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# CAUSES OF FLUCTUATIONS IN R&D EXPENDITURES A QUANTITATIVE ANALYSIS

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## INTRODUCTION

Business expenditures on research and development (R&D) levelled-off in most OECD countries in the early 1990s, after a period of steady growth. Although growth in many countries has now resumed, it is important to consider whether a structural shift in R&D investment by business and government has occurred, as this could have possible adverse consequences in the long run.[1] A concern is that a reduced level of R&D, with a more short-term orientation, could generate a slowdown in technical change, hence in future productivity and economic growth. The purpose of this study is to assess the role of macro-economic and policy factors in the levelling-off, through an econometric analysis. It is found that these factors can account for the bulk of the levelling-off. More specifically, the economic downturn of the early to mid-1990s, and reductions in government funding of research played a major role, along with high real interest rates and a shift in the industrial composition of GDP (*i.e.* an expansion in the share of the services and a reduction in the share of high-tech manufacturing).

## THE STYLISED FACTS OF R&D IN OECD ECONOMIES

Business enterprises in the OECD performed 314 billion US PPP dollars of R&D in 1996. The OECD-wide R&D intensity (the ratio of business enterprise R&D - BERD - to business GDP) was 1.75 per cent in 1995.[2] BERD has grown on average by 1 per cent a year since 1990, as compared with more than 5 per cent per annum in the 1980s and 3 per cent per annum in the 1970s (Table 1). This sharp slowdown is a feature of almost all OECD countries, with the exception of Iceland, Australia and Ireland (in Ireland, the growth of BERD accelerated sharply over this period). In some countries, notably Japan, Germany, Italy, and the United Kingdom, BERD decreased in the 1990s. The levelling-off started in the mid-1980s in a first group of countries (including the United States, Canada, Netherlands and Sweden), and in the early 1990s in a second group (including Japan, Germany, France, the United Kingdom, Italy).

This pattern. is also apparent in measures of R&D intensity (Figure 1) with five of the G7 countries having experienced a levelling off or decrease in R&D intensity

Table 1. **Growth of R&D expenditures in the business sector**

Average annual growth rate at 1990 GDP prices

| | Total | | | | Financed by the business sector | | | | Growth differential 1990-96/1980-89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1960-69[1] | 1970-79 | 1980-89 | 1990-96[2] | 1960-69[1] | 1970-79 | 1980-89 | 1990-96[2] | Total | Financed by business |
| United States | 2.0 | 2.0 | 4.9 | 0.8 | 6.2 | 3.8 | 5.7 | 2.6 | -4.1 | -3.1 |
| Canada | 3.9 | 5.0 | 7.7 | 6.1 | 4.9 | 5.6 | 6.2 | 6.0 | -1.5 | -0.2 |
| Japan | .. | 6.4 | 9.2 | -0.6 | .. | 6.4 | 9.2 | -0.7 | -9.8 | -9.9 |
| France | 5.7 | 4.3 | 5.2 | 0.7 | 9.9 | 5.2 | 5.2 | 2.5 | -4.5 | -2.7 |
| Germany | 10.5 | 4.5 | 3.9 | -1.5 | 11.1 | 4.1 | 4.7 | -1.0 | -5.4 | -5.7 |
| Italy | 10.4 | 3.3 | 8.2 | -4.0 | 9.6 | 2.6 | 6.5 | -2.6 | -12.2 | -9.1 |
| United Kingdom | 2.4 | 2.6 | 3.3 | -1.2 | 2.2 | 2.5 | 4.2 | -0.8 | -4.5 | -5.0 |
| Australia | .. | 6.9 | 11.0 | 13.1 | .. | 2.9 | 12.8 | 12.5 | 2.1 | -0.3 |
| Austria | 16.5 | 10.2 | 4.5 | 2.5 | 17.6 | 10.0 | 4.6 | .. | -2.1 | .. |
| Belgium | .. | 6.3 | 3.1 | 0.9 | .. | 6.4 | 3.2 | 0.7 | -2.2 | -2.5 |
| Denmark | 13.1 | 4.1 | 7.6 | 5.6 | 12.7 | 3.1 | 7.5 | 4.2 | -2.0 | -3.3 |
| Finland | 19.3 | 6.6 | 10.4 | 3.9 | .. | 6.5 | 10.5 | 4.1 | -6.5 | -6.4 |
| Iceland | .. | .. | 15.2 | 17.6 | .. | .. | 20.4 | 17.3 | 2.4 | -3.1 |
| Ireland | 14.5 | 5.1 | 10.0 | 20.5 | 14.3 | 3.7 | 10.7 | 20.6 | 10.5 | 9.9 |
| Netherlands | 0.0 | 1.7 | 3.7 | 1.2 | 0.0 | 1.1 | 3.8 | 0.0 | -2.5 | -3.8 |
| Norway | 9.2 | 8.1 | 5.7 | 3.5 | 10.3 | 6.4 | 7.0 | 5.0 | -2.2 | -2.0 |
| Spain | 22.7 | 11.9 | 11.8 | -1.7 | 21.7 | 11.9 | 9.7 | -0.7 | -13.5 | -10.4 |
| Sweden | 4.9 | 5.6 | 5.8 | 7.3 | 8.1 | 6.2 | 6.0 | 7.3 | 1.5 | 1.3 |
| Switzerland | 2.4 | 1.2 | 3.7 | -4.8 | 3.1 | 1.4 | 3.5 | .. | -8.5 | .. |

