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# TARGETING R&D: ECONOMIC AND POLICY IMPLICATIONS OF INCREASING R&D SPENDING (STI WORKING PAPER 2003/8)

**Science and Innovation**

**Jerry Sheehan & Andrew Wyckoff**

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**TARGETING R&D:**
**ECONOMIC AND POLICY IMPLICATIONS OF INCREASING R&D SPENDING**

**Jerry Sheehan – Andrew Wyckoff**

**Abstract**

Setting R&D spending targets based on R&D intensities (GERD as a share of GDP) has been a part of science and technology policy in many OECD countries for at least 35 years. What is new is that the targeting of R&D has become more widespread and a more visible goal commanding considerable attention in high-level white papers, summits and policy proclamations. This paper examines the factors that have contributed to the growing popularity of these targets and analyses in more detail the economic and structural consequences of achieving the increased levels of R&D spending by looking at the profile of individual countries with a high R&D intensity and those countries who have achieved a recent significant gain in their intensity. It then traces some of the implications of a higher R&D intensity for the European Union: the R&D spending levels that would be required to meet the target announced by Ministers at the 2002 summit in Barcelona, the human resources needed to conduct this R&D and the possible geographic distributional issues. It concludes by outlining the policy issues--many of which exceed the traditional boundaries of S&T policy--that will have to be addressed in pursuit of these R&D intensity goals.

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# INTRODUCTION

Recent years have seen an increasing number of national and regional governments establish explicit targets for levels of R&D spending. These targets are often expressed as a goal of increasing gross expenditures on R&D (GERD) to a specified level of GDP (*i.e.* R&D intensity) by a specified year, or as achieving a specific ranking among OECD countries in R&D intensity. Such targets reflect the growing recognition of the linkages among R&D, innovation and economic growth and more widespread attempts to use science and technology policy (*e.g.* R&D funding policy) to meet economic objectives. Increased levels of R&D funding are viewed as an input to an innovation process that will improve economic performance, boost productivity and result in increased wages and standards of living.

While much work to date has focused on the downstream effects of R&D targeting and R&D investments more generally – measuring the contributions of R&D funding to output and productivity growth and identifying good practices for improving the economic returns to R&D investments by the public and private sectors – little analysis has examined the upstream effects of R&D targeting. What kinds of structural and regulatory changes are necessary to boost R&D spending sufficiently to meet established? What is the likely effect of such targets on the public and private-sector R&D performers? What are the implications for human resources and on the geographic distribution of R&D? Empirical evidence from countries that have achieved high levels of R&D spending or have rapidly increased R&D intensity provides some insight into these questions, even if it cannot answer them conclusively for all countries.

This paper examines the policy implications of R&D targeting at the national and regional levels. It first discusses the apparent motivations behind the increased tendency to establish R&D spending targets – changing drivers of economic growth and the role of R&D and innovation in that process – and reviews the targets that have been established by OECD member countries. It then analyses the recent R&D target set for the European Union as a specific example with which to illustrate the likely implications of R&D targets on industry structure, human resources and geographic distribution of resources. While the analysis is specific to the EU, the conclusions are applicable, to varying degrees, to other attempts at targeting, and show that high levels of R&D funding – and significant increases in R&D funding – are as much the end result of significant economic and policy restructuring as they are drivers of subsequent improvement in economic performance.

**SCIENCE, TECHNOLOGY AND ECONOMIC GROWTH**

## The changing nature of growth in the 1990s

The bursting of the dot-com and telecommunications bubbles and a series of recent accounting scandals have cast doubt on the performance of some of the fast growing firms during the 1990s and dissipated some of the hype associated with the so-called new economy. In this environment, a more sober assessment of the determinants of economic growth during the 1990s can occur. While the fundamentals of a stable macro policy – competitive product markets, flexible labour markets and a well functioning financial system – can be asserted, it is clear that science and technology, especially as regards the information and communication technologies (ICT), were key differentiating determinants of growth performance across countries. The United States has been the laboratory for much of this analysis, but in fact the importance of ICT to growth, both in terms of production and use, has been confirmed for several other countries as well (Colecchia & Schreyer, 2001). Sceptics who believed that the above-trend productivity growth of the US was attributable to ICT producing sectors or cyclical trends have to account for recent productivity data that shows that strong gains continue even as ICT production declines, a shake out occurs and the economic cycle goes through a downturn (Sichel and Oliner, 2002; Baudchon, 2002).

While the importance of science and technology to economic growth has been asserted for some time (Freeman *et al.*) it was never fully incorporated into mainstream economic policy, such as that promulgated by central bankers and Ministers of Finance. This attitude started to change in the mid-1990s when the Chairman of the US Federal Reserve Board, Alan Greenspan, began publicly to question the accuracy of measures of output, especially in the service sector, and the real price movements of output, leading to the conclusion that productivity was underestimated and inflation overestimated (Wessel, 1996). Greenspan became an early advocate of the important effect of ICT on the US economy, describing it as another industrial revolution (Greenspan, 1998). Subsequent work found that the contribution of computers to output growth more than doubled between the first and second half of the 1990s, and that multifactor productivity growth had increased by nearly a factor of four from the 1980s and a factor of five from the early 1990s (Sichel and Oliner, 1999). Such analyses began to illustrate that ICT (in particular the Internet) was a transforming technology that, while not repealing fundamental laws of economics, was having a significant economic impact, and that the US and a handful of other countries like Australia, Finland and Ireland were capturing many of the economic benefits.

These observations led Ministers who were meeting at the OECD in June of 1999 to ask the Organisation to analyse the observed divergence in growth trends across Member Countries during the 1990s. In particular, Ministers highlighted the need to better understand *"…rapid technological innovation, the growing impact of the knowledge society and conditions for fostering the start-up and growth of new enterprises*" (OECD, 1999). The interest in science and technology as a determinant of economic growth a high-level has been particularly evident at recent EU summits (Lisbon and Barcelona) as well as recent meetings on European central bankers.

**S&T vs. S&T policy**

While economists increasingly agree that innovation led growth is important, there is considerably less recognition that S&T policy has anything to do with it. Instead, mainstream economists stress getting the fundamentals right and sound macro-economic policy are the critical factors that allow businesses to invest in R&D and innovate. Accepting that market failures and difficulties in appropriating the returns from investments in innovation may limit business R&D investments, they may see a role for R&D tax incentives, government financing of public R&D or the granting of intellectual property rights, but they tend not to see a need for direct government support of business R&D, viewing such programmes as unnecessary subsidies that are subject to political capture (Noll and Cohen, 1991). In general, mainstream economics tends to accept the belief espoused by many entrepreneurs during the 1990s that the government should get out of the way and let the market place, best symbolised by free wheeling Silicon Valley, work.

These concerns are well founded. Economic fundamentals are important, direct government involvement in S&T can result in bad decisions especially when politics intervene, and in general the marketplace is best able to pick winners and punish losers. However, these conditions are necessary, but not sufficient, for fostering innovation-led growth. These views fail to accurately reflect the history of many scientific and technological breakthroughs in which governments played a direct role in financing technological development and in creating new markets for resulting inventions. In this sense, the notion of getting the fundamentals right is akin to having a farm where the soil is fertile, the sun shines and sufficient rain falls, but nothing will grow without the seed, and the seed is frequently the result of government S&T policy.

The important role of direct government S&T policy is possibly best seen in the high-profile technologies of the 1990s – the Internet, e-commerce and ICT more generally. Many of the fundamental innovations in this area, including the Internet, the World Wide Web and the Web browser, emerged not from competitive market processes, but from government-funded research that was conducted in universities, industry, and government laboratories (CSTB, 1999). More generally, the history of many important ICT innovations such as computer timesharing, inter-networking, work stations, graphical interfaces, e-mail, parallel computing, and relational databases all involved significant R&D on novel types of computing systems, much of which was conducted as part of government programmes, in some cases after the market had abandoned the research (CSTB, 1995 and 1999).

Granted, in the case of ICT, much of this research was not sponsored with the explicit aim of launching new commercial industries, but was linked to other government missions, most notably defence. This is the case with most government funding of industry research: it does not aim at fostering economic development directly, but is public procurement aimed at ensuring government's ability to carry out certain missions: promoting health, providing defence, protecting the environment, etc. Only a small part of government funded business expenditure on R&D consists of direct subsidies: about 19% in the US, 7% in Japan, 24% in France, 4% in the UK, and 25% in Germany (Young, 2001). Moreover, a close look at the concerned programs shows that most of them are not industry-specific, but address generic technologies, such as new materials. In general, OECD governments have funded R&D in a manner where these funds have had a high, positive impact on MFP growth over the past 20 years (Guellec and van Pottelsberghe de la Potterie, 2001).

**Putting round S&T policy plugs into square economic policy holes**

As S&T policy begins to be better appreciated by economic policy makers, a transition appears to be occurring where there is now a desire to include S&T in more general economic frameworks. This has led to a desire for quantification and more accountability. The S&T community has also seen it as an opportunity for solidifying their new position and gaining resources.

These dynamics have fuelled demand for statistics and related indicators that attempt to measure various parts of the innovation process – R&D, human capital, innovative products or processes, the role of universities, business, government, etc. More recently, these indicators have been compiled into various scoreboards or competitiveness reports that are now used to benchmark performance against world leaders. Most benchmarking exercises use these indicators only as a point of departure and then undertake comparative policy analysis looking at the interrelation of these different elements and qualitative factors such as polices in other realms (*e.g.* competition policy), the evolution of institutions in the country (*e.g.* Department of Defense in the US) and cultural norms (*e.g.* the lack of private universities in Europe). Nevertheless, the numbers have begun to assume a life of their own, partly because they convey in a simple way the messages that can help maintain political momentum for particular programmes.

The most popular indicator is the R&D intensity of a country, as measured by the amount of R&D it performs divided by GDP. This interest persists notwithstanding the fact that the weaknesses of this indicator are well known, most notably that it measures only one type of S&T input (R&D) and not the results or S&T outputs. A primary reason why the indicator of R&D intensity is more popular than other data such as commercial successes from innovation or fundamental breakthroughs or the diffusion and adoption of technological advances that will boost productivity is that R&D spending is a quantifiable entity that has been measured in OECD countries for some 40 years. Furthermore, numerous econometric studies have demonstrated a quantifiable relation to economic growth that has been growing over time, providing further justification for efforts to improve economic performance by boosting R&D spending.[1]

The use of the indicator of R&D intensity as a measure of innovative capability is hardly new. OECD documents dating back to 1968 use it to document technology gaps, particularly one that was perceived to have existed between the US and Europe (OECD, 1968). What is new is that now these indicators are not used merely for comparisons that lead to more probing qualitative analysis, but they are used as explicit targets that politicians have pledged to achieve by certain dates. As of 2003, a number of OECD countries, including Austria, Canada, Finland, Germany, Japan, Norway and Spain, and the regional grouping of the European Union had set specific R&D spending targets (Table 1). The EU’s target, along with those of Austria, Germany and Spain, are linked to absolute measures of R&D intensity; those of Canada, Norway and Hungary are based on a relative ranking of R&D intensity among OECD countries (see Box 1 at the end of this document for a discussion of such relative R&D intensity targets); Korea’s is linked to government R&D expenditures measured as a share of total government expenditure, but Korea also established a target in the 1980s to boost R&D intensity to 3.1% of GDP by 2001 — a goal it more or less achieved. Most of these targets are inspired by countries such as Finland, the United States and to a lesser degree Ireland, whose economic performance in the 1990s appeared to be innovation-driven and who succeeded in rapidly increasing their R&D intensity.

1. Guellec and van Pottlesberghe find a long-term elasticity of MFP to business R&D of 0.13 (OECD, 2001). See Nadri (1993) for a survey of the literature.

**Table 1. Examples of R&D spending targets in the OECD**

| Country/region | R&D intensity in 2001[1] | R&D target | Target date |
|---|---|---|---|
| European Union | 1.88% | 3.0% of GDP | 2010 |
| Austria | 1.90% | 2.5% of GDP | 2005 |
| Canada | 1.94% | Top 5 on OECD | 2010 |
| Germany | 2.49% | 3.0% of GDP | 2010 |
| Hungary | 0.95% | OECD average | 2006 |
| Korea | 2.96% | 5% of total government spending | 2002 |
| Norway | 1.62% | At least OECD average | 2005 |
| Spain | 0.96% | 1.29% of GDP | 2003 |

1. 2000 for European Union.
*Source:* OECD (2002).

R&D targets serve a clear political purpose by providing a tangible goal for S&T policy. By their simplicity, they can at the same time suggest fairly straightforward solutions to complex problems: increasing public and private investments in R&D will lead to increased innovation, productivity and economic performance, without having to address thorny structural and social issues such as labour and financial market reform, strengthening of education systems, and sectoral policies.[2] In this view R&D spending is seen as an input to economic processes that will generate increasing outputs. Nevertheless, high levels of R&D intensity are the outcome of industry, economic, and social structures, and reaching R&D targets often implies that a range of economic and social issues be addressed head-on. Achieving high levels of R&D can demand significant structural and regulatory change beyond those that are immediately apparent in what appears to be a straightforward financial goal.

