CHAPTER 19

THE IMPACT OF R&D ON PRODUCTIVITY

DIRK CZARNITZKI AND NIALL O'BYRNES

ABSTRACT

Studies have shown that is not only firms' own internal Research and Development (R&D) that leads to positive productivity effects. Firms can also make use of knowledge which has been generated elsewhere if they maintain sufficient absorptive capacity to utilise such information. Further, more recent research suggests that the benefits from spillovers may be larger for firms or countries that are lying behind the 'technological frontier'. Such findings have important policy implications for the Irish economy. While Ireland has shown impressive growth rates and industry restructuring towards a modern knowledge economy, it still lags behind the European average when it comes to R&D investment.

19.1 Introduction

Ireland's economy has changed without recognition from the pre-boom year 1995 to the later years of the current boom. Gross Domestic Product (GDP) grew from $65 billion to $171 billion (current PPP), the labour force grew from 1.2 million to two million and unemployment dropped from 17 per cent to four per cent. While factors such as the 1970's population boom entering the workforce and the global environment (Information Technology boom) surely contributed to Ireland's transformation, it was its fiscal responsibility and openness to Foreign Direct Investment (FDI) that created the necessary conditions for such breakneck growth reaching 10.5 per cent per annum for ten years.

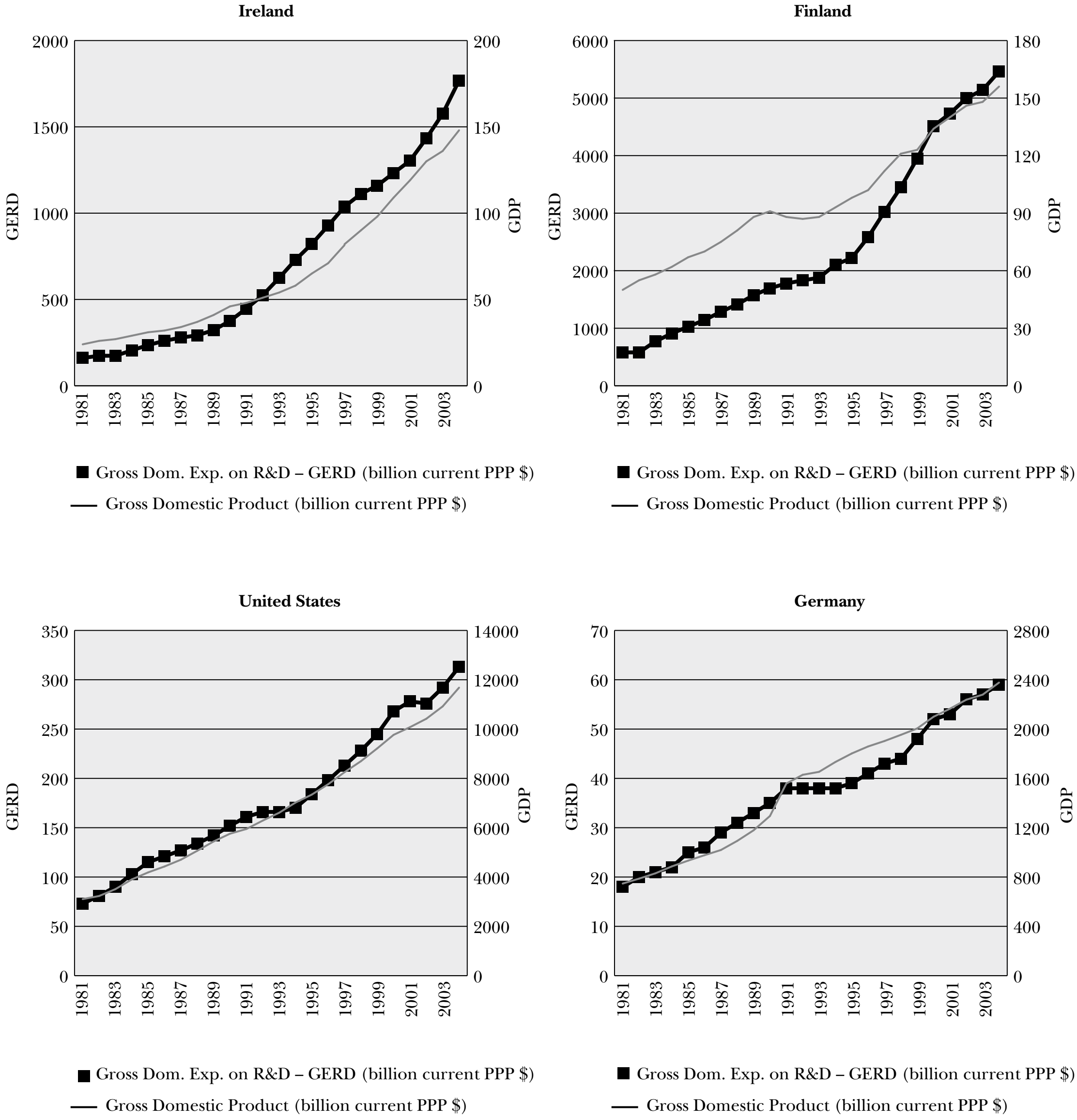
This inward investment boom, 23 per cent of GDP in 2002 (IMF, Balance of Payments Report 2005) was led by US multinationals in IT, financial services and remote customer services. The state supported its development through a massive infrastructure program and increased investment in education, particularly third level institutions. Its commitment to the Euro and successful wage pacts delivered a sound macro environment that allowed the productivity increases to deliver higher real wages. On the domestic front the indigenous sectors responded to competitive pressure, delivering international standards by adopting best international practices. As spare capacity in the economy was reduced (unemployment dropped from 16 per cent in 1993 to two per cent 2005), and real wages increased, the profile of Ireland's inwards investments began to change. Earlier low-skilled investments, for example the North West textile industry moved out to newly open foreign labour markets.

