Discussion Paper No.9

December 2005

Assessing the Case for a Higher Rate of R&D Tax Credit in Northern Ireland

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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. 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 −1.3 for Northern Ireland.

JEL codes: L25; R11; R38

Keywords: R&D tax credit; Northern Ireland; productivity

1. INTRODUCTION

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 (2005) for details. Increased R&D by plants in a region like Northern Ireland, 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.[i]

Business spending on R&D in Northern Ireland is relatively low compared to average spending in the UK as a whole. Data from the 2001 Community Innovation Survey shows that in terms of the percentage of establishments undertaking such spending in 2000, the Northern Ireland figure for manufacturing was 14.4% (the total for the UK was 18.6% of establishments), and 6.9% for services (9.7% in the UK). Thus, the Northern Ireland percentage was only 77.6% of the UK figure for manufacturing, and 70.8% of the UK figure for services. In terms of the amount spent on R&D per employee, the Northern Ireland figure was £783 per employee (or 26.7% of the UK level of expenditure per employee) for manufacturing, and £463 per employee (or 22.9% of the UK level) for services. Thus, while Northern Ireland had fewer establishments spending anything on R&D, the biggest difference was the amount spent per employee with establishments in the Province who spent anything devoting much less to the amount that was spent.

There are two main ways in which governments 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. Typically in the UK the authorities have resorted to grant-based schemes, such as national schemes like SMART and SPUR,[ii] or regional schemes like R&D grants in Northern Ireland (since 1977) through the operation of Selective Financial Assistance (see Harris *et. al*., 2003).

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.

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, 2002), 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.[iii] 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.[iv]

This study is structured as follows. Section II briefly reviews the literature on the relationship between R&D and productivity. Section III then discusses the dataset we constructed for Northern Ireland. 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 last section concludes.

2. LITERATURE REVIEW

There are two main strands of the micro-based literature on the impact of business R&D on firm-level productivity. The first 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). A second approach has evolved from the literature on trade and growth, and the role that R&D and technology transfer play in allowing lagging countries to 'catch-up' with technological leaders (e.g. the U.S.). This latter approach considers the 'two faces of R&D' concept introduced by Cohen and Levinthal (1989), whereby R&D has a direct impact on TFP through innovation, and an indirect impact in that R&D provides the firm with absorptive capacity so that it can internalise the benefits to be gained from technology transfer.

Wieser (2005) has recently provided an extensive review of the literature on the first approach we shall cover. We start with the following log-linear version of the augmented Cobb-Douglas production function:

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

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 former considers long-run effects and the latter only allows for short-run impacts.[v] 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 rate of return on (or marginal productivity of) internal and external R&D, rather than elasticities.

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 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).

Lastly, 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 Caramone, 2005, report a ratio of 4.5:1, while this ratio in Tsai and Wang, 2004, is closer to 4:1)

Recent examples of the 'two faces' of R&D approach to measuring the impact of R&D on productivity include: Griffith *et. al*. (2004), Cameron *et. al*. (2005), Kneller (2005), and Girma (2005). These studies nearly always require estimates of total factor productivity for firms located on the frontier of technology (e.g. the U.S.) as well as for firms in the area of interest (e.g. the U.K.). Obtaining initial estimates of TFP (often using a growth accounting approach), prior to then estimating whether R&D impacts on TFP, is problematic. Harris (2005a) discusses the likelihood of biased and inefficient estimates that can result from this type of approach. Assuming estimates of TFP are available, the approach taken is to appeal to the literature on endogenous innovation and growth (e.g. Romer, 1990; Aghion and Howitt, 1992) and argue that changes in TFP are determined directly by changes in the R&D knowledge stock (see equation (2) above), while changes in the R&D stock can be proxied by (real) spending on R&D per unit of sales (see equation (3)). Thus, up to this point the model is little different to those discussed above. However, the determinants of TFP are then supplemented by introducing technology transfer as a source of productivity growth; that is, the larger the gap between TFP in the *j*-th frontier plant/firm and TFP in plant/firm *i*, the greater the opportunity for 'catch-up' and thus for technology transfer.[vi] The latter may take place autonomously (i.e. there are no intervening variables that are included to link the technology gap $TFP_j - TFP_i$ to changes in TFP for firm *i*) or, more realistically, technology transfer may 'need' the firm to have absorptive capacity (as proxied by R&D intensity) in order for the plant/firm to be able to internalise the external technical knowledge potentially available from the frontier firm(s). Put another way, the 'second-face' of R&D spurs faster adoption of new technologies. Thus, in its simplest form, the model is specified as:

$$\Delta \ln TFP_{it} = \rho_1 \left(\frac{R}{Y}\right)_{i,t-1} + \delta_1 \ln\left(\frac{TFP_j}{TFP_i}\right)_{t-1} + \delta_2 \left[\left(\frac{R}{Y}\right)_{i,t-1} \times \ln\left(\frac{TFP_j}{TFP_i}\right)_{t-1}\right] \quad (4)$$

where the first term on the RHS of the equation refers to the direct effect of R&D on TFP (via innovation), the second term measures autonomous technology transfer, and the third term (with associated impact δ_2) shows how technology transfer impacts on the firm's TFP depending on how much absorptive capacity the firm has (see Griffith *et. al*., 2004, equation 4).

Griffith *et. al*. (2004) found that based on panel industry data for 12 OECD countries and up to 9 industries, covering 1974-1990, R&D positively impacted on TFP directly (it generated innovations) and indirectly through the technology transfer gap with the U.S. (all three coefficients, ρ_1, δ_1, and δ_2 in equation (4) were positive and significant). They also found that human capital stimulated innovation and absorptive capacity, but could find no role for international trade. In contrast, Cameron *et. al*. (2005), using data for 14 manufacturing industries in the U.S. and U.K. for the 1970-1992 period, and a similar approach, found that there was no significant role for the 'second face' of R&D – i.e., their equivalent to the coefficient δ_2 in equation (4) was not statistically significant. Instead they did find that international-trade-based technology transfer was significant in determining UK productivity growth.[vii]

In this study we have adopted the use of the 'knowledge production function' approach, rather than the 'two faces of R&D' concept, as we are not including frontier

TFP estimates from outside Northern Ireland (we do not have such data) and thus we are not directly including 'catch-up' effects.

3. The Data

The dataset used for this study is the merged BERD[viii] and ARD[ix] data for the years 1998-2003. Here plant level (i.e. local unit) ARD data is employed.[x] Total capital expenditure data for each manufacturing plant (1998-2003) was broken-down 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.[xi] 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 (2005b).

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.[xii] 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 & 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.[xiii]

4. 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).[xiv] 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 (i.e. impacts on output not directly associated with factor inputs). These additional TFP effects included the age of the plant; location of the plant in terms of a sub-regional breakdown of Northern 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[xv], 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 greater ability to internalise any spillovers from external R&D that takes place in the same industry and/or location.

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 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; Oughton *et. al.*, 2002; Cooke *et. al.*, 2003; Howells, 2002; Asheim and Gertler, 2005).[xvi] 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.[xvii] 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. [xviii]

All the variables used to estimate equation (1) are set out in Table A.1 (in the Appendix). We have estimated this equation using 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:

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

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)[xix], 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.[xx]

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.[xxi] 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.

Since we are more interested in the steady-state (i.e. equilibrium, long-run) results, these are presented in Table 1[xxii]. 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 –62% in Food & Drink[xxiii] (although there was no significant effect in the Textiles, Clothing, Non-metallic Minerals, and Fabricated Metals sectors).

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 $\text{R\&D}_t$	0.166	2.78	–	–	0.026	2.27	0.077	1.65	0.031	2.13	0.041	2.16
No R&D	-0.960	-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 $(\text{NI R\&D})_t$	–	–	–	–	–	–	-0.114	-4.81	–	–	–	–
ln $(\text{UK R\&D})_t \times \text{R\&D}_t$	–	–	–	–	–	–	–	–	–	–	–	–
ln $(\text{UK R\&D})_t$	–	–	–	–	–	–	–	–	–	–	–	–

See Table A.2 for details

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 $\text{R\&D}_t$	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 $(\text{NI R\&D})_t$	–	–	–	–	–	–	–	–	–	–
ln $(\text{UK R\&D})_t \times \text{R\&D}_t$	–	–	0.002	2.16	–	–	–	–	0.012	4.71
ln $(\text{UK R\&D})_t$	–	–	–	–	–	–	0.085	2.84	–	–

Spillover effects were largely absent. 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.* (2005). 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 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.