To illustrate the economic and policy implications of R&D targets, this paper examines the recent example of R&D targeting by the European Union. It quantifies the economic consequences of achieving these targets and the kinds of broad-based policy reforms that will be demanded: how much additional R&D spending does the target entail? How much funding will come from government treasuries and how much can industry be expected to contribute? What are the likely effects on the industrial structure of a country and on international flows of R&D funding, such as through foreign affiliates of MNEs? How many additional S&T workers are needed to perform the R&D? The policy implications are significant, as they affect not only R&D funding policies, but incentives to stimulate business R&D investments, education policy, international mobility of workers, and structural adjustment. Although the specific objectives and figures relate to the EU situation, the general results apply, to differing degrees, to all countries that establish R&D spending targets.

2. The former Chairman of the US Council of Economic Advisors, Martin Bailey, stated in regard to the EU target: “Europe is in danger of looking for technological answers because they do not want to face hard choices on issues where there is so much political opposition” (WSJ 2002). Presumably, he was referring to the unwillingness of Ministers to address the politically charged issues associated with labour market reforms, privatisation of state owned firms, increased competition in product markets and regulatory reform of financial markets.

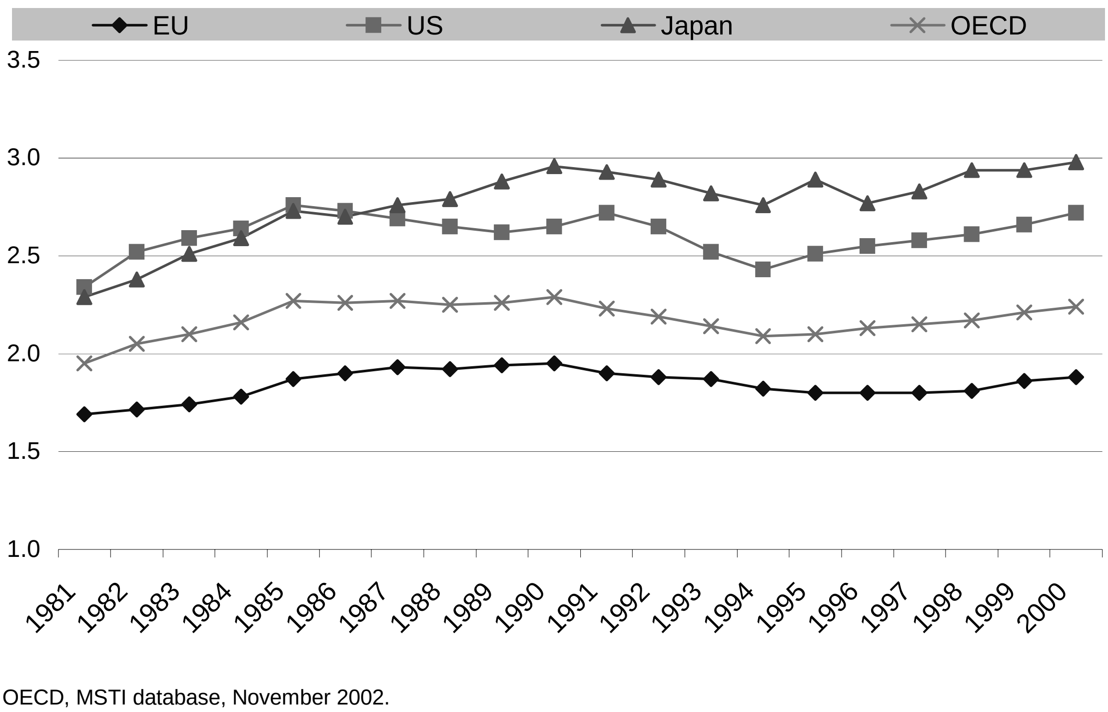
## THE EU R&D TARGET: CLOSING THE GAP

At the March 2002 meeting of the European Council in Barcelona, European Ministers announced a goal *of "…turning the EU into the most competitive knowledge-based economy in the world."* One identified objective for achieving this status is to raise spending on R&D and innovation in the EU so that it approaches 3% of GDP from its current level of 1.9% by 2010. Approximately two-thirds of the increased R&D spending is to come from the private sector.[3] This objective has received considerable attention and achieved high visibility, especially because the European Commision has been at the forefront of developing benchmarking as a policy tool and because it is a continental-wide goal being pursued by a large economic grouping. The objective is not for each member country to raise its R&D intensity to 3% of GDP, but to achieve that target as a region, recognising variation in the R&D intensities of individual countries.

The target results largely from gaps between US and EU economic performance over the last decade. In contrast to the US experience during the 1990s, many European countries, especially the large ones, had relative weak productivity gains and more sluggish GDP growth. The EU, US and Japan saw declining levels of R&D spending as a share of GDP in the early 1990s, but R&D intensity climbed in the US and Japan during the latter half of the decade, widening the R&D gap with Europe (Figure 1). Whereas US R&D intensity climbed from 2.4% to 2.7% during the economic boom of the late 1990s, regaining the levels achieved in 1985 and 1991, and Japan's increased from 2.7% to 3.0%, R&D intensity in the European Union declined during most of the decade, recovering slightly after 1997 to 1.9%.

**Figure 1. Trends in R&D intensity, 1981-2000**

as a % of GDP



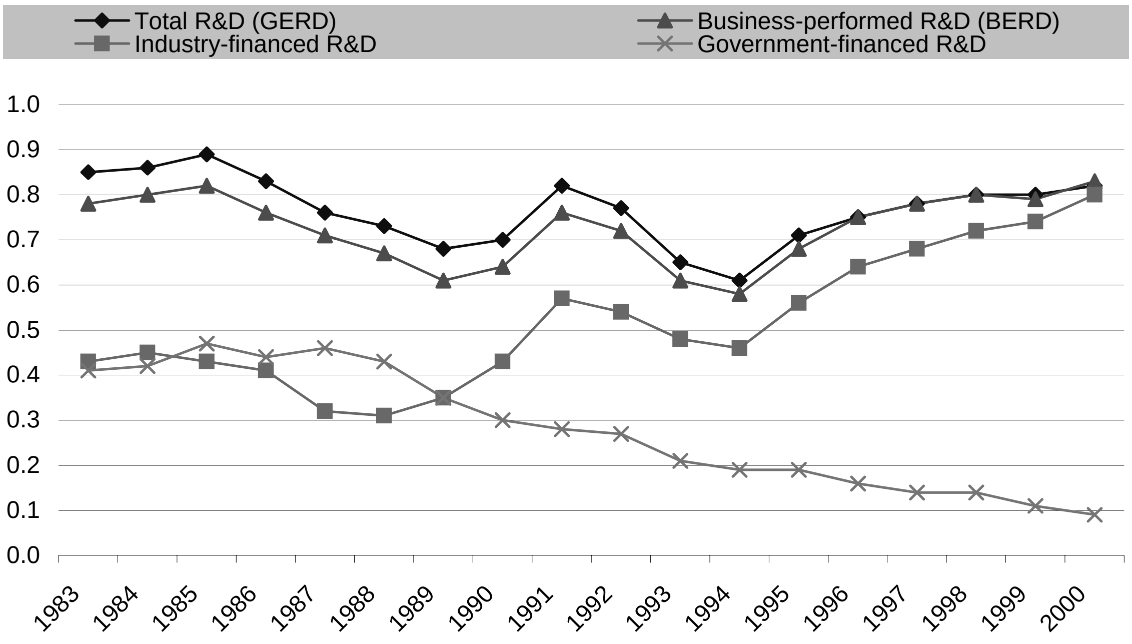

*Source:* OECD, MSTI database, November 2002.

3. See page 20 of European Commission (2002).

The gap between R&D spending in the US and Europe derives mostly from differences in relative levels of industry-financed and business-performed R&D (BERD) – a gap that has widened over the past two decades (Figure 2). On the R&D financing side, the gap of 0.85 percentage points in 1983 was evenly divided between shortfalls in industry – and government-financed R&D. Both measures lagged the US by approximately 0.4 percentage points. Since then, the source of the financing gap has changed dramatically as government support for R&D declined in the US and industry financing grew. By 2000, the gap between the EU and US in government financing of R&D had declined to just 0.1 percentage points of GDP, while that for industry-financed R&D had widened to more than 0.8 percentage points. This shift is also evident in R&D performance, where by 2000 the gap in GERD intensity was accounted for almost entirely by a gap in BERD intensity of 0.8 percentage points, up from less than 0.6 percentage points in 1994.

**Figure 2. Gaps in R&D intensity between the US and EU**

Percentage point difference in R&D as a share of GDP

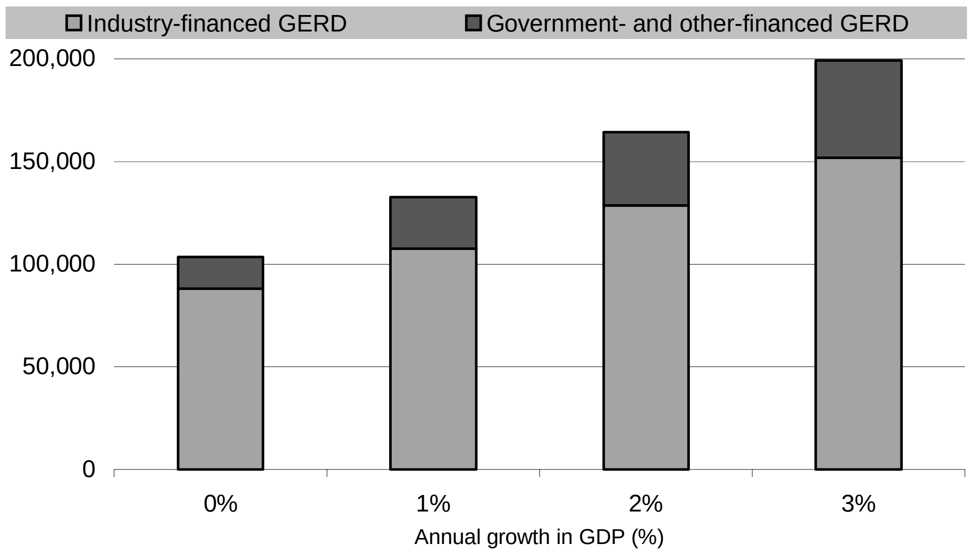



*Source:* OECD, MSTI database, November 2002.

Closing the gap between the US and the EU and meeting the proposed EU target for R&D intensity will require considerable increases in R&D expenditures. The exact figure will of course depend on the rate of growth of GDP over the remainder of the decade. Assuming no growth in GDP (a rather unattractive assumption from the perspective of increased living standards), a 3% R&D intensity target implies that total EU R&D expenditures would need to grow to USD 278 billion PPP in the year 2010 – a USD 100 billion increase over their 2000 levels (Figure 3). If GDP growth were closer to historical levels of 2%, R&D spending would have to grow by an additional USD 164 billion by 2010 – to roughly twice the 2000 level. The average annual real rate of growth of R&D spending will have to rise to almost 7% a year, more than three times the real annual rate of growth during the 1990s.

**Figure 3. Estimated growth in R&D spending needed to meet proposed EU target in 2010**

Millions of PPP $




Note*:* Based on 15 current EU members..
*Source*: OECD, based on data from the OECD Main Science and Engineering Indicators database, November 2002.

The burden of meeting the proposed target is even greater for industry than for government. Not only is industry-financed R&D the primary source of the R&D gap, but also Ministers at the Barcelona meeting of the European Council called for industry-financed R&D to account for two-thirds of total R&D spending in 2010 (*i.e.* 2% of GDP). Even with no growth in GDP, industry R&D spending would have to increase by USD 88 billion between 2000 and 2010 (from its level of USD 97 billion in 2000) to meet this target. Government-funded R&D, in comparison, would need to increase by only USD 15 billion. With 2% growth in GDP, industry R&D spending would need to increase by USD 128 billion by 2010, or at a rate of almost 9% annually. This is roughly three times the rate of growth in industry-financed R&D during the 1990s and would result in more than a doubling of industry R&D investments during the course of the decade. In this scenario, government R&D funding would need to increase by USD 36 billion.

It must be noted that the ability of firms to boost their expenditures on R&D is influenced by rates of GDP growth and vice-versa. Within larger, established firms (which account for most business R&D), R&D is funded largely from retained earnings, making R&D a difficult investment during periods of slow economic growth. New firm creation also tends to decline during economic slowdowns, limiting R&D increases that might derive from the creation of R&D-intensive new technology based firms. During periods of economic expansion and growing corporate profits, on the other hand, firms have greater latitude to boost R&D spending, and new firm creation picks up. In fact, increases in R&D spending can spur productivity increases and stimulate — or lend further support to — economic growth. Hence, the apparent "catch-22" situation is resolved: while rapid economic growth raises the absolute amount of additional R&D funding that needed to meet the target, such growth can actually enable firms to make larger increases in their R&D spending.