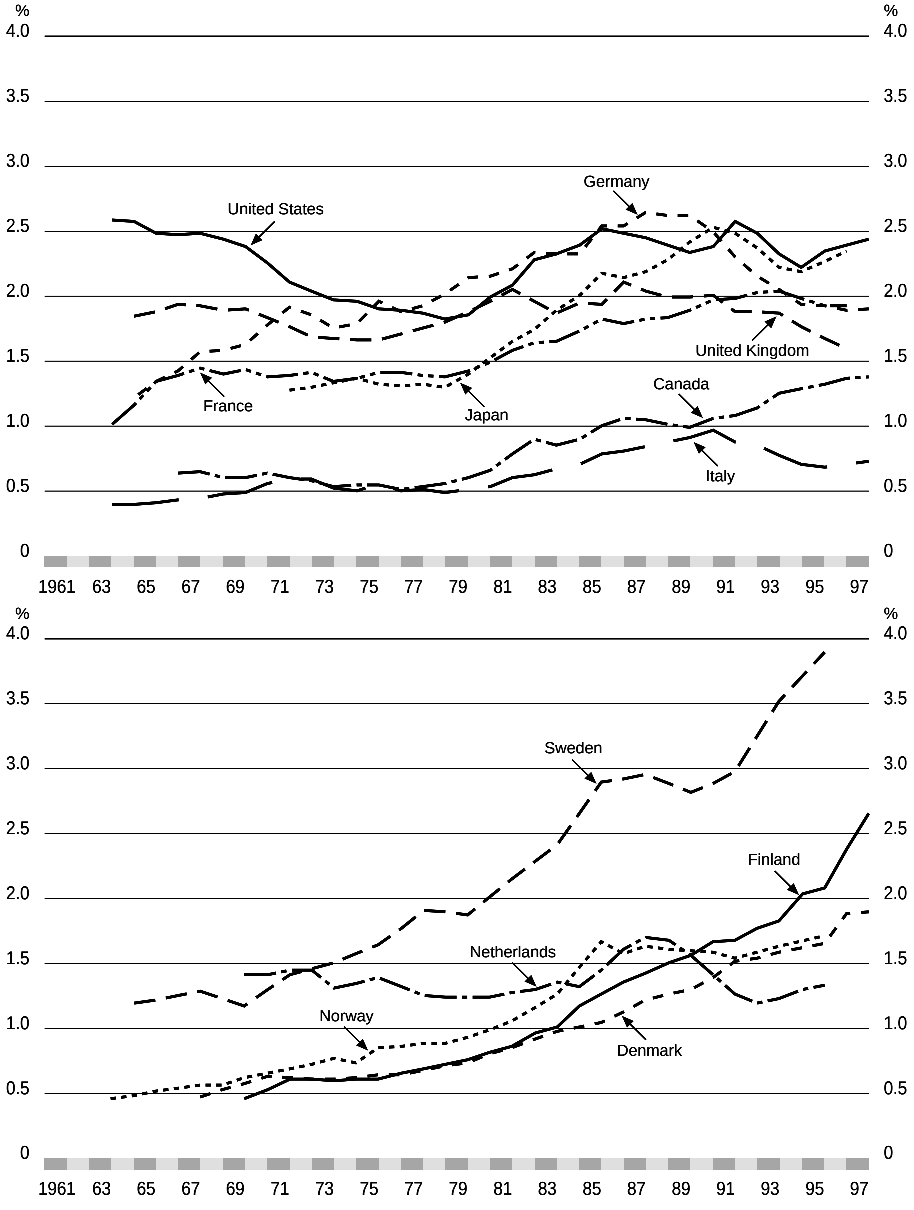
1. First year available: 1963 - France, Ireland, Italy, Norway, Switzerland, United States; 1964 - Austria, Germany, Spain, Sweden, United Kingdom; 1966 - Canada and 1967 - Denmark.
2. Last year available: 1996 for Canada, France, Germany, Iceland, Italy, Spain, United States; 1995 - Australia, Denmark, Finland, Ireland, Japan, Netherlands, Norway, Sweden, United Kingdom; 1993 - Austria.