5. 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).[xxiv] This will help to establish 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*. (2004, equation A.6), it is possible to measure the own-price elasticity of R&D (ϕ) with respect to its price based on:[xxv]

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

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); 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)[xxvi]; A^{d} is the net present 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. 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).

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.[xxvii] 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.

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 $stock_{t-1}$	0.900	84.8	–	–
ln user $cost_t$	-0.415	-4.8	-1.279	-2.38
ln user $cost_{t-1}$	0.287	3.1	–	–
ln gross $output_t$	0.022	2.1	0.218	1.96
—”— × Food & drink (15)	0.063	2.56	0.629	2.48
—”— × Chemicals (24)	0.137	3.49	1.366	3.40
—”— × Rubber & plastics (25)	0.086	2.08	0.857	2.07
—”— × Fabricated metals (28)	0.087	2.04	0.871	2.04
—”— × Machinery & equipment (29)	0.078	2.14	0.781	2.17
—”— × Electrical & precision (30-33)	0.106	3.86	1.055	3.81
—”— × Motors & other transport (34-35)	0.077	2.40	0.773	2.40
Constant	-0.428	-4.95	-4.280	5.55
Restricted (β= 0) χ^2 (P-value)	22.10	[0.105]		
Sargan test χ^2 (P-value)	17.94	[0.160]		
AR(1) (P-value)	-3.47	[0.001]		
AR(2) (P-value)	0.26	[0.793]		
R^2	0.94			
No. of observations	2,063			
No. of units	563			
Instruments	Δt−1, t−2			

Note: year dummies were included but are not reported.

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 10 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 −1.28, which is not very different from 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 42% associated with the introduction of UK-wide enhanced tax credits (in 2001), this implies that (*cet. par*.) the long-run R&D stock should rise by some 54% in the Province. The short-run impact is much smaller (only about a 5% rise p.a. assuming nothing else changes).

The long-run elasticity of R&D with respect to output demand is low (at 0.218) 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 1.584.[xxviii]

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 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%). Based on our results for the impact of the 'user cost' of R&D on the demand for R&D, these changes would lower the 'user cost' as at 2003 by over 85% for all manufacturing plants (a 31% fall for larger firms and a 91.4% fall for SMEs). In the long-run, this would result in a rise in the demand for the R&D stock by nearly 109% (in the short-run the initial effect in year 1 would be an increase in demand of 10.9%). Of course, we are imposing no supply-side constraints on the ability of the economy to respond to such large increases in demand, but it is very likely that the supply of qualified R&D workers would be insufficient 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*. (2005), 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[xxix]; and (ii) the fall in price induces an additional 10% of plants to start spending on R&D.[xxx] This figure of 10% is fairly arbitrary but we think it is likely to be a lower 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 £979m (in 2000 prices), or 9.3%. If an additional 10% of plants also start to spend on R&D we estimate the total increase in output would be about £1178m, or 11.2%. In terms of the cost to the Government of this exercise, if the R&D stock increases by 109% and we separate out this increase into large firms and SMEs, with an associated cost of 50% and 25% of this increase 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 £76.7m (in 2001 prices).[xxxi] 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 £46m (in 2000 prices).[xxxii]

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	2914.9	18.1	3067.2	24.3
Textiles (17)	355.8	355.8	0.0	355.8	0.0
Clothing (18)	197.4	203.0	2.8	197.4	0.0
Chemicals (24)	506.0	548.5	8.4	552.1	9.1
Rubber & Plastics (25)	643.5	665.3	3.4	677.1	5.2
Other non-metallic minerals (26)	631.7	659.9	4.5	631.7	0.0
Fabricated Metals (28)	467.6	481.8	3.1	467.6	0.0
Machinery & Equipment (29)	657.4	678.2	3.2	680.5	3.5
Electrical & Precision (30-33)	1596.5	1824.4	14.3	1845.9	15.6