## HITTING THE TARGET

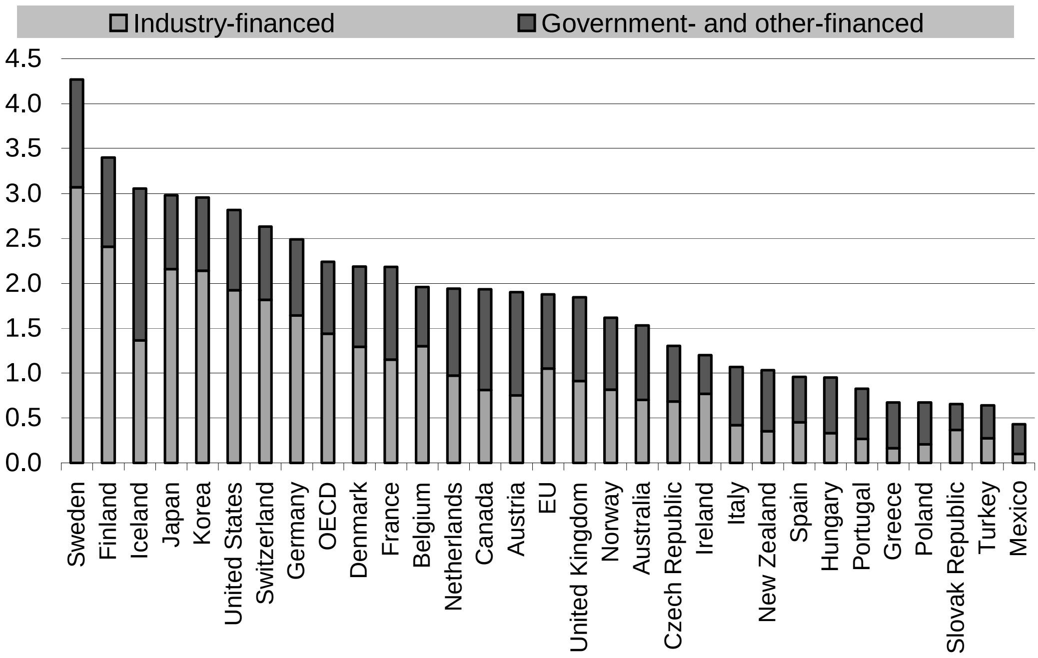
Regardless of the exact rate of economic growth, the size of the R&D spending increases required to meet the 3% target will be large, on the order of USD 100 billion in additional private-sector financing over a ten-year period. This figure contrasts with the experience of the 1990s, during which total industry-financed R&D in the EU increased by just USD 21 billion in real terms. This implies significant changes in the industrial landscape of the EU and suggests that a business-as-usual approach to S&T policy is unlikely to succeed. Attempts to use government R&D funding to directly leverage business R&D investments are on their own unlikely to achieve the desired effect: the needed ratio of increased industry-financed R&D to government-financed R&D ranges from 3.2 to 5.7, depending on the rate of GDP growth. Such leverage is far in excess of most estimates of the additional business R&D investments that can be spurred by direct government funding of business R&D or by tax incentives.

Some insight into the ways of meeting the R&D target – and the implications of meeting the target – can be gleaned by examining countries that have achieved high R&D intensities (near 3%) and/or have made sizeable gains in their R&D intensity in a relatively short period of time (0.5 to 1.0 points in a decade). Similarities in the structures of business R&D investments in these countries can indicate the types of business R&D structures that are inherent to high levels of R&D intensity and fast growth. They can also provide insight into the effects of high levels of R&D intensity on industry structure, the mix of large and small firms in the economy and the most efficient routes for boosting R&D. While such examples cannot provide conclusive proof of the steps that must be taken to achieve the EU target, they can illustrate the likely economic and policy implications of achieving high levels of R&D intensity.

Few countries have achieved an R&D intensity of 3%. As of 2001, only Sweden, Finland, Iceland and Japan had achieved R&D intensities of 3% or more, while Korea, the United States, Switzerland, and Germany had R&D intensities between 2.5% and 3% of GDP (Figure 4). The larger EU economies – with the exception of Germany – lie below OECD average, and only France lies clearly above the 2% mark. In only four OECD countries – Sweden, Finland, Japan and Korea – did industry-financed R&D exceed 2% of GDP in 2001. While continuation of R&D growth patterns could enable a few additional countries to achieve an R&D intensity of 3% of GDP — or an industry-financed R&D intensity of 2% of GDP — in coming years, these remain ambitious targets. Reaching them will be even more difficult if economic growth remains sluggish..

**Figure 4. R&D intensities across the OECD, 2001[1]**

GERD as a % of GDP

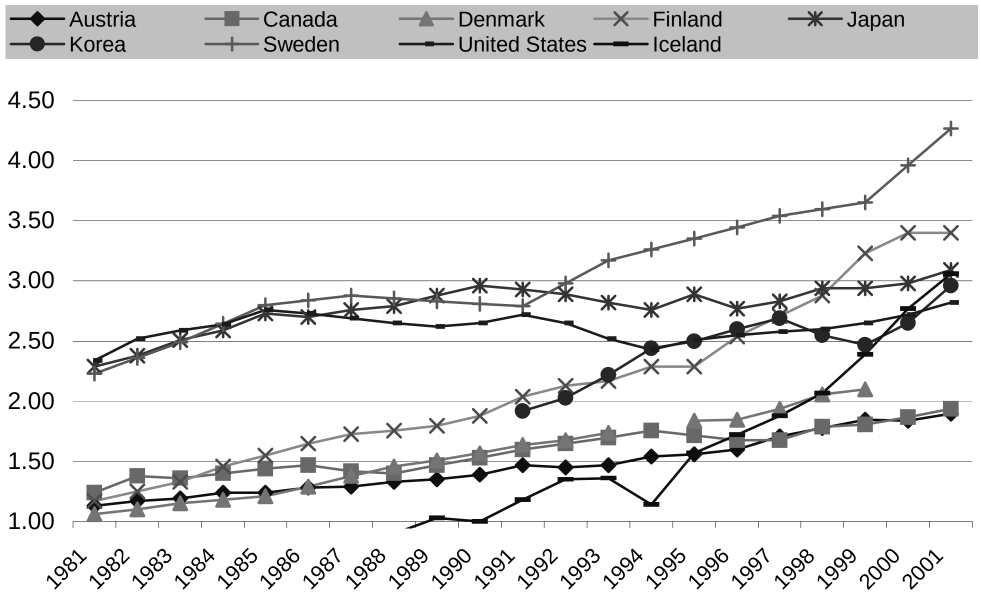



1. Or nearest available years. 2001 for Austria, Canada, Czech Republic, Finland, Germany, Hungary, Iceland, Korea, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, US; 2000 for Australia, EU, France, Italy, Japan, Netherlands, Switzerland, Turkey, UK, OECD; 1999 for Belgium, Denmark, Greece, Ireland, Mexico, New Zealand.
2. Shares of GERD financed by industry and government/other are estimated for Italy and Norway.
*Source:* OECD, MSTI database, May 2003.

Furthermore, only a small number of countries have made significant jumps in R&D intensity during the course of a single decade (Figure 5). Between 1991 and 2001, Sweden added a 1.6 percentage points to its R&D intensity, Finland added 1.4 points (after adding almost 0.9 points in the 1980s), Iceland added 1.9 points, and Korea added 2 points. Austria, Canada, and Denmark also made steady increases in R&D intensity, but each gained between 0.7 and 1.0 points over a 20-year period from 1981 to the turn of the century, and their R&D intensities remain at 2.0% of GDP or less. Japan and the United States each saw periods of rapid R&D growth between 1981 and 2001, but neither made sustained leaps of the magnitude envisioned by the EU. Japan added 0.7 percentage points between 1981 and 1990, with only marginal gains thereafter. The United States added 0.5 points over a four-year period between 1981 and 1985 and 0.4 points between 1994 and 2001, but saw declining R&D intensity during the intervening years.

**Figure 5. Countries with fast growth in R&D intensity**

GERD as a % of GDP

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*Source*: OECD, MSTI Database, April 2003.

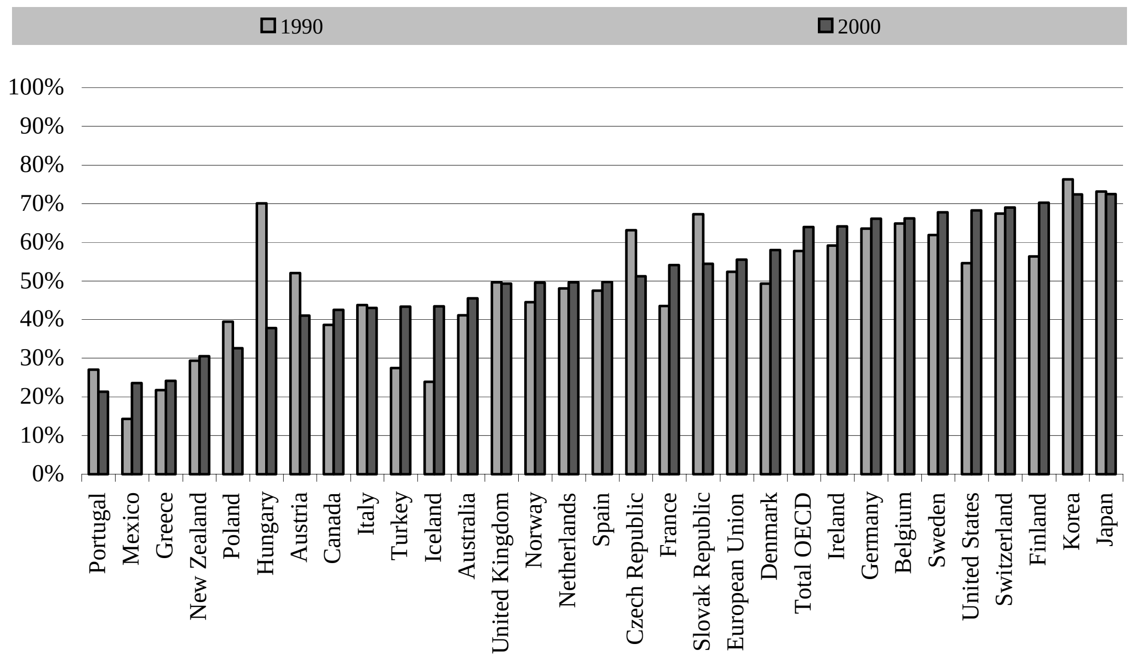
What is striking about the sample of countries that have achieved the most rapid growth in R&D intensity is that they tend to be smaller economies—Finland, Iceland and Sweden had combined populations of 14 million people in 2001 and a combined GDP of USD 372 billion. Korea, with 47 million people and a GDP of USD 753 billion, is something of an exception to this general rule, but it is still only a fraction of the size of the EU. In addition, all of the fast-growth countries except Sweden started with low levels of R&D intensity at the beginning of the 1980s (as did intermediate-growth countries of Austria, Canada, and Denmark). This combination of a small GDP and low levels of initial R&D intensity makes it easier to rapidly boost R&D intensities. Frequently this boost is due to a small number of firms: Nokia in Finland, Ericsson in Sweden, and Northern Telecom in Canada. Such growth tends to be a one-time effect that is potentially unstable and volatile as markets change (as was seen in telecommunications markets in 2002). In addition, small countries can exhibit greater specialisation in their industry structures, which can allow them to grow high-technology industry sectors disproportionately fast and achieve significant gains in R&D intensity. This specialisation is harder to achieve in larger, more diverse economies like that of the US, Japan or the EU.

## Industry as the driver

Another common feature of R&D-intensive countries is that industry accounts for a larger and growing share of their R&D than in most other OECD countries. In each of the eight countries with R&D intensities of 2.5% or more (with the exception of Iceland) industry finances between 68% and 72% of total R&D, compared to 64% on average in the OECD and 56% in the European Union (Figure 6). Not surprisingly, industry also performs the lion's share of R&D in these countries: the business enterprise sector accounted for between 71% and 75% of all R&D performed in these countries (again, with the exception of Iceland), compared to averages of just under 70% on average in the OECD and less than 65% in the European Union. This reinforces the notion implicit in the EU target that high levels of R&D intensity are not easily achieved with government resources alone, but must come largely from private-sector investments in R&D.

**Figure 6. Share of GERD financed by industry[1]**

Percent of total GERD

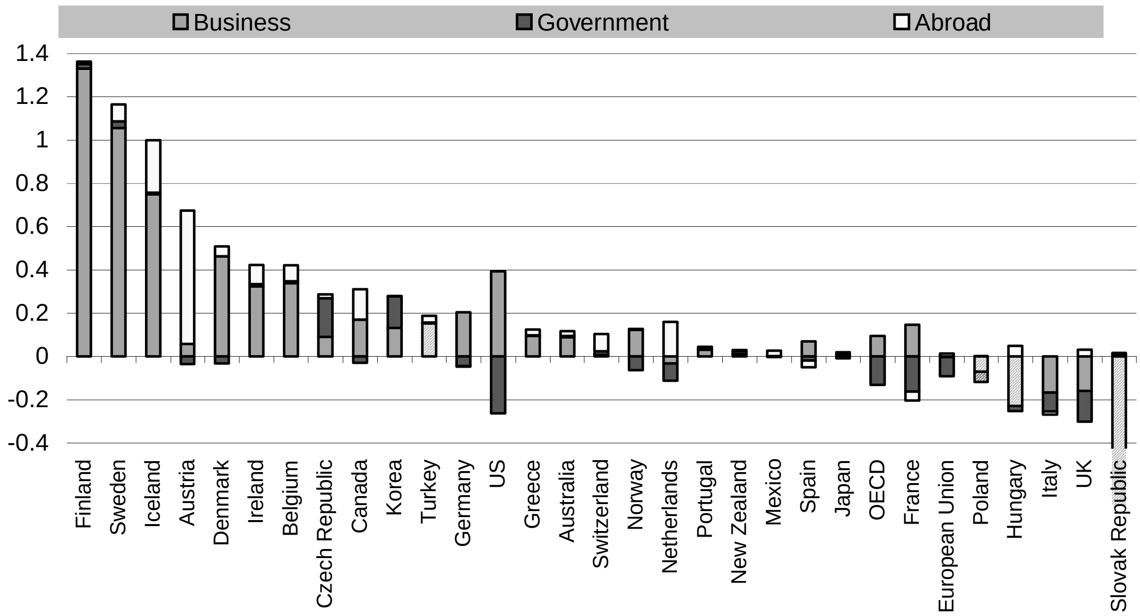



1. Nearest available years. 1999 for Belgium, Denmark, Iceland, Ireland, Mexico, Netherlands, New Zealand, Norway, Portugal, Sweden. 1996 for Italy.
*Source*: OECD, MSTI Database, November 2002.