The economy in 2004-2005 has been characterised by continued growth but also a noted productivity growth change from 4.9 per cent to two per cent in 2004 (ESRI, 2005). Growth is now mostly due to demand for domestic services, from an increase in the working population through inward migration which is supported by sustained FDI. While these two factors will sustain the economy in the short term, it is not sustainable in long term growth projections. With higher inflation (3.7 per cent) and higher wage growth (five per cent) than the EU15 in 2005, Ireland must be careful that its higher wages are justified by increases in productivity (ESRI, 2005). Productivity is increased in various ways, but in an economy like Ireland's without significant natural resources or indigenous manufacturing industry, the 'knowledge stock' becomes very important. The accumulated R&D expenditures of a country or firm are often interpreted as its knowledge stock.

It can be seen from the simple correlation in Figure 19.1 that economies exhibit an increase in R&D with an increase in the size of the economy, because as 'knowledge stock' becomes more important to the economy, investments in R&D to generate new 'knowledge' becomes imperative. It has been shown that R&D indeed causes growth, to a certain extent, in many scholarly articles.

In this chapter, we first outline how scholars in economics have approached the relationship between productivity and R&D, and second we briefly summarise empirical studies on the impact of R&D on productivity. Furthermore, we stress the importance of spillovers, and discuss the 'technological frontier' of production. We close the discussion with an Irish perspective on the impact of R&D on productivity, where the fact that the Irish economy is largely dominated by foreign firms is a focus of the discussion. The final chapter closes with conclusions and policy recommendations.

Figure 19.1: Correlation of GDP and R&D



Source: OECD Main Science and Technology Indicators, 2006/1.

19.2 The Relationship between R&D and Productivity

19.2.1 The Production Function

When the contribution of R&D to productivity is considered, econometric studies typically start from a production function, that is, an equation describing how factor inputs such as capital and labour are combined to produce output. A common functional form is of Cobb-Douglas type:

$$Y_{it} = Ae^{\lambda t} K_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\gamma} e^{\varepsilon it} \quad (1)$$

where Y = real output, A = total factor productivity, K = the stock of physical capital, L = labour, R = R&D and e is the error term, that is the difference between what is observed and what is predicted by the equation. The subscript I denotes firm (or sector or country) and t is time.[1] The R&D variable can be measured as the stock of R&D capital or the investment in a given year. The Total Factor Productivity (TFP) A denotes the output per unit of combined factor input, and is often estimated as a time trend or a constant in the regression model.

Eq. (1) can be rewritten in logs as

$$\log(Y_{it}) = log(A) + \lambda t = \alpha\ log(K_{it}) + \beta\ log(L_{it}) + \gamma\ log(R_{it}) + \varepsilon_{it} \quad (2)$$

Scholars either estimate eq. (2) with (pooled) cross-sectional data of firms, (or industries or countries), so that it can be shown that firms with higher R&D realise higher output, or they make use of time-series methods for estimation such that changes in the right-hand side variables induce change in Y. In the latter case, one would estimate eq. (2) either in first differences, or in terms of growth rates. In all cases, the parameters α, β, and γ represent the elasticities of output with respect to capital, labour and R&D. If, for instance, the estimate of $\gamma = 0.15$, and is statistically significantly different from zero one would conclude that a ten per cent increase in R&D results in a 1.5 per cent increase in output (all else constant).[2]

Through the functional form of eq. (2), it is implicitly assumed that the elasticity of output with respect to R&D is constant over firms (and through time). Therefore, other researchers specified a different equation to be estimated as they preferred to estimate the rate of return of R&D rather than the elasticity. This can also be derived from eq. (2) (see Griliches, 1980, Griliches and Mairesse, 1984):

$$\frac{\Delta Y_{it}}{T_{i,t-1}} = \lambda + \alpha \frac{\Delta K_{it}}{K_{i,t-1}} + \beta \frac{\Delta L_{it}}{L_{i,t-1}} + p \frac{\Delta R_{it}}{Y_{i,t-1}} + \Delta\varepsilon_{it} \quad (3)$$

where ΔR is the net investment in R&D capital, and p the rate of return to R&D.