Motors & Other Transport (34-35)	915.7	962.6	5.1	973.9	6.4
Other Manufacturing n.e.s.	2117.4	2242.0	5.9	2285.8	8.0
Total	10557.3	11536.3	9.3	11734.9	11.2

[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

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).[xxxiii]

6. CONCLUSIONS

In this study, we have considered the impact of R&D spending on output from the supply-side, by estimating the 'knowledge' production function. 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 –62% in Food & Drink. Spillover effects were largely absent. 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 it would be relatively expensive in terms of the net increase in public subsidy needed.

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 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*. (2005) that shows that this line of research is likely to provide some useful insights into why R&D activities are relatively underdeveloped, and thus why an enhanced R&D tax credit is an important part of any portfolio of policy instruments designed to develop enterprise and systemic innovation capabilities in Northern Ireland. But in isolation it is likely that R&D tax credits may not produce the desired results of significantly boosting R&D in the Province, and consequently productivity levels.

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APPENDIX

R&D Tax Credit Scheme in Northern Ireland

R&D tax credits were introduced in April 2000 for SMEs,[xxxiv] 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.[xxxv] That is, the scheme does not cover capital expenditure associated with R&D on land, building, plant and machinery.[xxxvi] 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.[xxxvii]

User Cost of R&D

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

<u>Corporation tax rates</u>

- 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

<u>R&D tax credits</u>

- For SMEs: from 2001 these equalled 0.5 (50%); no separate role for the 'payable'scheme covering loss-making SMEs is included here.
- For larger firms: from 2002, 0.25 (25%)

<u>Depreciation allowances</u>

- For qualifying current expenditure, A^{d} = 0, 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.

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	-0.735	-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.

NOTES

[ii] 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).

[ii]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.

[iii] 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).

[iv] Short-run effects are much lower, implying that the demand for R&D responds very slowly over time to changes in its price.

[v] To reconcile the two would require the estimation of, for example, an error-correction model that incorporates both short- and long-run impacts.

[vi] The gap between productivity in firm j and firm i allows for a potential spillover in technology from the frontier firm j.

[vii] Kneller (2005) also could find no role for the 'second face' of R&D, but greater physical distance from the frontier firms did have the expected negative impact on technology transfer.

[viii] The Business Expenditure on Research and Development data is obtained from an annual survey conducted by the UK Office for National Statistics (ONS) designed to measure R&D expenditure and employment in the UK. These annual data can be linked to other datasets through Inter-Departmental Business Register (IDBR) fields, at the level of the reporting unit.

[ix] The Annual Respondents Dataset 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). Establishments/plants can be linked through time to form a panel, and information is also available on the population of establishments or plants, which can be used to weight the financial data to obtain population estimates. Further details are provided in Harris (2005a). Note, the Northern Ireland government collects a boosted sample for its own version of the ARD.

[x] The raw data files supplied to us by the Department of Enterprise, Training and Investment for Northern Ireland were merged and 'cleaned', and missing data was repaired with regard to postcodes, ownership, and enterprise level codes (the later are necessary to calculate whether the plant is a single-plant enterprise or belongs to other enterprises). Postcodes were needed to link plants to travel-to-work areas (TTWA) and sub-regional areas; ownership and enterprise level data means that plants can be identified in terms of whether they are single plants, belong to UK enterprises – i.e. are GB-owned – or are foreign owned.

[xi] Note, data for non-manufacturing in the ARD is only available from 1998 and therefore only manufacturing plants can be analysed using plant and machinery capital stock information.

[xii] Note, nominal R&D spending is converted to real spending using the implied GDP deflator.

[xiii] Further details on the methods used are available in Harris *et. al.* (2005). Note during 1998-2003 manufacturing accounted for 82% of the total R&D capital stock in Northern Ireland.