Industry financing is especially important in boosting levels of business performed R&D. Over the past decade most of the growth in business-performed R&D was been fuelled by industry spending on R&D (Figure 7). Government funding of business R&D played a much smaller role — and declined in several countries in the 1990s. Funding from abroad, which includes some R&D in foreign affiliates (where control over spending is exercised from abroad) and from other foreign sources (*e.g.*, the European Commission in the case of European countries), also had sizeable affects in some countries, most notably Iceland, Austria, Canada, and the Netherlands. These patterns reflect a continuing shift in the financing of R&D from the public to the private sector across the OECD. Between 1990 and 2000, the share of financial support for R&D provided by industry grew from 57.7% to 63.9%, while the government share fell from 39.6% to 28.9%. Growth in the share of industry financing of R&D was particularly strong in Finland, Switzerland, and the United States, although France, Iceland, and Turkey also posted large gains.

**Figure 7. Increase in BERD intensity by source of funds, 1990-2000**

Percentage point increase in BERD as a share of GDP[1]




1. 10-year averages based on data for nearest available years. 1990-2001 for Canada; 1990-2000 for Hungary, Japan, Slovak Republic, Spain, UK, US, and OECD; 1991-2000 for Belgium and Finland; 1990-99 for Australia, Denmark, France, Iceland, Ireland, Hungary, Netherlands, New Zealand, Portugal, Turkey and EU; 1991-99 for Greece, Mexico, Norway, Sweden; 1992-2000 for Germany; Switzerland; 1994-2000 for Poland; 1995-2000 for Czech Republic and Korea.; 1993-98 for Austria.
Source: OECD MSTI database, May 2002.

## The role of large firms

Countries with high R&D intensities also tend to have more of their R&D performed by large, MNEs than lower-R&D intensive countries. In Japan, Korea, Germany, Sweden, and the United States, more than 80% of business R&D is conducted in large enterprises (with 500 or more people) – more than in any other OECD countries (Figure 8), and much of this is concentrated in a small number of firms. In 1999, more than half of all business-performed R&D in the United States was performed by firms with 10 000 or more employees – even though such firms represented less than 1% of all R&D-performing companies (NSB, 2002). Ten large firms accounted for about one-quarter of all business enterprise R&D (IRI, 2001).[4] This pattern is repeated in other countries with high levels of R&D and in which business R&D intensity climbed rapidly in the 1990s:

- In Sweden, the top ten R&D-performing companies account for about half of all business R&D, and the top 20% of firms hold approximately 80% of all patents (IPTS 2002). The R&D expenditures of Ericsson were equivalent to almost 60% of Sweden's BERD in 1999, although some of this R&D was performed elsewhere in Europe, Asia and North America (Ericsson 2001).

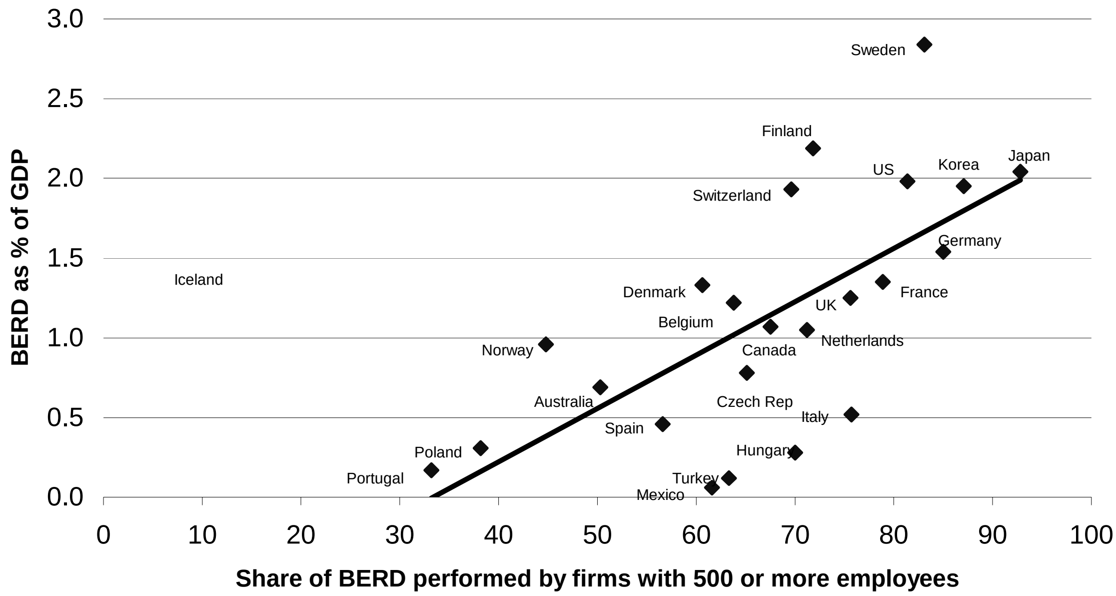
4. The Industrial Research Institute (2001) reports that in 1999 Ford invested 7.1B$ in R&D, GM 6.8, Lucent 4.8, IBM 4.6, DuPont 3.9, Motorola 3.5, Intel 3.5, Microsoft 3, Pfizer 2.8, Johnson & Johnson 2.6.

- In Finland, Nokia was responsible for performing approximately one-third of Finnish BERD in 1999, and Nokia's global R&D expenditures were equivalent more than 80% of Finnish BERD in 2001, although an estimated 40% of this funding was invested in foreign R&D centres (Ali-Yrkkö et al, 2000).

- In Korea, the top 5 companies account for 35% of the total business expenditure on R&D, and 29.6% of the total researchers employed in industry. The top 20 companies account for 55.4% and 40.2% respectively (MOST, 2002).

- In Canada, almost 40% of business R&D was concentrated in 10 firms in 2000 (Statistics Canada 2002). The R&D expenditures of Nortel Networks were equivalent to more than one-third of Canadian BERD in 2001, although the company's R&D was conducted in more than 10 countries, including Australia, China, France, the UK and the US, in addition to Canada.[5]

**Figure 8. Comparison of business R&D (BERD) intensity and the share of R&D performed by firms with 500 or more employees**




*Source:* OECD R&D database, February 2003.

This observation does not detract from the importance of small and medium-sized enterprises (SMEs) in the innovation process. In the United States, for example, the share of business R&D performed by SMEs grew during the 1990s, from approximately 12% to 18% of all business R&D. The largest US firms (those with more than 10 000 employees) saw their share of business R&D performance decline during decade. Moreover, R&D growth was fastest amongst the smallest firms (*e.g.* those with fewer than 25 employees), suggesting that start-ups and new technology based firms (NTBFs) — often drawing upon growing venture capital investments — played an especially important role.

5. Additional information on Nortel's R&D centres is available online at http://www.nortelnetworks.com/corporate/technology/innovation/randd.html.

Nevertheless, the presence of large firms may be important to the establishment and growth of NTBFs. Not only are large firms customers for the goods and services produced by NTBFs, they also serve as the seed for spin-off companies and play a role in their financing. Large firms invest directly in NTBFs through mechanisms like corporate venture capital funds, and they can indirectly stimulated additional outside investments. Mergers and acquisitions by large firms can provide investors, such as venture capitalists, with an alternative to initial public offerings for recouping their investments in NTBFs, thereby encouraging venture financing. Strong links between NTBFs and large firms therefore appear to be important in boosting R&D intensity, whether such links are forged domestically or internationally.

**Courting multinationals**

Increasing R&D investments among large firms implies courting multinational enterprises (MNEs). Many large R&D performing firms are MNEs with affiliates operating across borders. Increasingly, these affiliates are playing a significant role as performers of business R&D. They accounted for approximately 15% of total manufacturing BERD in the United States in 1998, more than 16% in France and Germany, and more than 30% in the United Kingdom. In smaller economies their importance can be even more pronounced. Almost 40% of total business R&D in Canada and Australia and more than 65% in Ireland and Hungary is performed by foreign affiliates.

Patterns of investment by MNEs account for part of the widening gap in R&D financing between the US and EU. Total R&D investments by foreign affiliates increased by more than 50% between 1991 and 1998 in the OECD area. Much of this went increase occurred in the US, which experienced a gain in the share of OECD foreign affiliate R&D from 45% to 55% over the period. A significant portion of this shift towards the US came from EU firms. Between 1994 and 1998, the R&D expenditures of US-based affiliates of EU firms climbed from approximately USD 9 billion to more than USD 15 billion – an increase of 14% annually, which was even faster than the rate of increase in overall industry-financed R&D in the US (Figure 9). In contrast, EU-based affiliates of US firms increased their R&D expenditures by only USD 1.5 billion (from USD 7.4 billion to USD 8.9 billion), or less than 5% annually. This figure is even lower than the increase in overall industry-financed R&D in the EU during this time period (5.8%). Such patterns are likely to continue. A recent survey by the European Roundtable of Industrialists (ERT) indicates that member companies (42 of the largest firms in Europe) invest almost 40% of their R&D outside of Europe. These firms plan to increase their R&D expenditures in future years, but the bulk of that increase will likely be spent outside Europe.[6]

While these findings related to R&D by foreign affiliates should be interpreted with caution because they cover only a short time period and can be distorted by mergers and acquisitions, they illustrate the considerable flexibility that MNEs enjoy in locating R&D and the effects MNEs can have on nationally-rooted measures of R&D intensity. They further suggest that countries interested in boosting R&D intensity might attempt to attract R&D investments by MNEs, possibly diverting investment flows into other regions.[7] To successfully attract MNE investments, countries must offer more than a lucrative market for new products and services. Increasingly firms report that they locate R&D facilities near centres of scientific and engineering expertise. Inward R&D investments in the US were aimed primarily at high-technology areas in the 1990s. In 1997 (the latest year for which complete data are available), the pharmaceutical and communications equipment sectors alone accounted for 54% of the R&D expenditures by foreign affiliates in the US. Given the significant expansion of the US ICT sector between 1997 and

6 . Results of the ERT survey as reported in Betts (2002).

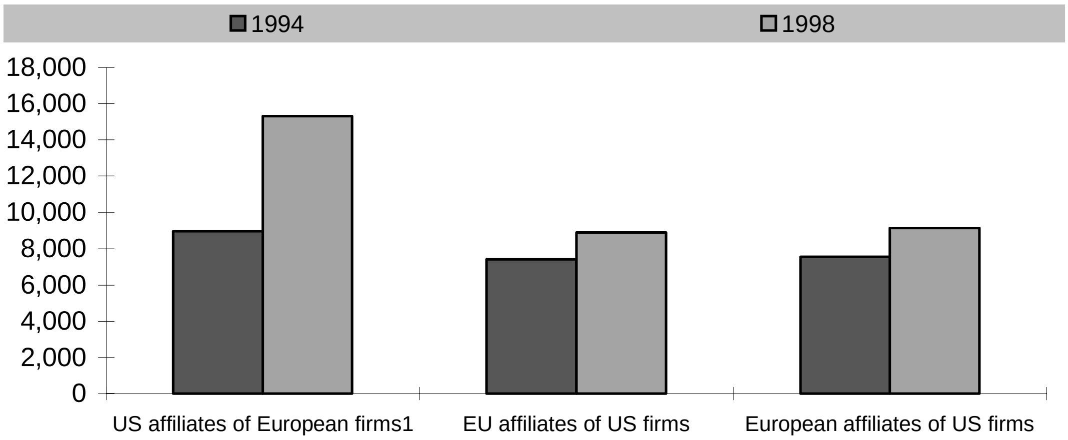
7 The EU's R&D intensity target refers to R&D conducted within the EU, not by firms headquartered in the EU. Hence, attracting and retaining R&D investment by foreign-owned MNEs is a viable option for helping achieve the target.

2000, it is likely that ICT related R&D investments by foreign affiliates increased sharply during this period.

Policy makers therefore need to ensure that countries offer sources of such expertise, which has implications for the concentration of government financed R&D resources, as well as the manner in which such funding is awarded. Institutional forms of R&D financing, in which funds are provided in block grants to universities and other public research organisations (as is common in many countries other than the US), do not provide policy makers with an opportunity to target R&D funding to particular scientific and technological fields or to particular institutions. OECD governments are experimenting with mechanisms for targeting R&D, but in many countries such efforts remain at a small scale.

**Figure 9. Growth of R&D in US and European foreign affiliates**

R&D expenditures in manufacturing firms, millions of current PPP USD




1. 1994 data refers to R&D funded by majority- and minority-owned affiliates; 1998 data refers to R&D performed by majority- and minority-owned affiliates.
2. Data refer to majority-owned affiliates only.
*Source:* Estimates data based on OECD MSTI database May 2002 and OECD AFA database, June 2002.

