	–	–	–	–	–	–	–	–	–	–	–
ln employment$_t$	0.159	2.52	0.333	10.20	0.657	4.85	0.331	20.50	0.233	2.23	0.542	2.85
ln employment$_{t-1}$	-0.056	-2.39	-0.097	-2.83	-0.294	-1.77			–	–	-0.345	-2.65
ln intermediary inputs$_t$	0.880	60.50	0.743	23.30	0.850	10.10	0.609	28.90	0.896	34.30	0.756	8.84
ln intermediary inputs$_{t-1}$	-0.155	-3.07	-0.139	-2.39	-0.254	-3.78	-0.158	-4.05	-0.316	-1.64	-0.304	-4.44
ln Age$_t$	0.074	1.43	-0.090	-3.14	–	–	–	–	–	–	–	–
ln R&D$_t$	0.127	2.70	–	–	0.022	2.92	0.058	1.69	0.033	2.69	0.024	2.29
No R&D	-0.352	-1.88	–	–	–	–	-0.056	-3.22	-0.177	-2.32	–	–
North/North West	–	–	0.094	2.92	–	–	0.122	1.24	–	–	–	–
South	–	–	–	–	–	–	–	–	–	–	–	–
West	–	–	–	–	–	–	–	–	–	–	–	–
Mid-Ulster	–	–	–	–	–	–	–	–	–	–	–	–
Old Commonwealth	–	–	–	–	–	–	–	–	–	–	–	–

US-owned	–	–	0.449	2.14	–	–	–	–	-0.226	-2.95	–	–
GB-owned	–	–	–	–	-0.178	-1.44	–	–	–	–	–	–
Single plant	0.154	2.32	–	–	0.292	2.05	–	–	–	–	–	–
SME	-0.093	-1.48	–	–	–	–	–	–	–	–	–	–
ln (NI R&D)$_t$	–	–	–	–	–	–	-0.087	-5.48	–	–	–	–
ln (UK R&D)$_t$ × R&D$_t$	–	–	–	–	–	–	–	–	–	–	–	–
ln (UK R&D)$_t$	–	–	–	–	–	–	–	–	–	–	–	–
Restricted (β= 0) χ^2 [p-value]	8.9	[0.542]	5.4	[0.979]	7.8	[0.648]	5.7	[0.956]	3.9	[0.958]	3.5	[0.995]
Sargan test χ^2 [p-value]	53.5	[0.416]	48.2	[0.624]	33.6	[0.978]	–		25.6	[1.000]	61.2	[0.178]
AR(1) [p-value]	-2.12	[0.034]	-1.57	[0.116]	0.39	[0.696]	0.49	[0.623]	-2.02	[0.044]	-1.64	[0.100]
AR(2) [p-value]	0.95	[0.331]	-0.18	[0.854]	0.04	[0.971]	-1.16	[0.248]	1.47	[0.142]	1.48	[0.140]
R^2	0.96		0.98		0.95		0.94		0.95		0.82	
No. of observations	1,723		744		475		312		1,072		1,684	
No. of units	548		239		171		81		334		500	
instruments	Δt–1, t–2		Δt–1, t–2		Δt–1, t–2		GLS		Δt–1, t–2		Δt–1, t–2	

Table A.2 (cont)

	Fabricated metals (28)		Machinery & equipment (29)		Electrical & precision (30-33)		Motor vehicles & other transport (34-35)		Other manufacturing	
	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value	$\hat{\beta}$	*t*-value
ln gross output$_{t-1}$	0.385	8.39	0.215	6.90	0.478	5.33	0.346	5.04	0.238	4.65
ln capital$_t$	0.115	2.67	0.131	13.00	0.203	8.61	0.340	8.15	0.126	2.97
ln capital$_{t-1}$	–	–	–	–	-0.038	-5.37	-0.090	-5.51	-0.013	-2.09
ln employment$_t$	0.351	8.45	0.310	22.20	0.164	13.10	0.111	7.94	0.120	3.22
ln employment$_{t-1}$	-0.345	-2.65	–	–	0.055	6.10	0.076	3.40	0.067	2.23
ln intermediary inputs$_t$	0.596	36.90	0.429	13.60	0.208	14.20	0.231	15.40	0.740	40.40
ln intermediary inputs$_{t-1}$	-0.253	-11.60	-0.074	-3.82	-0.071	-3.39	-0.044	-1.06	-0.196	-5.49
ln Age$_t$	–	–	-0.146	-7.30	–	–	–	–	–	–
ln R&D$_t$	0.017	3.26	0.023	1.75	0.068	2.62	0.031	4.18	0.041	1.63
No R&D	–	–	-0.027	-3.22	-0.076	-3.28	-0.087	-6.73	-0.177	-1.72
North/North West	–	–	–	–	–	–	–	–	-0.062	-4.17
South	–	–	–	–	–	–	–	–	-0.047	-3.04
West	–	–	–	–	–	–	–	–	-0.041	-2.75
Mid-Ulster	–	–	–	–	–	–	–	–	-0.045	-3.16
Old Commonwealth	–	–	–	–	–	–	–	–	–	–
US-owned	–	–	0.184	1.78	–	–	–	–	–	–
GB-owned	–	–	0.149	2.06	–	–	–	–	–	–
Single plant	–	–	–	–	–	–	–	–	–	–

SME	–	–	–	–	–	–	–	–	-0.117	-4.11
ln (NI R&D)$_t$	–	–	–	–	–	–	–	–	–	–
ln (UK R&D)$_t$ × R&D$_t$	–	–	0.002	2.19	–	–	–	–	0.009	4.34
ln (UK R&D)$_t$	–	–	–	–	–	–	0.055	2.75	–	–
Restricted (β= 0) χ^2 [p-value]	16.6	[0.278]	5.5	[0.939]	17.6	[0.226]	18.0	[0.387]	6.2	[0.517]
Sargan test χ^2 [p-value]	60.2	[0.292]	na		na		na		49.6	[0.568]
AR(1) [p-value]	0.84	[0.398]	1.32	[0.188]	-1.45	[0.146]	2.11	[0.034]	-5.06	[0.000]
AR(2) [p-value]	0.99	[0.324]	1.72	[0.085]	0.86	[0.389]	1.56	[0.118]	0.60	[0.547]
R^2	0.99		0.93		0.82		0.93		0.96	
No. of observations	2,972		1,405		839		552		6,459	
No. of units	986		376		221		148		2,129	
instruments	Δt–1, t–2		GLS		GLS		GLS		Δt–1, t–2	

Note: year dummies are also included but not reported here.
* For some models (denoted GLS), we use a panel-GLS instrumental-variable estimator incorporating fixed effects. Data limitations did not allow the system-GMM model to converge.