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

[xv] See for instance, Caniels (2000); Verspagen and Schoenmakers (2004); Cantwell and Piscitello (2005). More significantly, Peri (2005) finds that the externally accessible stock of R&D has a positive impact on firm innovation but that only about 20 percent of average knowledge is learned outside the region of origin and only 10 percent outside the country of origin.

[xvi] This strand of literature argues that regional proximity facilitates the diffusion of tacit knowledge and thus the firm's learning behaviour, which may be reinforced by agglomeration economies in production and pools of skilled human capital. The innovative ability of firms in a region is critically dependent upon the learning ability of a region, namely, the ability of regional economies to create, assimilate and transform technological knowledge. Moreover, the regional effect on innovative activity is further substantiated by the significance of regional R&D spillovers.
[xvii] For instance, Harris and Trainor (1995) suggested that "…in general, it would seem that R&D inputs and innovation outputs are not a strong feature of the Northern Ireland economy" (p. 596). Part of the reason is likely to be that growing external-ownership, and the resulting branch plant status of many peripheral regions, has lowered the inventive capabilities of such regions. Harris (1991a) showed that plants operating in Northern Ireland that had their headquarters' outside the region were some 40 per cent less likely to have an R&D department in the Province, while having such an R&D department increased the likelihood of patenting an innovation by some 23 per cent (which was more important than the availability of technical workers and/or firm size on innovativeness).
[xviii] For instance, the existence of industry effects in firm's innovative activities, in terms of varied technological performance, has provided a rationale for grouping firms into high-tech and low-tech sectors in empirical studies, e.g. Frenkel *et. al*. (2001) and Shefer and Frenkel (2005).
[xix] Note, we use the DPD sub-routine available in PcGive (v10) since it is an updated version of the original DPD programme written by Arellano and Bond.
[xx] Using the GMM systems approach the model is estimated in both levels and first-differences. This is important, since Blundell and Bond (1999) argue that including both lagged levels and lagged first-differenced instruments leads to significant reductions in finite sample bias as a result of exploiting the additional moment conditions inherent from taking their system approach.
[xxi] PcGive reports tests for the first-differenced residuals, thus there should be evidence of significant negative first-order serial correlation in differenced residuals and no evidence of second-order serial correlation in the differenced residuals, which is the case here.
[xxii] 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. These figures are arrived at using the parameter estimate for *ln* gross output$_{t-1}$. If this is given the value λ, then the speed of adjustment is $1/(1-\lambda)$.
[xxiii] Recall, that since the dependent variable is logged, the impact of dummy variables is obtained as $e^{\hat{\beta}} - 1$.
[xxiv] A brief introduction to the R&D tax credit scheme in Northern Ireland is available in the appendix.
[xxv] 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 the 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.
[xxvi] 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.

[xxvii] 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; other models usually failed either on the Sargan test, or the results were not particularly plausible.
[xxviii] i.e 0.218 + 1.366.
[xxix] To calculate this impact for each plant we have simply multiplied gross output by the *ln* R&D parameter estimate in Table 1 and multiplied this result by 1.09 (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.
[xxx] 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 × $[e^{-0.96} - 1] \times 0.1$. Note the minus sign in this calculation reflects the fact that plants now no longer experience the negative impact of doing no R&D.
[xxxi] Note, only current (not capital) expenditure qualifies for a tax credit and thus we use the relevant proportions for 2003. We also have assumed that only 80% of plants will apply for the R&D tax credit. If 100% take-up is assumed, the public subsidy would be £95.9m.
[xxxii] Specially we take 17.3% of the increase in gross output (equals £169.2m) 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.
[xxxiii] For empirical evidence of a positive link between firm's internationalisation and R&D expenditures and/or innovation activities, see for instance, Buxton *et. al.*(1991); Kumar and Saqib (1996); Canto and Gonzalez (1999); and most recently Yang *et. al.* (2004).
[xxxiv] 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).
[xxxv] 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.
[xxxvi] 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.
[xxxvii] 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 interesting figure as it implies (if take-up is high) that most SMEs who undertake qualifying R&D make losses.