*Source:* OECD, *Economic Outlook 60* and *MSTI databases, 1998.*

in the early 1990s. There are signs of an upturn in the most recent years (since 1995) in some countries, notably in the United States and Japan. European countries are also starting to recover slightly after the deep trough of 1992-1994, although growth rates of BERD remain very low. The levelling-off is still more striking when contrasted with the acceleration of BERD which took place in most countries in the late 1970s-early 1980s. In countries for which figures are available for a longer period of time, the 1980s seem to have been an era of atypically high growth of BERD as compared with the 1960s and 1970s.

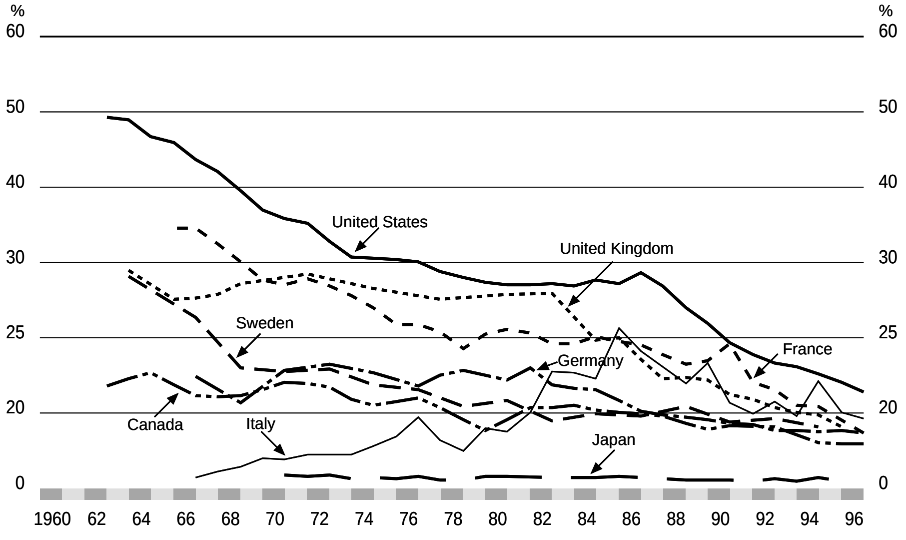
BERD is funded partly by business, partly by the government. The shares of BERD funded by business and by government vary across countries (Figure 2), with the share of business funding averaging about 85 per cent across the OECD in the mid-1990s. The trend of business funded BERD (Table 1) is very similar to the trend

Figure 1. ***R&D intensity in the business sector***[1]




1. Business enterprise R&D (BERD) divided by GDP of the business sector.
*Source:* OECD, *Economic Outlook 60* and MSTI database, 1998.

Figure 2. ***Share of government funding in total business enterprise R&D (BERD)***




*Source:* OECD, MSTI database, 1998.