Estimating the parameters of production functions is not a trivial task as many problems such as omitted variable bias, simultaneity and multicollinearity may bias the results. An omitted variable bias occurs if some firms are more productive than others due to reasons unrelated to R&D (and the other regressors in the estimation equation). For instance, firms could have better R&D management and are thus more successful in their R&D process which would lead to higher spending in R&D. Then there would be differences in productivity that are related to such unobserved factors which may be correlated with R&D. As a result, the estimated coefficient of R&D will be biased upwards. Nowadays, scholars control for such unobserved heterogeneity across firms by applying panel data econometric methods controlling for 'individual fixed effects', that is, one would include a firm specific parameter c_i in eq. (2). By estimating the equation in first differences over time, the individual firm effect is differenced out.

A simultaneity bias arises when one or more right-hand side variables are correlated with the error term. The variables are only uncorrelated with the error term if causality runs only from the factor inputs to productivity. If there is feedback, however, a simultaneity bias occurs. For instance, scholars mostly believe that R&D and productivity are mutually dependent, that is, growth of output is a function of R&D, but R&D investment is in turn a function of past output growth and expected future growth. Today's common practice is the use of instrumental variable techniques that allow consistent estimation of the production function's parameters even if output and factor inputs are simultaneously determined.

The common problem of multicollinearity refers to the fact that typically an almost linear relationship among independent variables, the factor inputs, exists. If the colinearity among regressors is high, researchers may not be able to calculate the separate effect of each regressor on the dependent variable. Colinearity results in imprecise estimates, that is, estimated coefficients exhibit large variance. Estimating in first differences usually reduces the problem of multicollinearity.

19.2.2 Private Returns to R&D

Table 19.1 shows an overview of studies that relate R&D to productivity at different levels of aggregation. The core of the empirical literature on R&D consists of studies on the private return to R&D. These studies are usually divided into two types, cross-sectional and combined cross-sectional time-series, i.e. panel data. The cross section studies look at either a number of firms or a number of countries and try to measure their productivity return due to R&D in a single point of time. The time-series studies try to measure the change in the productivity over time relative to inputs and so determine its effect. A listing of a number of these studies is detailed in Table 19.1. The relationship between productivity and R&D is usually stated as elasticity and is defined as a percentage increase in a variable in relation to a percentage change of the other. For example the Griliches (1980) study reports an elasticity of 0.07, so a ten per cent increase in R&D expenditure will be a 0.7 per cent increase in the output. This implies a rate of return on R&D of 27 per cent.

The cross-section studies report higher rates of return and with greater certainty than the time-series studies. The reason as stated by Mairesse and Sassenou (1991) attributes the difference to the treatment of the share of labour in the economy or its scale affects. The cross-sectional studies also consistently predict positive elasticities in the region of 0.10 and 0.20. Other studies examining time-series data show weaker and smaller (0.02 to 0.15) results but are still positive. The macroeconomic studies show a much wider band of predicted rates of return and are probably due to the specification of the model and production function used to estimate the data. Reconciling the results of the cross sectional data with time-series data and the macroeconomic evidence are an area of intense research, but nearly all studies show positive and significant rates of return to R&D.

Table 19.1: Empirical Studies on the Elasticity of Output with Respect to R&D

Selected Estimates of the Elasticity of Private R&D from Firm Level Data		
Study	**R&D Elasticity**	**Sample**
Griliches (1980a)	0.03 – 0.07	39 U.S. manufacturing industries; 1959 to 1977
Schankerman (1981)	0.10 – 0.16	110 U.S. firms (chemical and oil industries); 1963 cross-section
Griliches and Mairesse (1984)	0.19	77 U.S. firms (scientific sectors); 1966 to 1977
Griliches and Mairesse (1990)		
Sample 1	0.25 – 0.41	525 U.S. manufacturing firms; 1973 to 1980
Sample 2	0.20 – 0.56	406 Japanese manufacturing firms; 1973 to 1980
Hall and Mairesse (1995)	0.05 – 0.25	197 French firms; 1980 to 1987, cross-sectional estimation
	0.00 – 0.07	197 French firms; 1980 to 1987, time-series estimation
Minasian (1969)	0.08	17 U.S. firms; 1948 to 1957
Griliches and Mairesse (1984)	0.09	133 U.S. firms; 1966 to 1977
Hall and Mairesse (1995)		197 French firms; 1980 to 1987
Selected Estimates of the Elasticity of Private R&D from Studies Using Aggregate Data		
Study	**R&D Elasticity**	**Sample**
Patel and Soete (1988)	0.61	United States (TFP); 1967 to 1985
Lichtenberg (1992)	0.07	98 countries (per capita output); 1960 to 1985
Coe and Helpman (1995)	0.23	G7 countries (TFP);a 1971 to 1990
Australian Industry Commission (1995)		
Sub-sample 1	0.02	Australia (TFP); 1975 to 1991
Sub-sample 2	0.14	Australia (output); 1975 to 1991
Verspagen (1995)	(0.02) – 0.17	14 industries in 11 OECD countries; 1973 to 1988
Griliches and Lichtenberg (1984b)	-0.04	27 U.S. manufacturing industries; 1959 to 1976

Source: Based on Congressional Budget Office (2005), Mairesse and Sassenou (1991), Mohnen (1992), Griliches (1992), and Australian Industry Commission (1995).