## Changing industrial structure

A country's R&D intensity is largely a reflection of its industrial structure. Countries with high R&D intensities have a high share of their business R&D and a significant part of their economic output in high-technology sectors.[8] In Finland, Germany, Japan, Switzerland and the United States, these industries account for three-quarters or more of business-performed R&D. In low R&D-intensity countries, such as Norway and Australia, high-technology industries (and medium-high technology industries) account for less than 40% – a fact that can be attributed to the natural resource endowments that these countries enjoy that affects their industrial structure.

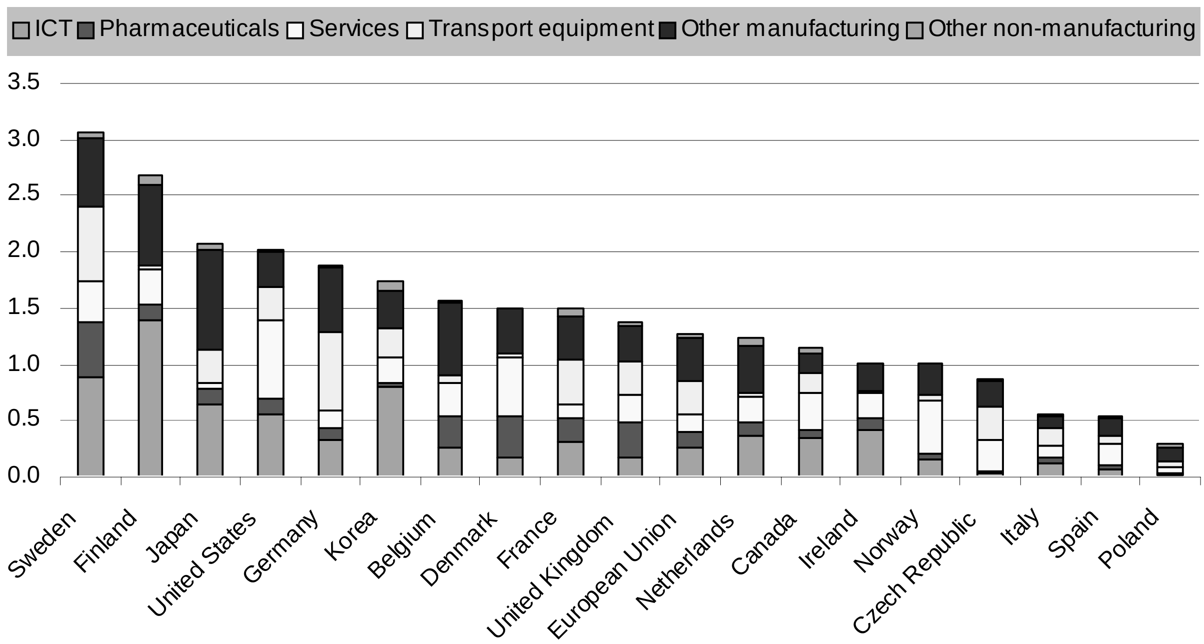
In those countries with a high R&D intensity funded by businesses, most of the high intensity comes from a few sectors that are high-tech (Figure 10). In Sweden, for example, the ICT, pharmaceuticals, and

8. As defined by the OECD, high technology industries include: pharmaceuticals (ISIC 2423), computing and office equipment (30); radio, television and communications equipment (32), scientific instruments (30), and aerospace manufacturing (353). Medium-high technology industries include: chemical products other than pharmaceuticals (24 less 2423); machinery and equipment (29); electrical machinery (31); automobiles (34); and railroad and other unclassified transportation equipment (352+359).

services sectors account for more than half of all business R&D, with the transportation equipment sector (a medium-high technology sector) accounting for another 25%. Within the service sector, more than 90% of Sweden's R&D occurs in the posts and telecommunications, computer and related services, and research and development industries.[9] In Finland, which has a BERD intensity of 2.7%, more than 1.8 percentage points derive from ICT, pharmaceuticals, and services, and more than 80% of services R&D is accounted for by the post and telecommunications and computer and related services industries. Even in the US, which has a much larger economy, almost 70% of BERD is performed in ICT, pharmaceuticals and services, and more than half of all service-sector R&D is in the computer and related services industry.

**Figure 10. Business R&D (BERD) intensity by industry sector**

% of GDP



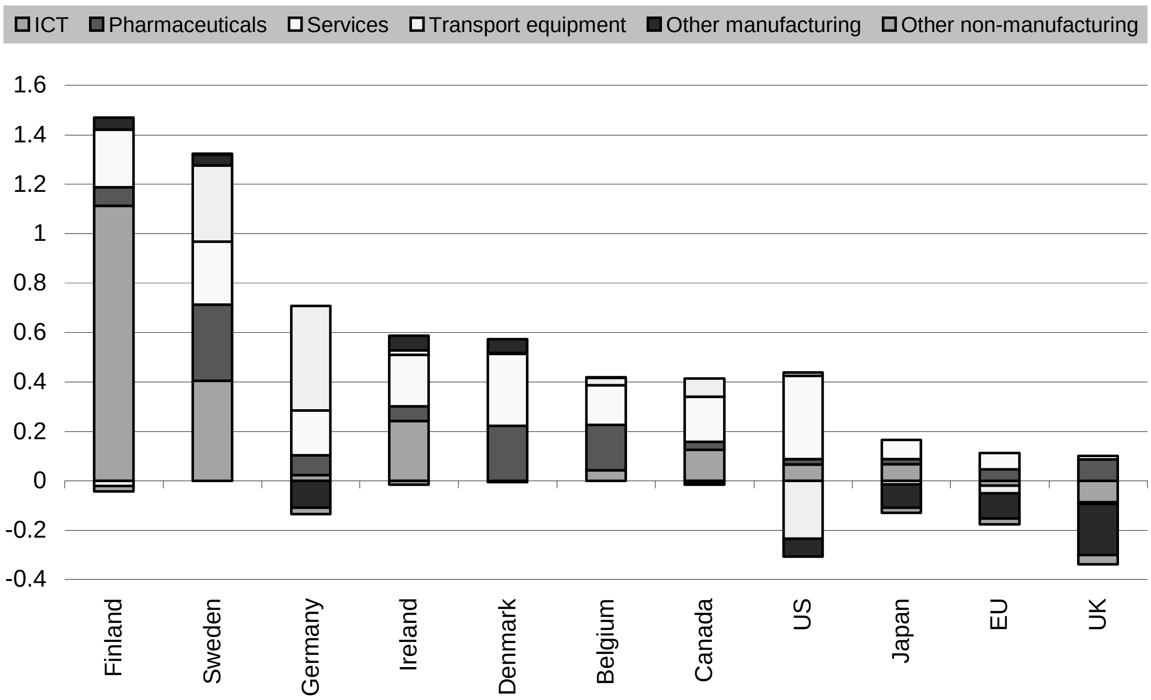

1. Nearest available years. 2000 for Belgium, Czech Republic, Finland, Germany, Italy, Poland, Spain and US; 1999 for Denmark, France, Netherlands, Korea, UK; 1998 for Ireland, Japan, Norway, Sweden, EU; 1997 for Canada.
2. IT manufacturing includes office, computing and accounting machines; communications equipment; and electronic components.
*Source:* OECD ANBERD database, November 2002.

Moreover, growth of high-technology manufacturing and service sector industries accounted for most of the growth in BERD intensity during the 1990s (Figure 11). In Finland growing R&D expenditures in ICT manufacturing, pharmaceuticals and services accounted for 80% of total business R&D growth between 1990 and 2000 – with ICT manufacturing alone accounting for over two-thirds of total growth. A similar situation held in most other countries that experienced large increases in BERD intensity during the 1990s: Sweden, Denmark, Ireland, Belgium, Canada, and the Unites States. Only in Germany were large annual increased in BERD intensity driven mostly by the transportation equipment sector. Moreover, much of the growth in the service sector in fast-growth countries derived from ICT-related services or other high-technology services firms This situation stands in contrast to that of countries, such as Japan and the United Kingdom in which declines in manufacturing R&D intensity that were not matched by increases in the service sector.

9. These industries correspond to ISIC codes 64, 72, and 73, respectively, in ISIC revision 3.

**Figure 11. Increase in business R&D (BERD) intensity by industry sector, 1990-2000**[1]

Percentage points of GDP




1. 10-year averages based on nearest available years. 1990-2000 for Finland and US; 1990-99 for Denmark and UK; 1990-98 for Belgium, Ireland, Japan and Sweden; 1990-97 for Canada; 1995-2000 for Germany; 1992-1998 for EU.
2. IT manufacturing includes office, computing and accounting machines; communications equipment; and electronic components.
*Source*: OECD ANBERD Database, October 2002.

Of course the R&D intensity of a particular industry sector, measured as a share of GDP, is itself a function of two underlying factors: *1)* R&D as a share of value-added in industry in that sector; and *2)* value-added in the sector as a share of GDP. The first of these a measure of sectoral R&D intensity; the second measures the relative size of the sector within the economy. Increases in either of these two measures can boost overall R&D intensity

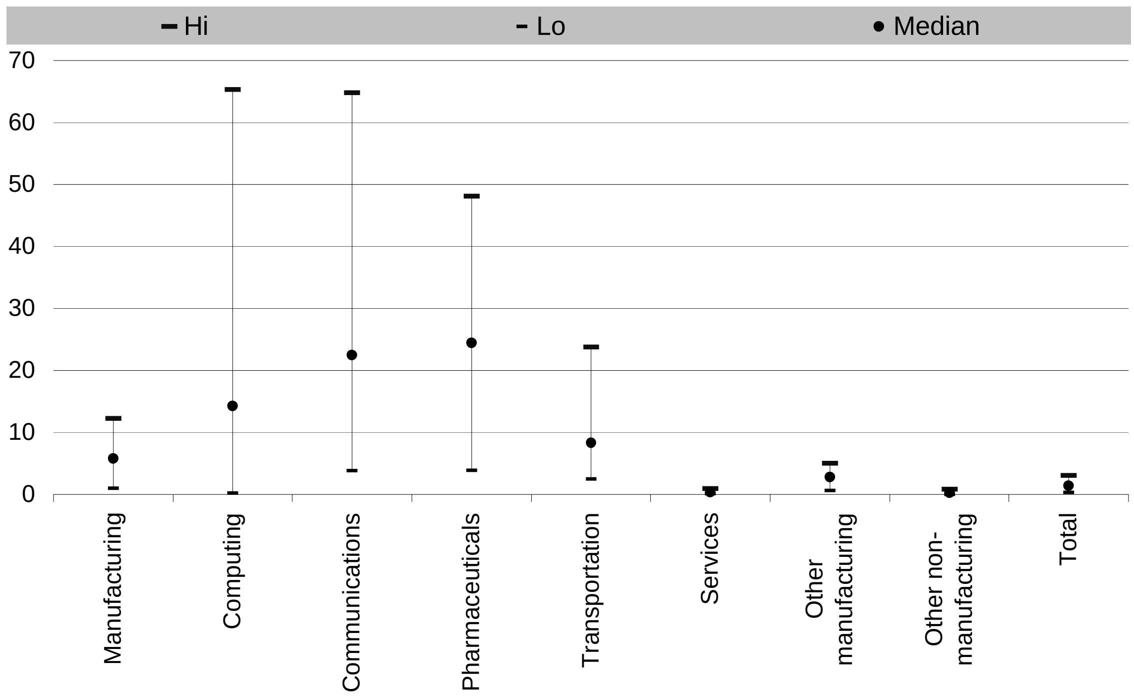
High-technology sectors offer considerably more room than low-technology sectors for increasing R&D spending as a share of value added (Figure 12). In the communications sector, for example, R&D as a share of value added in OECD countries ranges from a low of 3.8% in Poland to a high of 65% in Sweden, with a median of 22.5%. In the transportation sector, corresponding values range from a low of 2.5% in Norway to 24% in Sweden, with a median of 8.3%. In other manufacturing industries (all manufacturing less ICT, pharmaceuticals and transportation equipment), R&D as a share of value-added has a much smaller range, from 0.6% in Italy to 5.0% in Japan. In the service sector – which accounts for a large share of value added in most OECD countries – overall levels of R&D as a share of value added are small, but the range between high and low (0.09 in Poland to 0.92 in the United States) is still more than a factor of ten and is driven largely by increases in a limited number of sub-sectors where the range is considerably greater.[10] These figures indicate a close linkage between efforts to raise national R&D intensities and the need to expand industrial activity in high-technology sectors. High-technology sectors offer considerably

10. Insufficient detailed data are available for a large enough number of OECD countries to make comparisons at the sub sector level in the service industries.

opportunity than other industry sectors for improving R&D as a share of value added, and high levels of overall R&D intensity are unlikely to be achieved without them.