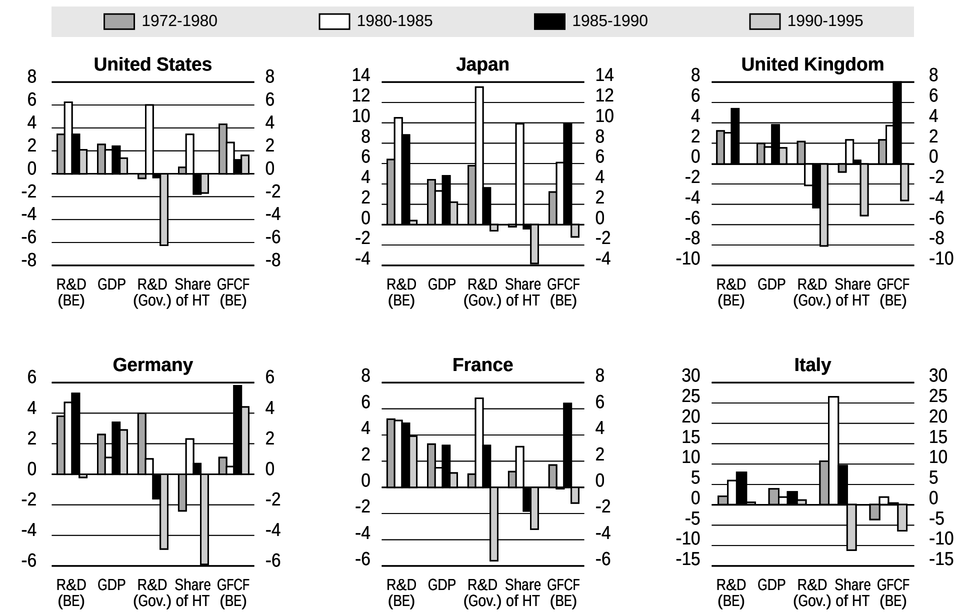
of total BERD as reported above, with a levelling-off starting in the mid-1980s or the early 1990s, following a sharp acceleration in the late 1970s. The slowdown is weaker, however, for the business funded component: the levelling off of BERD was partly due to a sharp reduction in government funding. The United Kingdom, Australia, the Netherlands and Norway were the only countries where business cut its R&D expenditures more (or increased it less) than the government.

## THE DETERMINANTS OF BUSINESS R&D EXPENDITURES

The empirical analysis reported here allows for an influence on R&D expenditures from the business cycle (fluctuations of GDP), government funding, interest rates and industry structure. This list is not exhaustive but probably captures most of the measurable macroeconomic factors at work.

The time profile of BERD in recent years has been similar to the profile of physical investment (Figure 3). In most OECD countries, physical investment declined in real terms in the early 1990s, before recovering subsequently.[3] This suggests that physical investment and R&D share some of their determinants, which is not surprising

Figure 3. ***Patterns of average annual growth rates over sub-periods***[1]




1. R&D (BE) is R&D performed and financed by the business enterprise sector; R&D (Gov.) is R&D performed by the business enterprise sector but financed by government; Share of HT is the value added share of high technology sectors in the economy; GFCF (BE) is investment by the business enterprise sector. All variables are deflated by the GDP deflator.

*Source:* OECD, *Economic Outlook 60*, STAN and MSTI databases, 1998.

since R&D is an investment for firms: a current expense which is supposed to provide returns in the future. However there are also differences, as pointed out in the following analysis.

The sensitivity of R&D to GDP, giving rise to "cyclicality" can be explained by both supply and demand factors. Case studies and statistical evidence show that R&D expenditures are financed primarily by the firm's cash flow (Hall 1992, Himmelberg and Petersen 1994). A firm gets little external funding for R&D projects, due to the difficulty of providing collateral, and to the difficulty for an external party to assess the value of a project and the ability of the firm to carry it out. Cash flow is very pro-cyclical, since it is generated by the current activity of the firm. A further reason why R&D might be pro-cyclical is that a large share of research is oriented towards short-term needs: it is devoted to adapt existing goods to new requirements or new markets and hence follows demand fluctuations. Finally, there are static as well as dynamic increasing returns to scale in R&D, implying that a downturn in economic activity will reduce the rate of return on R&D.

There are arguments supporting the alternative view that R&D should not be responsive to fluctuations in economic activity. Fluctuations in R&D are limited by high adjustment costs: R&D is a sunk investment, which at least in its intermediate phase (before a project is completed) is specific, non tradable; when an R&D project is interrupted before completion, it usually has no output that can be sold. Therefore the cost of stopping an ongoing project is high. It is also costly and time-consuming to build an efficient R&D team, and this must be restarted almost from scratch if an R&D project is interrupted. Moreover, about half of R&D expenditure consists of wages, the other half being intermediate equipment and goods. Adjustment costs are higher for labour than for intermediate goods and for investment in equipment. This is demonstrated by the time volatility (as measured by the standard deviation) of R&D, which is much lower than that of physical investment (Table 2), although it exceeds the volatility of GDP. The volatility of these variables did not decline over time, even though their growth rates did. The volatility of R&D