19.2.3 Social Returns to R&D and Policy Implications

Besides the private return of R&D, scholars have emphasised that R&D is subject to positive externalities, that is, the returns of R&D are not only of private nature, but R&D also has social benefits. Unlike investments in tangible assets where firms can appropriate the returns of their investment more easily, the knowledge creating process of R&D investments is assumed to create high social returns as firms cannot capture all the returns of such investments. In a seminal paper, Arrow (1962: 615) stated that "no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information. The very use of the information in any productive way is bound to reveal it, at least in part. Mobility of personnel among firms provides a way of spreading information. Legally imposed property rights can provide only a partial barrier, since there are obviously enormous difficulties in defining in any sharp way an item of information and differentiating it from similar sounding items".

The imperfect appropriability of R&D gave rise to studies where scholars have estimated not only the private return to R&D, but also the social return to R&D. In a pioneer study, Mansfield et al. (1977) present results of case studies of four process and 13 product innovations. They find that the social return largely tends to exceed the private return. At the median, their estimates of social returns to R&D are more than twice as high as the private return.

Further quantitative studies that attempt to estimate the unintended benefits of pursuing some new research, the social return, also find consistently positive results and they are much larger than the private return. Table 19.2 summarises the social rate of return on various manufacturing firms. The first column presents the rate of return due to spillovers from the manufacturing sector while the second column gives the spillover return from other industries. Both added together give a combined rate of return of about 100 per cent.

Table 19.2: Estimates of the Social Rate of Return in the Manufacturing Industry

Study	Own R&D (Spillovers within Industry)	Used R&D (Spillovers from other industries)
Terleckyj (1980)	0.25	0.82
Sveikauskas (1981)	0.17	
Scherer (1982)	0.29	0.74
Griliches and Lichtenberg (1984a)	0.34	0.41
Griliches(1994)	0.30	

Source: Jones and Williams (1988). All studies are carried out on manufacturing industry except Scherer (1982) which includes some service sectors.

All these studies overwhelming show that R&D contributes significantly to productivity and that social rates of return are higher, and consequently spillovers are very important to growth. Griliches (1992) a pioneer in innovation economics summarised, “In spite of (many) difficulties, there have been a significant number of reasonable well-done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large and social rates of return remain significantly above private rates”.

Griffith et al. (2004) extend the standard spill-over discussion to an analysis on countries leading in certain technologies, so-called frontier countries, and others lying “behind the frontier”. They compute a TFP measure and rate those countries (or their firms) with the highest productivity as leaders, or “frontier” countries. The use of frontier is deliberate because of the idiom that knowledge created cannot be lost, though its value can change. Those countries on the frontier must be creating knowledge or using existing knowledge more effectively, but either way leads them to carry higher productivity rates. The other countries are termed as lying “behind the frontier”.

They use industry-level data and show that some countries are more or less permanently on the frontier in some technologies, but “behind frontier” countries are typically catching up to the frontier over time. However, they also find evidence that single countries diverge in certain industries. The issue of convergence is intrinsically linked to the productivity growth rate, because those behind the frontier must exhibit higher growth rates, while the frontier countries may also be continually increasing. Griffith et al. (2004) also show some sectors that have experienced leap-frogging of the technological frontier. In the chemicals sector Japan and

Germany reciprocate the leadership. In 1971 Japan has higher productivity but by 1981 it has fallen into second place. Then again in 1990 Japan has regained the frontier position.[3]

In the study distance from the frontier is shown to exhibit greater potential for productivity growth as those countries capture spillovers from the frontier. However the authors also find "strong evidence that R&D has a second face, country industries lagging behind the productivity frontier catch up particularly fast if they invest heavily in R&D". Some knowledge is tacit, and difficult to imitate without direct investigation, so in order to fully benefit from new-knowledge they need to have some intellectual or technical experience already in that industry. This is usually called the 'absorptive capacity', and is assumed to be increased by increasing R&D within that technical field. Absorption can also be thought of as imitation costs, and Mansfield et al. (1986) present evidence of substantial costs of imitation: on average, 65 per cent of innovation costs. It is no use for non-frontier countries to hope to contribute or pick up the spillover effects to improve computing developed elsewhere if no-one in their country has ever heard of a qubit. Griffith et al. conclude that those countries behind the frontier, with higher spending on R&D display faster convergence. Another implication from this conclusion is firms behind the frontier will gain a higher return to their R&D because this is where most social return applies.