**Figure 12. Range of R&D intensities across OECD countries by industry sector**

BERD as a % of value added

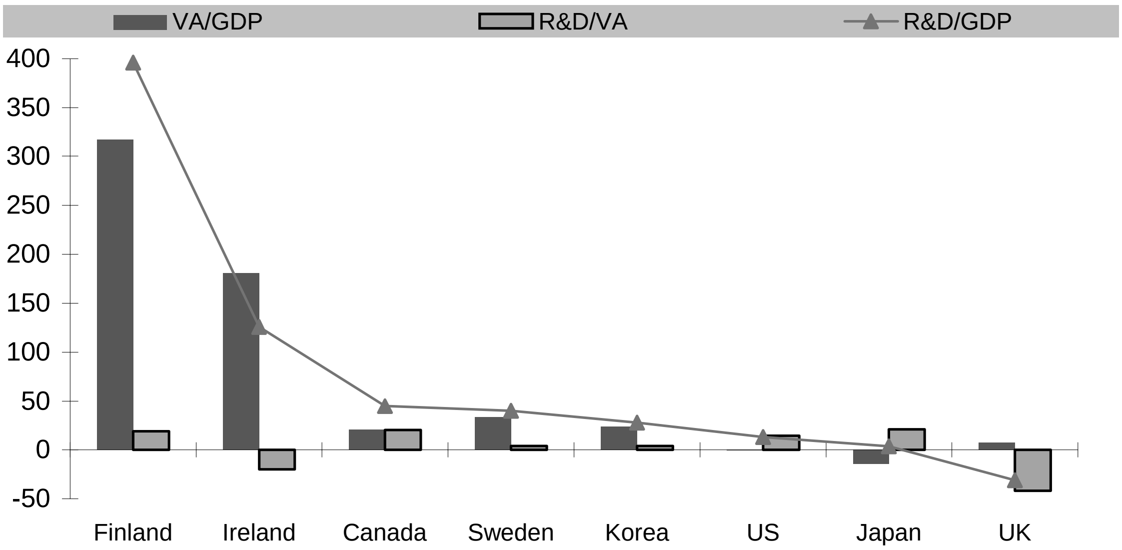



*Source*: OECD ANBERD database, November 2002.

Market size and growth also play an important role in boosting R&D intensity. In manufacturing, much of the growth in R&D intensity (BERD/GDP) within individual industry sectors appears to come not come from a deepening of the R&D intensity (R&D as a share of value added), but from a structural shift of the economy towards these high-technology sectors. In other words, the increase in BERD as a share of GDP is due a greater share of economic activity being performed by activities that are inherently more R&D intensive, leading to an increase in the overall R&D intensity. This is especially true for countries that have already achieved a high degree of technological capability and have little room to further improve ratios of R&D to value added. In Finland, for example, R&D intensity in the ICT sector (R&D/GDP) grew by a factor of four in the 1990s as the share of the sector in total industrial output more than tripled (as measured by value added as a share of GDP); R&D as a share of value added increased by only 20% (Figure 13). In Sweden, R&D as a share of GDP in the communications equipment industry grew by 40%, boosted by 34% growth in value added as a share of GDP and only 4% growth in R&D as a share of value added. Similarly, R&D intensity in the Swedish pharmaceuticals industry doubled, driven entirely by expansion of the sector as a share of Swedish industrial output. In contrast, countries that experienced only small increases in business R&D intensity during the 1990s tended to see high-technology sectors decline as a share of total industrial output. In Japan, for example, R&D intensity grew as a share of value added in both pharmaceuticals and ICT manufacturing, but both sectors declined as a share of industrial output. The same situation occurred in the UK’s pharmaceutical sector.

**Figure 13. Drivers of growth in BERD intensity in the ICT sector, 1990-2000**

Percent change




Note: ICT sector includes only the radio, TV and communications equipment sector for Ireland and Canada. Data shown for most recent years available.
*Source:* OECD ANBERD database, November 2002.

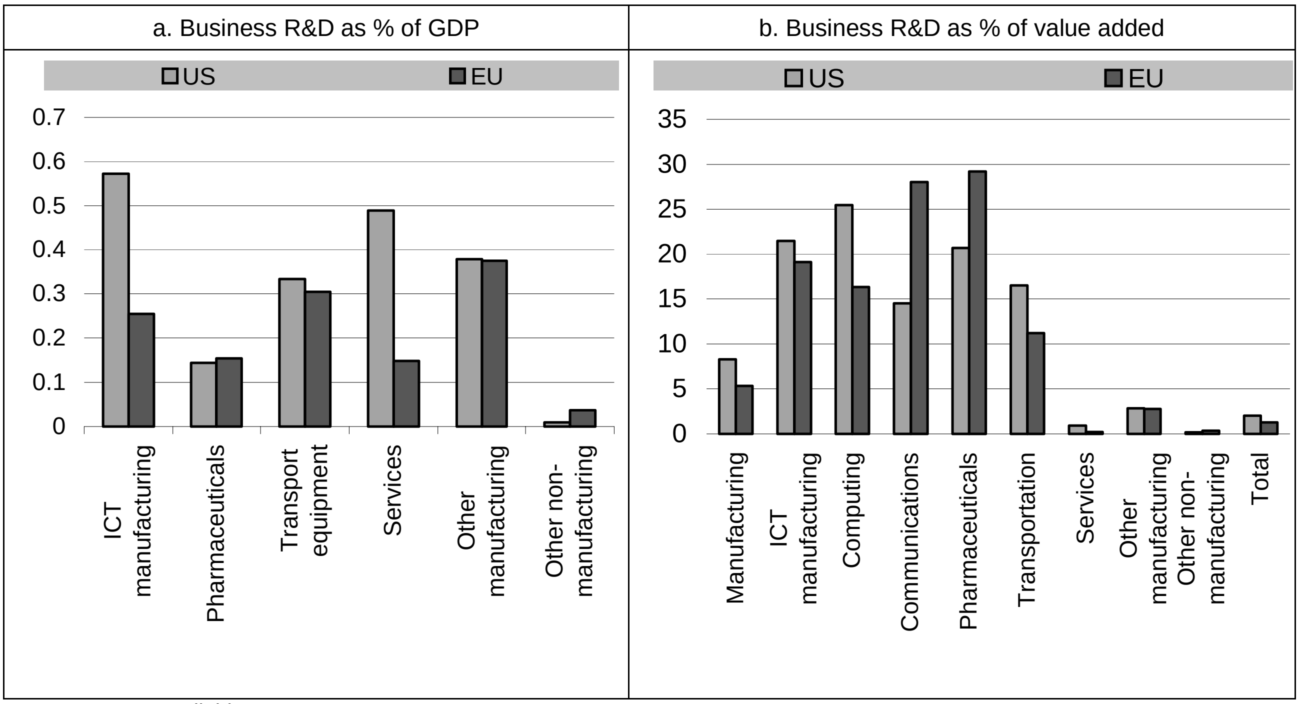
The notable exception to this general trend is the service sector. Countries that experienced the greatest percentage point increases in R&D as a share of GDP in the service sector tended to be those with the greatest increases in R&D as a share of value-added in services. In the United States, for example, R&D in the service sector nearly doubled as a share of GDP between 1990 and 1999: value added in services grew only 6.5% as a share of GDP, but R&D in services increased by 61% as a share of value added. Similar patterns were seen in Finland, Sweden and Denmark, which also experienced significant increases in service sector R&D as a share of GDP. These results reflect the fact that the service sector accounts for most of the value added in OECD countries, making significant increases in value added as a share of GDP difficult to achieve. They also reflect some reclassification of R&D-intensive firms from the manufacturing to the services sector (*e.g.* computer companies that are shifted into the computer and related services sector). Within individual service sector industries (for which limited data is available), the contribution of expanding value added may become more visible. In Finland, for example, value added as a share of GDP in the computer and related services sector increased by 85% between 1990 and 2000 compared to 3.4% for the service sector as a whole, and the post and telecommunications sectors grew by 49%. These two sectors are estimated to have accounted for at least 70% of the 0.24 percentage point increase in R&D as a share of GDP in the Finnish service sector.

Structural differences account for much of the gap between the US and the EU in business R&D intensity. The largest differences in R&D as a share of GDP between the US and EU exist in the ICT manufacturing and service sectors (Figure 14a). Whereas the ICT sector provides almost 0.6 percentage points of BERD intensity in the US, it accounts for only 0.25 percentage points in the EU. Nevertheless, R&D as a share of value added in the ICT manufacturing sector is roughly equal in the US and EU, implying that the US ICT industry comprises a larger share of overall GDP (Figure 14b).[11] The same is

11. The relative sizes of the office and computing equipment and the communications equipment industries in the US and EU may also be a factor. The US has a higher level of R&D as a share of value added in the computing equipment industry, but the EU leads in the communications equipment industry.

true in the pharmaceuticals industry, where despite the EU's higher levels of R&D as a share of value added R&D as a share of GDP is approximately equal to that of the US. In the service sector, in contrast, the US has both higher levels of R&D per GPD (0.49 versus 0.15) and of R&D per value added (0.92 versus 0.21), implying that it is a higher level of knowledge-intensive services in the US service sector that accounts for the difference in overall R&D intensity.

**Figure 14. Comparison of business R&D intensity in the US and EU by industry sector**




1. Most recent available years.
2. IT manufacturing includes office, computing and accounting machines; communications equipment; and electronic components.

## Geographical distributional effects

Another issue that could ensue as Europe increases its R&D intensity is a change in the allocation of R&D activity across member states. R&D tends to be regionally concentrated benefiting from clusters of high-tech firms or proximity to leading universities and government laboratories. An increase in the R&D intensity of the EU could increase regional differences, resulting in a distribution similar to the one that in the US where six states – California, Michigan, New York, Massachusetts, Texas and Pennsylvania – account for about one-half of the entire national effort (NSB, 2002). California alone accounts for about one-fifth of the national effort. California, Michigan, Massachusetts and Washington have R&D intensities that range from 4 to 6.1, higher than in the R&D intensities of all European countries, except Sweden, even though the size of their economies are as large as those of the high R&D intensity European countries.[12] South Dakota, Wyoming, Louisiana, Alaska and Arkansas each have R&D intensities below 0.6, even though their combined economic output exceeds that of several smaller European economies (*e.g.* Belgium, Greece, Ireland, Portugal, Sweden, Switzerland). Thus as the R&D intensity of Europe increases, it is likely that the existing discrepancies among national R&D intensities could widen, leading to political

12. New Mexico leads the US with a R&D intensity of 6.7%, although the size of its economy is USD 45.2 billion, makeing it about five times larger than Iceland and about twice the size of Luxembourg (NSF, 2002).

intervention so that those behind can catch-up. This could in turn reduce the pace of growth, especially of business-funded R&D.

### Implications for human resources

Whereas the popular image of R&D is one of scientific instruments like particle accelerators, space stations or wind tunnels, the biggest part of R&D expenditures, about half, are wages paid to researchers. Consequently, the most direct impact of raising the level of expenditures on R&D will be the demand it will produce for additional researchers. Estimates of the number of additional researchers[13] needed to meet R&D spending targets depend on several factors, including the growth rate of GDP (for targets expressed in terms of R&D intensity), increases in the labour productivity and wage levels of researchers, and average R&D spending per researcher. They will also depend on the degree to which R&D spending targets are met by increased R&D in the public versus private sectors, as R&D spending per researcher can vary significantly between sectors, as well as between countries, reflecting differences in wage levels and overall spending on research equipment.[14]

A comparison of R&D spending per researcher in the EU, US, and Japan illustrates this point. While the average R&D expenditure per researcher in the OECD was USD 179 300 in 2000, it ranged from USD 194 000 in the US, to USD 182 000 in the EU, and USD 152 000 in Japan. The ratios for the EU, US and Japan all increased in the 1980s, after which they levelled off in the US and Japan, but declined in the EU. Sectoral differences were even larger and display national differences. In the EU, public R&D expenditure per public researcher was USD 129 000 in 2000, while business R&D expenditure per business researcher was USD 232 000 (Table 2). A similar, but less pronounced pattern was seen in Japan. The situation was reversed in the US, however, with a ratio of publicly-performed R&D to public researchers at USD 250 000 and a ratio in the business sector of USD 180 000. The comparatively high levels of R&D spending per researcher in the US public sector reflect both higher wages compared to public researchers in other countries, plus greater expenditures on research equipment.

13. Exact, internationally comparable categories that identify workers engaged in R&D do not currently exist. Differences exist across countries as to classify by occupation, skill level or whether or not the person is actively engaged in the process of research and experimentation as opposed to playing a supporting or administrative role. For this reason, the category "researchers" (converted to a full-time equivalent basis) has been selected because it adheres most closely to the idea of people actively engaged in R&D and is generally the most internationally comparable of the various categories. See OECD Sources & Methods Database.

14. See Dominique Guellec, "Human Resources: A Potential 3% Bottleneck," presentation to the European Commission, DG Research, 5 November 2002.

**Table 2. R&D spending per researcher in the EU, US and Japan, 2000**

USD PPP

| | EU | US[1] | Japan |
|---|---|---|---|
| Business R&D expenditure per business researcher | 232 270 | 179 890 | 165 990 |
| Public R&D expenditure per public researcher[2] | 128 640 | 249 900 | 126 520 |
| Total R&D expenditure per researcher | 180 260 | 193 520 | 152 200 |

1. US data for 1999.
2. Public R&D expenditure is defined as R&D performed in the government and higher education sectors; Public researchers are defined as researchers in the government and higher education sectors.
*Source:* OECD MSTI database, January 2003.