Table 2. **Standard deviations of annual growth rates from their means, 1969-94**

| | Business entreprise R&D financed by business | Business entreprise R&D financed by business | GDP | Gross Fixed Capital Formation | Number of researchers, or university graduates |
|---|---|---|---|---|---|
| United States | 3.4 | 6.3 | 2.5 | 6.3 | 3.3 |
| Canada[1] | 6.6 | 10.2 | 2.7 | 7.9 | 4.6 |
| Japan[2] | 5.4 | 17.5 | 3.5 | 9.1 | 3.8 |
| France | 3.6 | 8.9 | 2.2 | 4.9 | 2.1 |
| Germany[1] | 4.4 | 10.3 | 2.4 | 7.1 | 4.7 |
| United Kingdom | 4.4 | 7.4 | 2.4 | 6.7 | 3.3 |
| Switzerland[3] | 4.6 | 22.2 | 2.8 | 7.3 | 6.8 |
| Denmark[1] | 4.3 | 11.5 | 2.7 | 9.3 | 3.0 |
| Netherlands | 5.3 | 21.4 | 1.8 | 6.6 | 4.4 |
| Finland[1] | 5.6 | 17.7 | 3.6 | 13.1 | 4.5 |
| Norway[1] | 7.9 | 9.2 | 2.4 | 13.3 | 4.3 |
| Sweden[1] | 3.7 | 8.9 | 2.2 | 9.7 | 3.7 |
| G6[4] | 4.6 | 10.1 | 2.6 | 7.0 | 3.6 |
| G12[5] | 4.9 | 12.6 | 2.6 | 8.4 | 4.0 |

1. 1993 instead of 1994.
2. 1971 intead of 1969.
3. 1992 insted of 1994.
4. Simple average of first 6 countries above.
5. Simple average of all countries above.

*Source:* OECD, *Economic Outlook 60 and MSTI databases, 1998.*

even increased somewhat over time. Moreover, when R&D is adjusted in response to a change in its determinants, personnel is more stable than other components of R&D, as shown by the lower volatility of R&D employment as compared with R&D expenditures.

There have been few attempts in the literature to assess the relationship between R&D expenditures or other innovative activities and the business cycle. Microeconomic evidence, based on panel data, supports the pro-cyclical thesis (Hall and Mairesse 1995). Himmelberg and Petersen (1994) find that cash flow, which is pro-cyclical, has a strong influence on the R&D expenditure of firms. Macroeconomic evidence is less clear: Geroski and Walters (1995) find a pro-cyclical behaviour of innovation and patents in the United Kingdom over the period 1948-83, whereas Saint-Paul (1993) does not find any relationship between short-term fluctuations of GDP and R&D in OECD economies.

Government funding is a second obvious factor in determining business R&D expenditure. Governments of most OECD countries spend much money on R&D, either by supporting their own facilities (universities and public laboratories) or by funding firms. Beyond fulfilling certain public needs (defence or health), a rationale for government support is that the social rate of return on R&D is higher than the private rate of return. Subsidisation reduces the private cost, therefore increasing the private return. Although a positive relationship between public funding and private funding might be expected, it is sometimes argued that government support essentially substitutes for, or even crowds out, business funding.

Interest rates should influence R&D expenditures since they constitute an investment. As with physical investment, research is profitable only in the future, and expected profits have to be discounted. Moreover R&D must be financed, and interest rates reflect the actual cost of external funds or the opportunity cost of internal funds.

Finally, changes in industry structure may play a prominent role since the distribution of R&D across sectors is very skewed. Some sectors, such as aerospace or drugs, are highly research intensive, whereas others, such as food or wood products, perform nearly no research. Thus, even if research remains stable at the industry level, changes in the pattern of demand can have important aggregate effects.

## MODELLING R&D EXPENDITURES

The quantitative analysis is performed on the basis of econometric estimates of the equation presented in the annex. The factors taken for explaining business funded BERD are: GDP, government funded BERD, long-term real interest rates and an indicator of industry structure. The equation is an "error correction model", which separately allows the short-term and long-term influence of the variables to be identified. The model has been estimated on two fitted panels of countries. The largest one ("G12") includes 12 OECD countries: the United States, Canada, Japan, France, Germany, the United Kingdom (this sub-group is labelled "G6"), Italy, the Netherlands, Denmark, Finland, Norway, and Sweden. Isolating the G6 is justified by the fact that it includes the largest R&D spenders in the OECD. The period of estimation is 1972-1996 (or the latest year available). Results for various specifications are reported in Table 3.