This raises the potential for governments to raise the absorptive capacity of the economy in order to capture higher social rates of return delivering higher overall productivity. While the results pointing to strong spill-over effects emphasise the importance of R&D for an economy, they, in turn, also highlight an economic dilemma: firms will only invest in innovation projects showing a positive expected private return. However, there may be many projects that promise a high social return, but those may not be privately profitable as firms cannot appropriate all returns as hypothesised by Arrow. The positive external effects of R&D lead to an underinvestment into R&D from a social point of view, which also gave rise for active innovation policies by the government. If the government subsidises such R&D projects that are privately not profitable but generate high positive social returns it is believed that the governmental intervention into the market for R&D would stimulate private R&D such that the gap between socially desirable R&D and actual private investment would close. Of course, for governmental agencies distributing subsidies, it may be difficult to detect such projects. Furthermore, as soon as subsidies are available in an economy, firms would always have an incentive to apply for subsidies even for privately profitable projects as public funding comes at zero marginal cost (if one abstracts from administrative cost for proposal submissions etc.) which may lead to crowding-out effects.

Whether or not the crowding-out effects of public R&D funding occur has been discussed at length in the economic literature. David et al. (2000) and Klette et al. (2000) review the literature on public R&D subsidies and find mixed evidence, but the majority of studies point to the conclusion that full crowding-out effects of policy measures can be rejected. They also highlighted several econometric problems that were not handled well in the literature; especially econometric results that were subject to sample selection bias. Aerts et al. (2006) review studies that have taken the comments on the econometric shortcomings into account, and find that there is vast support for the rejection of crowding-out effects in more recent literature. Hall and Van Reenen (2000) surveyed the literature on fiscal measures, that is, R&D tax credits, and also confirmed positive effects. They conclude that, on average, studies have found that $1 of R&D tax credit increases private R&D spending by about $1. Thus, the majority of policy studies indeed confirm that governments can overcome the gap between privately conducted and socially desirable levels of R&D by actively encouraging firms to invest.

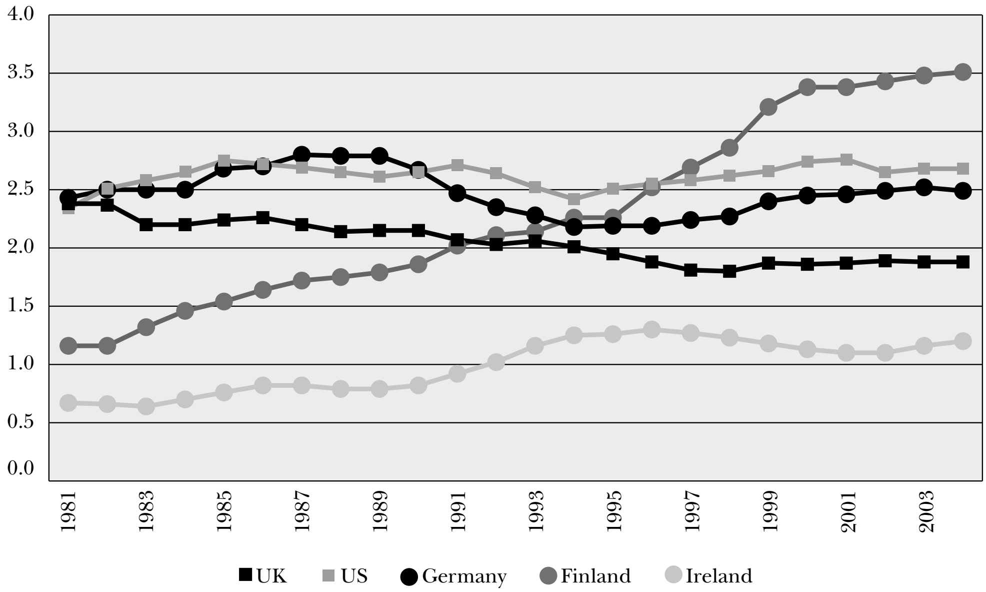
19.3 Ireland's Potential from R&D and Spillovers

As the review of the literature shows, firms and, in turn, sectors and countries seem to exhibit higher productivity (growth) the more they engage in R&D activities. First, own internal R&D spurs productivity through new products being introduced in the market that increase firms' revenue or through the implementation of new processes in production that lower cost or increase quality. Second, firms may benefit from spillovers of knowledge that others generated. In order to absorb such spillover effects, scholars have pointed out that a certain level of own R&D is required for building the capacity to benefit from knowledge generated elsewhere. Without the necessary capability to understand such newly generated knowledge firms may not be able to utilise information for their own benefit.