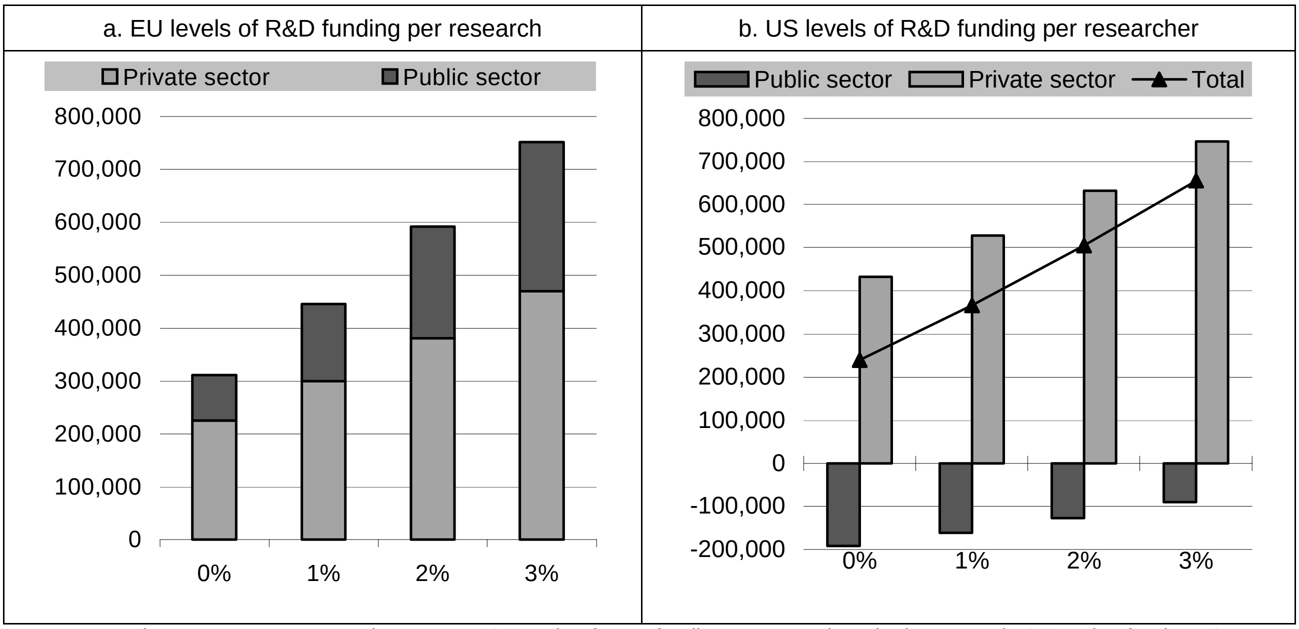
As a result of these differences, estimates of the number of researchers needed to meet the EU's R&D spending target depend on the strategy taken to meet the target. A basic scenario assumes that government and industry financing of R&D increases to 1% and 2% of GDP, respectively, with R&D spending per researcher in the public and private sectors remaining unchanged from present levels.[15] With no growth in GDP, the EU would need an estimated increase in total researchers of approximately 300 000 by 2010 (Figure 15a).[16] This would represent an increase of 32% from the 969 000 researchers in 2000, with almost three-quarters of the growth coming from the business sector. If GDP were to grow at an average rate closer to 2% a year, the additional number of researchers needed would double to almost 600 000—a 61% increase over 2 000 values—with just under two-thirds coming from the business sector.

An alternative scenario might assume that R&D spending per researcher in the EU in 2010 would evolve over time to look more like that of the US. Under this scenario, with 2% annual growth in GDP, the EU would need approximately 500 000 more researchers, an increase of more than 50% over 2000 levels. Interestingly, the number of public sector researchers would *decline* by more than 125 000, while the number of business researchers would increase by more than 630 000 (Figure 15b). While presenting a numerically easier target to meet in aggregate, this second scenario is perhaps more challenging to achieve than the first. Reducing the R&D expenditure per worker in the private sector imply reductions in the capital-intensity of firms' R&D departments and more stringent limits on wage increases; restructuring of the public research sector would involve significant improvements in wages and equipment expenditures and only a partial replacement of staff as they depart (*e.g.* due to retirement or to take positions in the private sector).

15. This scenario also assumes that the shares of government- and industry-financed R&D used to support public and private research also remain unchanged. OECD data indicates that 95.6% of industry-financed R&D in the EU supported business-performed R&D in 1999, and 4.4% supported R&D performed in the public sector; 84% of government R&D expenditures financed public sector R&D, with the remaining 16% financing business R&D.

16. These estimates assume a 1.5% annual increase in researcher productivity.

**Figure 15. Additional researchers needed to meet proposed EU targets for R&D intensity in 2010, as a function of GDP growth rate**




Notes: Based on current 15 EU Members; uses 2000 ratio of R&D funding to researchers in the EU and 1999 ratios for the US; uses 1999 data to estimate the shares of industry-financed and government-financed R&D used in the business and private; researchers are based on full-time equivalents; assumes 1.5% annual increase in researcher labour productivity.
*Source*: OECD, based on data from the Main Science and Engineering Indicators, January 2003.

Adding another 500 000 to 600 000 researchers to the EU workforce by 2010 will present a challenge to Europe. Looking back over the last two decades, many smaller countries have succeeded in making similar percentage increases in the number of their researchers (approximately 50%) over the course of a decade, but this has meant an additional 10 000 to 30 000 new researchers for most countries (*e.g.* Australia, Finland, France, Germany, Spain, Sweden or the UK). Achieving a proportional increase on a continental scale is much more difficult. The largest gains in researchers registered in the past occurred between 1981 and 1991 in the US where ranks swelled by an additional 277 000 researchers. More recently, Japan (1990 to 1999), the EU (1991 to 1999) and the US (1989 to 1997) saw increases in the number of researchers of 76 000, 172 000 and 190 000 respectively. Even if all the Japanese and US gains had occurred in Europe, this growth still would not be enough to satisfy the growth in researchers needed for the 2% growth scenarios, although they could satisfy researcher needs if growth is slower. Producing and or attracting researchers to Europe to perform the R&D targeted represent a key challenge and a potential bottleneck for satisfying the goal of 3% R&D intensity.

Two approaches can be taken to address the researcher problem: *1)* increase the indigenous supply of researchers, and *2)* attracting researchers from abroad. In terms of the first approach, data issues and differences in classifications as to what constitutes a researcher confound a direct analysis of the pipeline of prospective researchers in the EU. Nevertheless, a little more than 32 000 new doctorates in science and technology fields were granted in Europe in 1998/1999 reflecting an upward trend of about 8% from 1994/5 (Eurostat, 2002). If this growth rate were sustained over the decade, the number of new scientists would come close to the level needed – if all these graduates were to become researchers.[17] These potential gains will, however, be offset to some degree by a smaller cohort of young people entering the educational

17. Graduation rates from higher education (university) for the population aged 20-24 are the main flow for new human resources for S&T have increased for the EU-15 from 5.8% in 1991 to 8.4% in 1997, albeit significantly lower than the prevailing rates in the US (14.2 in 1997) and Japan (11.0%) (OECD, 2002).

pipeline and by a demographic shift that leads to a generally ageing EU population. If 30% of the current research population retires in the next decade, the number of researchers that need to be added to the EU workforce will increase by another 290 000.

Attracting qualified personnel from abroad could augment an indigenous increase in researchers. The United States has been successful in attracting the highly skilled: between 1990 and 2000 an estimated 900 000 highly-skilled professionals entered the US labour market between under the so-called H-1B visa programme for the temporary entry of skilled workers (OECD, 2002*a*). In 1999 alone, about 400 000 highly skilled foreign workers immigrated to the US, the bulk of which were temporary in nature. In comparison, the large European countries, France, Germany and the UK, attracted 5 300, 8 600 and 39 100 temporary, highly-skilled immigrants, respectively (OECD, 2001). This cadre of workers a potential source to fill in the researcher gap, but it must be kept in mind that the term *highly skilled* in this context is rather expansive and refers to a range of skills for which a demonstrated shortage exists. In the US, only about 81 000 temporary work visas (H-1B visas) were granted to science- and engineering-related occupations from October 1999 to February 2000. Furthermore, other non-European countries with a heritage of immigration, such as Australia and Canada, are in competition for the same niche of the labour force, and new competitors such as Japan are changing policies to attract this cadre of talent.

A second source of highly skilled workers comes from foreign students who stay in the country in which they have studied. In 1998, the US had a stock of 430 000 foreign students, accounting for one-third of all foreign students studying in the OECD. France, Germany and the UK had 148 000, 171 000 and 210 000, respectively – more collectively than the US – but these figures include foreign students from other EU countries. Comparable data on stay rates of students across countries does not exist, but data from the US suggests that about half of the 14 000 foreign students who earned science and engineering doctorate degrees in the US in 1992-93 were still in the US in 1997 (NSB, 2002). Again, this is a potentially fruitful source of researchers, but not of sufficient magnitude to meet the overall demand projected for the EU. Better tapping into this source of researchers will require closer examination of the reasons why students choose to leave Europe to study abroad and the factors that are important in convincing foreign students to stay after they graduate. In general the factors that affect the flow of this group have much to do with the developing centres of excellence for scientific research and framework conditions within which technological innovation and entrepreneurship may thrive (OECD, 2002*a*).

## POLICY IMPLICATIONS

As the analysis illustrates, achieving high-levels of R&D intensity– in the EU as well as in other countries and economic regions – will require addressing many structural reforms that bring with them significant political challenges. To achieve the high R&D intensity targeted, with the bulk of the increase funded by private sources (as intended in the EU), will require reform in three different but linked policy areas: *1)* improving the environment for innovative businesses, *2)* enhancing the ability of public research organisations (government laboratories and universities) to serve as sources of industrially-relevant, fundamental research; and *3)* cultivating, attracting and retaining high-skilled workers. In addition, policy makers need to consider how R&D spending targets interact with other policies and social priorities.

### Building an environment conducive to innovative firms

Developing a business environment that is conducive to innovation includes a wide range of policies that run the gamut of macroeconomic fundamentals, such as stable prices, to competition policies that are flexible enough to allow collaboration but firm enough to prevent collusion, to microeconomic regulatory policies such as those governing intellectual property rights (IPR). At the heart of this environment are two crucial factors: *1)* ensuring sufficient demand for the products of R&D-intensive firms that markets can grow and firms can expand their R&D efforts; and *2)* the ability of firms (and the research community) to quickly respond to new scientific and technological opportunities. It is not possible to predict with great accuracy the technological fields or specific product and service markets that will generate high levels of growth in the future. Instead, firms must be able to react quickly to changing market signals so that they can enter emerging markets early in their lifecycle.

Generating demand for high-tech products is not readily amenable to government policy except broad monetary and fiscal policy. Nevertheless, government procurement (an element of fiscal policy) has played a role in the past in providing initial markets for new products and services, helping increase economies of scale. In the US, government procurement has been most effective in areas related to defense and space, where government missions required technological advances and government agencies were less cost-sensitive than private markets and more willing to accept technological risks.[18] Nevertheless, government procurement is temporary aid that should eventually give way to the public marketplace. Another important factor is the existence of a coherent common market where high-tech firms can easily sell their products on a continental scale without restrictions. This is the long-term goal of the European Union, but achieving this goal is the key for generating the demand needed to create an environment conducive to the development of R&D intensive firms. This challenge will be especially difficult to meet over the next few years, as many high-technology sectors are adjusting to the economic downturn and demand for many high-technology products and services is abating. The growth that many high-technology sectors experienced in the 1990s may not be duplicable in the current decade as demand slows and markets are saturated by existing competitors:

18. For a more complete discussion of the US government's role in stimulating demand for new technology-based products and processes, see OTA (1995).

- *ICT*. While the importance of ICTs remains high, several existing product markets (*e.g.* PCs and portable phones) appear to be reaching saturation levels. Future growth will depend on the introduction of new products and services and on the cultivation of markets outside the OECD. The roll-out of broadband and 3rd generation wireless may provide a boost to some sectors, but broadband is making use of investments that have already been made and the availability of 3G is being delayed.

- *Aerospace.* Concerns regarding bankruptcy or consolidation circulate in the air travel industry, and orders for new planes are being curtailed. Coupled with growing security concerns and a desire by businesses to cut costs on travel, the commercial aerospace industry is not likely to be aggressive growth sector in the near-term, although this may be offset by demand for military aerospace.

- *Biotechnology*. While considered the next technological wave after ICT, biotechnology faces a different set of regulatory hurdles and public concern regarding cloning, stem cells and genetically modified organisms, etc. Predictions in the late-1990s that dedicated US biotechnology firms would be profitable in the early-2000s have not materialized, as net losses have increased by nearly 40% (Arundel, 2003).

Many high-tech commercial successes come from developments that are impossible to foresee. Converting these developments into market success places a premium on the ability of businesses to quickly respond to new opportunities. As illustrated above, those countries that had a sharp increase in R&D intensity in the 1990s did so by quickly allocating resources into growth markets. Creating an environment that supports this flexibility is essential for cultivating an R&D intensive economy. Such flexibility can be impeded by regulatory barriers that affect their ability to start-up, expand or exit activities. Flexibility also places a premium on forms of financing such as venture capital and equity financing for start-ups and on merger and acquisition rules and bankruptcy rules that allow firms to exit markets.