The Irish policy towards a very open economy has been successful in the past not only for the creation of employment through the attraction of FDI, but also with respect to the acquisition of knowledge and technology from abroad. Until World War II, Ireland's economy largely relied on agriculture and depended on the United Kingdom as the destination of the vast majority of exports. From the 1950s onwards, restriction on ownership and trade were continuously removed which opened the opportunity to attract foreign investment and international trade other than to the UK. By the late 1960s Ireland had become an industrialised nation that no longer relied solely on agriculture. This success was due to certain policies such as relaxing foreign ownership restrictions, and tax breaks for export-orientated firms. FDI brought knowledge and technology into the country which, in turn, enabled an export diversification away from the UK to other European countries. Joining the European (Economic) Community in 1973 resulted in a further surge of inward investment and access to new markets. More recent industrial policy with focus on sectors such as chemicals, pharmaceuticals, financial services and electronics, along with privatisation efforts of former public business encouraging competition and in combination with a highly skilled labour force and moderate wage levels led to a further restructuring of Irish industry. The importance of high-technology industries has been on the rise steadily. In 2003, about one quarter of Ireland's total exports where pharmaceutical products and Ireland was a major exporter of computer software and emerging as an important centre for financial services.

Despite its tremendous success in attracting high-tech industries, Ireland lags behind in cutting-edge R&D. According to Gordon (2003), industry spending on R&D stood at about one per cent of GDP which was below the European average of 1.2 per cent and well below the United States (two per cent) and Japan (2.2 per cent). Figure 19.2 shows the development of total R&D expenditure (GERD) in relation to GDP for the past decades in comparison to selected other countries. While in 2004 the GERD to GDP ratio reaches about 2.5 per cent in Germany and 2.6 per cent in the US, Ireland is significantly below at about 1.2 per cent.

Figure 19.2: GERD as a Percentage of GDP for Ireland and Comparison Countries



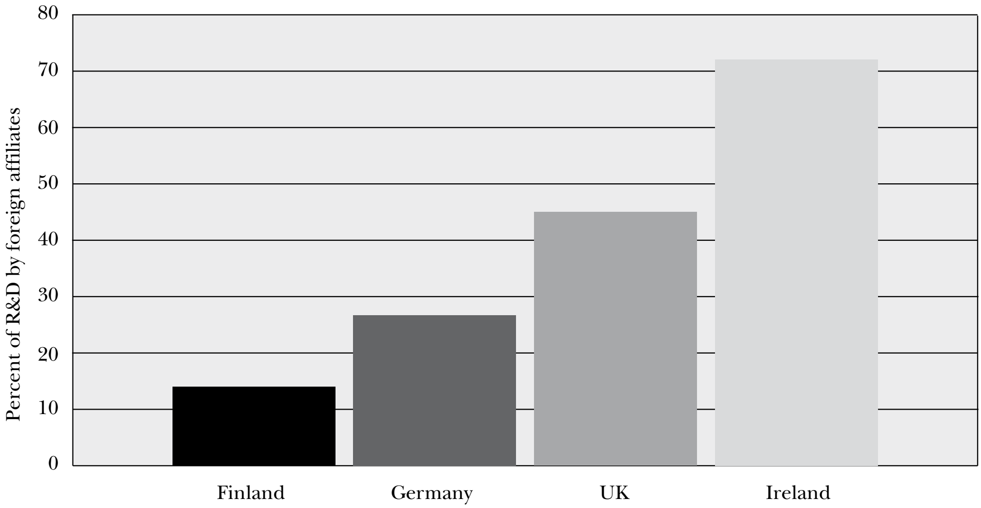
Source: OECD Main Science and Technology Indicators, 2006/1.

A remarkable difference with respect to R&D emerges between Ireland and Finland. Finland, also a small European economy on the rise, shows a much higher growth in R&D than Ireland. Finnish R&D to GDP started of at about 1.2 per cent in the early 1980s, and grew steadily to a value of about 3.5 per cent in 2004. While Finland almost tripled R&D relative to GDP, Ireland only doubled R&D from roughly 0.6 per cent to 1.2 per cent. This probably owes to the industry structure, the high extent of foreign ownership in Ireland. While FDI brought large multinational firms and, thus, employment to Ireland, R&D is still underdeveloped. While the country has a strong manufacturing base nowadays, the generation of ideas and knowledge may still be undertaken primarily in the parent companies' home bases. Figure 19.3 shows the share of R&D spend by foreign affiliates in Finland, Germany, the UK and Ireland. While Finland apparently managed to develop a strong R&D-intensive indigenous industry, Ireland heavily relies on R&D performed by foreign affiliates. This may have several implications for further productivity growth.

The currently low spend on total R&D may give room for additional innovation policy initiatives. However, this would have to be carefully evaluated beforehand. If the spillover arguments apply, the Irish situation should be a good starting point for a catching-up in cutting-edge research. The strong base in skilled labour force coupled with the recent developments in high-tech industry structure should constitute a necessary absorptive capacity allowing Ireland to utilise spillovers from local industries benefiting from the presence of large multi-national corporations.