Increasing flexibility does not necessarily mean that social concerns must suffer. Many of the countries that enjoy high R&D intensity or saw a large increase in R&D intensity during the 1990s, enjoy high levels of social protection (*e.g.* Finland, Sweden). This paradox is worthy of additional analysis and suggests that social capital in the form of well-functioning institutions, a trusting environment between businesses and governments and basic infrastructure such as communications and education are important elements in economic success. In this sense the optimal environment for innovation includes many quality-of-life factors that make a location appealing to a cadre of innovators who are highly mobile. While entrepreneurial opportunities, innovation-friendly regulations and a relatively low personal tax rate may be important factors in fostering innovation, a key element in attracting the best and brightest involves creating an opportunity to work at the cutting edge of their fields and leverage their abilities against those of others. This involves the creation of centres of excellence, many of which are anchored by universities or public laboratories that conduct high-quality, fundamental research.

**Capitalising on fundamental research in the public research sector**

If fundamental research is the seed of innovative activity, then universities and government research organisations are the seed banks and play an essential role in sustaining an innovation-led economy. Strengthening these actors and better integrating them in the innovation process is thus a key policy issue. While ensuring adequate levels of funding is an obvious policy lever to strengthen public research organisations, the nature of the funding is important as well. The way in which funding is provided and the way it is used within the public research sector have a significant influence on the degree to which geographic regions (whether particular countries or larger regions such as the European Union) become centres of scientific or technological excellence and can, in turn, attract additional R&D investments from large MNEs, contributing to the formation of new technology-based firms.

Considerable activity is underway in OECD countries to examine ways of increasing the social and economic returns from public sector research through new mechanisms for steering and funding such work.[19] Such mechanisms include greater use of project funding as opposed to institutional block grants, increases of funding for select fields of research that are thought to offer greater social and economic returns (*e.g.* life sciences, computer science, environmental sciences), and the creation of research centres that serve to both concentrate expertise in particular fields of science and technology and to foster multi-disciplinary research in emerging fields of interest (*e.g.* bio-physics, biological computing, nanotechnology). Such mechanisms represent a significant shift in way public research is governed in many OECD countries, and they appear to have played a critical role in the United States, where the concentration of large amounts of R&D funding in particular fields (such as computer science and electrical engineering) and particular institutions (*e.g.*, MIT, Stanford, Carnegie Mellon) contributed to rapid advances in the science and technology that underlie industrial innovation in related fields (CSTB 1999).

Implementation of such mechanisms is challenging. New centres of excellence can threaten existing academic disciplines and thus run afoul of established academic political constituencies and associated vested interests, forcing a political confrontation so that structural change within academia can occur. They can also exacerbate concerns about the geographic concentration of innovative activity. Through economies of agglomeration, innovative activity tends to cluster around particular areas, often building on pre-existing infrastructure, such as a leading university (*e.g.* Stanford to Silicon Valley), a key firm (*e.g.* Nokia) or an important public research facility (*e.g.* CERN). Building such poles of technical expertise is expensive and takes time. This approach is at odds with notions of using S&T policy to distribute innovation-led economic growth more evenly across countries or economic regions. Successful implementation of such policy approaches can require changes in the organisation and operation of related government functions. In the US, for example, it has required the recruitment of knowledgeable scientists and engineers into government agencies — even if only for limited periods of time — to formulate and manage R&D programmes. In some cases, it also required the development of new procedures for awarding R&D funding that differed from the traditional peer-review processes used in many funding agencies. In virtually all cases, it involved the active management and governance of publicly funded research, often in consultation with relevant stakeholders.

19. The OECD has an ongoing activity to explore changes in the steering and funding of public research institutions. Results of the ad hoc working group that is conducting the study are expected in the first half of 2003.

More selective funding approaches may be particularly important for small to mid-size countries that lack resources to fund all fields at high levels. Increasingly, as the cost of innovation at the scientific frontier becomes prohibitively expensive, even large countries need to be open to ideas generated abroad. At the same time, focusing of research presents a danger as innovation become more complex and advances in one field become essential to innovation in another (*e.g.* the symbiotic relationship between microelectronics, biotechnology and nanotechnology). Thus the reduction of the scope could have a detrimental effect unless compensated for by increased international linkages. This need underscores the challenge to Europe to better integrate its own research community while becoming better linked to the global community. This move towards greater specialization will place a premium on the ability to react to changes in technology and markets otherwise the niche being developed risks being obsolete.

**Cultivating, attracting and retaining the high-skilled**

At the heart of becoming an innovation-led economy is the need to have people who innovate. Policies in this area tend to focus on increasing the scientific and technical skills of the public at large through primary and secondary schools, vocational training facilities and training. This is an important component but its impact is diffuse, will only be felt in the long term and is more likely to result in a better public appreciation and acceptance of science and new technologies than it will have in their direct development. In this sense, policies that are directed towards increasing the overall S&T knowledge of the population rather than improving high-level S&T skills are less well suited to creating the next generation of innovations than to facilitating the diffusion of innovations created elsewhere. This is the paradox represented by the US: even though its capability to innovate is high, its primary and secondary school system has long been considered inferior to that in many OECD countries (NCEE, 1983). It is the country’s tertiary-level education that makes the difference.

Policies to build or attract top-calibre human capital have received less attention, but are increasing in the form of policy issues concerned about brain drain and the need to change immigration policies to prevent or encourage the immigration of the highly skilled. A critical point of entry for skilled immigrants is initially as students. In 1995, 50% of the US mathematics and computer science doctoral degrees and 58% of the engineering degrees were earned by foreign students (NSF, 1998). Many of these students then stayed on as skilled scientists and engineers: about half of the doctoral recipients from China and India electing to stay after receiving their degree. A necessary element of the ability of such students to study and remain subsequently in the US have been policies that facilitate and accommodate foreign students and researchers. In this sense, modifying immigration laws in Europe to encourage immigration may be necessary.

More important for cultivating highly skilled S&T workers, however, are factors linked to academic and research opportunities. The key policy implication is the need to create world class universities that act as a beacon for students around the world who want to study with the best and be taught by those at the forefront of the field. Doing so requires an examination of the role of universities in the community and their societal mission, especially in Europe where most universities are public and where student admissions are less selective than in the US. Creation of world-class universities often entails greater selectivity in the admission of students, funding from a variety of non-state sources, a diversion of faculty from a primary role of teaching to one more oriented towards research and an involvement of businesses that is relatively rare today outside the US. This change in structure and culture will not be easy to implement and constitutes a philosophical departure that could engender significant opposition. Even with a vastly different system in place that relies much more on private universities where public funding plays a minor role, it has taken the US university system decades to accommodate this new role and some observers still question if the US has achieved the correct balance. Policies to promote university quality are beyond the scope of this paper, but it is clear that government funding can play a key role. In the US for example, federal support has constituted about 70% of total university research funding in computer science and engineering since 1976 (NAS, 1999). Such funding has played an important role in creating top-tier computer science departments that attract students and faculty from around the world.

**Interaction between R&D targets and other policy objectives**

A final topic for policy makers to consider is the possible interaction between R&D spending targets and other social or policy objectives. At the most superficial level, additional government funding that is allocated to R&D competes with government funds that could be dedicated to other missions. While academic research illustrates high social returns to R&D investment, such investments must nevertheless be considered in the light of other possible investments and priorities. In addition, any overall increase in government R&D funding can, of course, conflict with attempts to restrain government spending or limit government deficits.

At a more nuanced level, the objective of boosting levels of R&D funding can create incentives that must be balanced against other policies and priorities. Within the realm of R&D policy, for example, efforts to boost R&D funding can distract attention from policies and programmes that attempt to boost the *efficiency* of existing R&D funds without necessarily raising their level. Efforts to encouraging greater networking and co-operation among firms or strengthening industry-science linkages—which might go a long way toward boosting levels of innovation and economic growth, as R&D targets are established to do—might receive lower priority. Similarly, specific strategies for achieving higher R&D intensities, such as by boosting immigration to expand the research work force, attracting R&D investment from foreign multi-nationals, or developing high-technology industries, can come into conflict with other social objectives, such as reducing unemployment, supporting development of local SMEs, or expanding local industries. The best way to ensure that such considerations are taken into account in policy making is to ensure that policy makers are aware of the range of social and economic implications that R&D spending targets entail.

## CONCLUSION

As this paper shows, achieving R&D targets – which typically implies significant increases in R&D intensity over a relatively short period of time – entail significant social and economic reform. While often viewed as a financial objective and an input that will drive economic growth, the process of meeting R&D targets implies changes in the structure of industry (*e.g.* toward high-technology sectors), in the governance of public research (*e.g.* to improve quality and establish centres of excellence), and in the nature of the labour force (*i.e.,* to increase the number of highly skilled workers and researchers). Implementing such changes can require policy initiatives across a broad range of domains, from R&D funding and entrepreneurship to immigration and education policy, to product, financial and labour market regulation. Such structural reforms can make achieving R&D targets much more difficult than they may appear on the surface and must be considered in policy debates regarding science and technology policy.

**Box 1. Hitting a moving target: The case of Canada**

The challenges of meeting R&D targets are even more difficult in the case of countries that attempt to reach not an absolute R&D intensity but a certain level of performance relative to other countries. Canada, for example, has identified a goal of "…becoming one of the most innovative countries in the world…" by setting a target of increasing its R&D intensity. Rather that specifying a particular R&D intensity level as the EU has done, it has set the goal of becoming the 5th highest R&D intensive country across the OECD by 2010, up from its current position of 14th out of OECD's 30 Member countries (Government of Canada, 2001).

Achieving an ordinal R&D target of the type Canada has set is harder to achieve than hitting an established 3% target because with so many countries trying to boost their R&D intensity, the target is moving upward. Over the past two decades, there has been improvement in the R&D intensity of OECD countries. Even with the recession of countries after 1981 (many of which had relatively low R&D intensities), the average R&D intensity increased from 1.95 to 2.23 between 1981 and 1991 before rising to 2.33% in 2001. Whereas the top 5 countries had R&D intensities between 2.17 and 2.43% in 1981, they had R&D intensities between 2.53 and 2.75 in 1991 and between 2.96 and 4.27 in 2001 (Box Table 1). The list of countries in the top 5 also changed significantly, with only the Sweden appearing on all three lists.

The growth in R&D intensity across the OECD implies that countries must invest more in R&D just to keep their existing ranking. This is seen in Canada as well where even though Canada's position in the OECD rank is unchanged between 1996 and 2000, the R&D intensity needed to maintain this position increased from 1.69 to 1.84. But the situation is made more complex by the fact that the fastest growth in R&D intensities in recent years has been at the top of the scale. Since R&D intensities began recovering from a relative nadir in 1994, the largest percentage point growth in R&D intensity occurred in Finland, Iceland, Japan and Sweden, each of which had relatively high levels of R&D intensity in 1994. Some countries with low R&D intensity (Hungary, Poland, the Slovak Republic and Italy) saw R&D intensity decline even further by 2000, increasing the differences among OECD countries. In short, the distribution of countries' R&D intensity has become more skewed over time. Such a distribution both presents a challenge for Canada since reaching the top-end has become harder, but also an opportunity, since Canada's current position is almost exactly the median of the OECD ranking.

This means that it will be relatively easy for Canada to move up from its current position since 6 countries are within 0.2 percentage points of its current position. Given that both the numerator and dominator factor into the calculation, it is relatively sensitive indicator of performance. Also, official statistics are subject to revision and a certain level of imprecision — thus not too much economic meaning should be given to a shift in position of 5 or even 6 places placing Canada in the top-10. A jump of 9 places to the top-5 is much harder, but not impossible: between 1991 and 2000, Finland climbed 6 places, and Korea climbed 5 to be ranked numbers 2 and 5 respectively. Iceland jumped from number 21 to number 4 over the decade, with significant increases in industry-and government-financed R&D.

These precedents suggest that Canada could meet its target. But unlike Finland which is one-sixth the size (GDP and population) and Iceland which is one one-hundredth the size, Canada is a medium-sized country where rapid movements are more difficult.. Korea is of the same relative size, but Canada's natural endowments and close interdependence with the US mean that a radical restructuring of the industrial mix of Canada is unlikely. Its proximity to the US may, however, make it an attractive location for foreign affiliates to conduct R&D. Already, foreign affiliates represent over a third of all business R&D in Canada. Also, Canada enjoys a heritage of being an immigration-based country, making it a potentially attractive destination for foreign highly-skilled researchers.

Nevertheless, the jump from the position of 14th with a R&D intensity lower than that of the EU in 2000 (1.84 vs. 1.88) to number 5 would require at a minimum that Canada raise its R&D intensity to the level enjoyed by number 5 country, Korea, which had an R&D intensity of 2.96 in 2001.

**Box Table 1. Top countries in R&D intensity**

GERD as % of GDP

| 1981 | | 1991 | | 2001 | |
|---|---|---|---|---|---|
| Country | R&D/GDP | Country | R&D/GDP | Country | R&D/GDP |
| Germany | 2.43 | Japan | 2.75 | Sweden | 4.27 |
| United Kingdom | 2.38 | United States | 2.72 | Finland | 3.40 |
| United States | 2.34 | Sweden | 2.70 | Iceland | 3.06 |
| Switzerland | 2.18 | Switzerland | 2.62 | Japan | 3.09 |
| Sweden | 2.17 | Germany | 2.53 | Korea | 2.96 |
| *OECD average* | *1.95* | *OECD average* | *2.23* | *OECD average* | *2.33* |

*Source:* OECD, MSTI Database, June 2003.

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