Figure 19.3: R&D Expenditure of Foreign Affiliates as a Percentage of Total BERD in Ireland

Source: OECD Main Science and Technology Indicators, 2006/1.



If one takes the Finnish case as a benchmark, fostering R&D collaborations among industry-industry or industry-science partnerships seems to be a possible initiative to stimulate the development of an Irish indigenous R&D-intensive industry. Recently, Czarnitzki et al. (2006) investigated the effects of innovation policies in Germany and Finland. They compare R&D projects conducted within consortia of firms and/or public research institutions with public R&D funding granted to individual firms. While they find that public innovation policies lead to more R&D in both countries, interesting differences are detected. The public funding of collaborative research seems to spur private R&D spending more than subsidies that go to single firms. However, they also conclude that Finland which exhibits a very high intensity of collaborative research already, may not gain from additional policies of this kind. In Germany, where joint research is less developed, possible effects of an extension of such policies seems to be more promising than in Finland. It should be noted, however, that it is not only the level of current policy intervention which is sufficient for the successful of implementation of such schemes. In addition, those strategies are subject to the risk that firms who collaborate in R&D also collude in product markets. In such a case, potential welfare benefits of additional R&D would be undermined by reduced consumer rents.

Fostering collaborative research among local firms and subsidiaries of multinationals may especially be promising if the productivity growth of local firms and foreign-owned firms is subject to divergence. Czarnitzki (2005) investigated productivity deficiencies in Eastern Germany by benchmarking Eastern German firms with comparable Western German firms. He found the alarming result that Eastern German firms not only exhibit a significant productivity gap when one controls for observable differences to Western German firms, it turned out that the productivity between Eastern German firms that are locally owned and those that are foreign-owned (or owned by Western German firms) is diverging since the German unification in 1990. Instead of a catching-up process of the local economy, it is found that the indigenous firms lose ground. This could be an interesting area to study for the Irish case and would possibly have important policy implications. Of course, it should be noted that Eastern German companies started basically from scratch in 1990. They thus lacked the necessary absorptive capacity for a fruitful catching-up process by making use of spillovers. The Irish situation may be different. Although the indigenous industry is lagging behind the high-tech multinational corporations, they may well maintain sufficient human capital and knowledge to show high growth rates as suggested in the study by Griffith et al. (2004).

19.4 Conclusions

The impact of R&D on productivity stems from the implementation of newly generated knowledge into new products or new production processes. Knowledge is interpreted as increasing the potential and capability of the economy to produce new products that better serve the needs of society or to produce existing goods more efficiently. Several empirical studies applying a production function framework have shown that R&D activity does indeed contribute to productivity resulting in improved competitiveness of firms or countries, and thus positive long-term growth and employment prospects in the economy.

The review of the productivity literature shows that R&D is an important input factor of production. Despite several econometric difficulties, studies have shown that not only firms own internal R&D leads to positive productivity effects, but those firms can also make use of knowledge which has been generated elsewhere if they maintain sufficient absorptive capacity to utilise such information. The benefits of spillovers may be significant so that complementaries among internal R&D and spill-over effects rise to an important factor when it comes to productivity growth and ensuring long term competitiveness.

More recent research suggests that there are important differences between firms or industries and countries producing on the 'technological frontier' and those that lag behind the frontier. Scholars suggested that the benefits from spillovers may be much larger for firms or countries behind the frontier than for those being currently on the frontier.

Such findings have important policy implications for the Irish economy. While Ireland has shown impressive growth rates and industry restructuring towards a modern knowledge economy, it still lags behind the European average when it comes to R&D. Thus, Ireland's situation with respect to cutting-edge research could be subject to future improvements, especially the industry structure which is characterised by a large share of foreign ownership in the high-tech sectors suggests that the local indigenous economy may have the tremendous opportunity to make use of spillovers if its R&D activity is spurred and reaches sufficient absorptive capacity. This may be beneficial for sustainable long-term development of the economy.

Notes

1 Henceforth we talk about 'firms' when we refer to the index *i*. It should be noted, however, that such analyses can also be conducted at the sectoral level or country level.

2 Sometimes, researchers did not use output on the left-hand side of the equation but TFP. In such case, one first has to estimate the production function (2) without R&D under the assumption of constant returns to scale ($\alpha + \beta = 1$). The estimates are used to calculate TFP, which is then related to R&D in a second regression.

3 The dynamics of technical leadership are complex and non-trivial but a discussion on leap frogging in a historical context can be found in Brezis et al. (1993).

References

Aerts, K., Czarnitzki, D. and Fier, A. (2006), *Econometric Evaluation of Public R&D Policies: Current State of the Art,* unpublished manuscript, Leuven.

Australian Industry Commission (1995), *Research and Development.* Report No. 44. Canberra: Government Publishing Service.

Brezis, E., Krugman, P. and Tsiddon, D. (1993), "Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership," *American Economic Review* 83, 1211–1219.

CBO (2005), "R&D and Productivity Growth", US Congressional Budget Office.

Coe, D. and Helpman, E. (1995), "International R&D Spillovers", *European Economic Review* 39(5), 859-887.

Czarnitzki, D. (2005), "Extent and Evolution of the Productivity Deficiency in Eastern Germany", *Journal of Productivity Analysis* 24(2), 209-229.

Czarnitzki, D., Ebersberger, B. and Fier, A. (2006), "The Relationship between R&D Collaboration, Subsidies and R&D Performance: Empirical Evidence from Finland and Germany", *Journal of Applied Econometrics,* forthcoming.

David, P.A., Hall, B.H. and Toole, A.A. (2000), "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence, *Research Policy* 29(4-5), 497-529.

ESRI (2005), "Quarterly Economic Commentary Spring 2005", *Economic and Social Research Institute,* Spring 2005.

Gordon, S. (2003), "Ireland Sets up Committee to Boost Industry R&D Spend", *EE Times UK,* Feb. 26, 2003.

Griffith, R., Redding, S. and Van Reenen, J. (2004), "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries", *The Review of Economics and Statistics* 86(4), 883–895.

Griliches, Z. (1980), "R&D and the Productivity Slowdown", *American Economic Review* 70, 343-348.

Griliches, Z. (1992), "The Search for R&D Spillovers", *The Scandinavian Journal of Economics* 94, 29–47.

Griliches, Z. (1994), "Productivity, R&D and the Data Constraint", *American Economic Review* 84(1), 1-23.

Griliches, Z. and Lichtenberg, F. (1984a), "Inter-industry Technology Flows and Productivity Growth: a Reexamination", *Review of Economics and Statistics* 66(2), 324-329.

Griliches, Z. and Lichtenberg, F. (1984b), "R&D and Productivity Growth at the Industry Level: Is There Still a Relationship?", in: Griliches, Z. (ed.), *R&D, Patents, and Productivity*, Chicago: University of Chicago Press.

Griliches, Z. and Mairesse, J. (1984), "Productivity and R&D at the Firm Level", in: Griliches, Z. (ed.), *R&D, Patents, and Productivity*. Chicago: University of Chicago Press.

Griliches, Z. and Mairesse, J. (1990), "R&D and Productivity Growth: Comparing Japanese and U.S. Manufacturing Firms", in: Hulten, C. (ed.), *Productivity Growth in Japan and the United States*, Chicago: University of Chicago Press.

Hall, B.H. and Mairesse, J. (1995), "Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms", *Journal of Econometrics* 65, 263-293.

Hall, B.H. and Van Reenen, J. (2000), "How Effective are Fiscal Incentives for R&D? A Review of the Evidence", *Research Policy* 29(4-5), 449–469.

International Monetary Fund (2005), "Balance-of-Payments", CD-ROM, edition: March 05.

Jones, C. and Williams, J. (1998), "Measuring the Social Rate of Return to R&D", *Quarterly Journal of Economics* 113(4), 119–135.

Lichtenberg, F. (1992), *R&D Investment and International Productivity Differences*, NBER Working Paper no. 4161, Cambridge, MA.

Klette, T.J., Møen, J. and Griliches, Z. (2000), "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconometric Evaluation Studies", *Research Policy* 29(4-5), 471-495.

Mairesse, J. and Sassenou, M. (1991), "R&D and Productivity: A Survey of Econometric Studies at the Firm Level", *OECD Science-Technology Review* 8, 9-44.

Mansfield, E.J., Rapoport, J., Romeo, A., Wagner, A. and Beardsley, G. (1977), "Social and Private Returns from Industrial Innovations", *Quarterly Journal of Economics* 91(2), 221-240.

Minasian, J.R. (1969), "Research and Development, Production Functions, and Rates of Return", *American Economic Review* 59(2), 80-85.

Mohnen, P. (1992), *The Relationship Between R&D and Productivity Growth in Canada and Other Major Industrialised Countries*, Ottawa: Economic Council of Canada.

Patel, P. and Soete, L. (1988), Measuring the Economic Effects of Technology, *OECD STI Review* 4, 121-166.

Schankerman, M. (1981), "The Effects of Double-Counting and Expensing on the Measured Returns to R&D", *Review of Economics and Statistics* 63(3), 454-458.

Scherer, F.M. (1982), "Inter-industry Technology Flows and Productivity Growth", *Review of Economics and Statistics* 64(4), 627-634.

Sveikauskas, L. (1981), "Technological Inputs and Multifactor Productivity Growth", *Review of Economics and Statistics*, LXIII, 275-282.

Terleckyj, N. (1980), "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries", in: J.W. Kendrick and B.N. Vaccara (eds.), *New Developments in Productivity Measurement and Analysis*, Chicago: University of Chicago Press.

Verspagen, B. (1995), "R&D and Productivity: A Broad Cross-Section Cross-Country Look", *Journal of Productivity Analysis* 6, 117-135.