GDP appears to play the most significant role in both the long and short run. The long-run elasticity of GDP ranges from 1.7 to 2 depending on the panel, reflecting the fact that over the estimation period R&D expenditures grew - on average - faster than GDP, in all countries. In the above estimate this phenomenon is picked up by the long-run coefficient of GDP. However, when a time trend and the structure variable are introduced, the long-run elasticity of GDP is not significantly different from unity. An increase in the share of R&D in GDP might reflect the transition towards the knowledge-based economy, an economy in which knowledge in all its forms (technology, but also human capital, high tech equipment and software) plays a crucial role. The knowledge base of all OECD economies has been expanding for years, more rapidly than their tangible base (OECD 1996, Abramowitz and David 1996, Minne 1996). Whether this is better captured by an elasticity higher than unity or by a positive time trend and a unit elasticity is an open question: the first approach assumes that it is GDP growth which has led to the emergence of the knowledge-based economy, because when an economy gets richer it increases its knowledge base (probably related to the relative cost of physical and intangible assets, to demand patterns and to competition with low wage - low technology countries); the second approach assumes that the growth of R&D intensity is partly autonomous, and should grow independent of GDP.

The total short-run GDP elasticity (the sum of contemporaneous and one-year lagged elasticities) is 0.8 for the G12 and 1.1 for the G6 (0.6 and 0.8 respectively when a time trend and structure variable are added). It turns out that short-term elasticities are not significantly different from long-term ones when a time trend is introduced in the equation, which means that it is specifically the long-term impact (beyond two years) which is captured by the time trend.

Over the recent period and particularly in the first half of the 1990s, most OECD economies have experienced slower economic growth and also a sharp slowdown or reduction in R&D expenditures. The upturn of economic growth in the United States since 1993 has been followed by an upturn in R&D expenditures, and similar signals have been reported in European countries more recently. The positive impact of GDP on R&D at a macroeconomic level is therefore strongly supported by recent developments. On the other hand, the various estimates of the short-run

Table 3. **Estimation results**[1]

Sample period: 1972-1995

| Models | G6 countries | | | | G12 countries | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Adjustment to long term | –0.26 t(–4.80)** | –0.42 t(–7.26)** | –0.31 t(–5.43)** | –0.44 t(–7.08)** | –0.06 t(–3.75)** | –0.07 t(–3.80)** | –0.10 t(–5.39)** | –0.12 t(–5.67)** |
| GDP long term | 1.68 t(28.82)** | 0.70 t(4.70)** | 1.84 t(25.81)** | 0.98 t(5.96)** | 1.67 t(7.23)** | 0.64 t(1.07) | 1.94 t(15.51)** | 0.69 t(2.22)** |
| GOV long term | 0.33 t(5.75)** | 0.35 t(10.27)** | 0.13 t(2.42)** | 0.24 t(5.37)** | 0.60 t(3.80)** | 0.52 t(3.69)** | 0.24 t(4.15)** | 0.19 t(4.02)** |
| STRUC long term | | | 1.00 t(3.95)** | 0.58 t(3.60)** | | | 2.09 t(5.81)** | 1.94 t(6.55)** |
| IR(–3) long term | –0.012 t(–1.65)* | 0.001 t(0.22) | –0.006 t(–0.94) | 0.004 t(0.99) | –0.077 t(–3.18)** | –0.070 t(–3.18)** | –0.035 t(–3.09)** | –0.027 t(–3.00)** |
| Trend | | 0.02 t(6.76)** | | 0.02 t(5.32)** | | 0.03 t(1.84)* | | 0.03 t(4.40)** |
| D(GDP) | 0.88 t(8.45)** | 0.61 t(6.41)** | 0.75 t(6.50)** | 0.55 t(4.63)** | 0.69 t(9.97)** | 0.65 t(8.68)** | 0.60 t(9.07)** | 0.49 t(6.66)** |
| D(GOV) | 0.03 t(1.14) | 0.07 t(3.01)** | –0.01 t(–0.36) | 0.03 t(1.45) | –0.01 t(–0.51) | –0.00 t(–0.31) | –0.01 t(–1.03) | –0.01 t(–1.03) |
| D(STRUC) | | | 0.45 t(4.77)** | 0.44 t(4.77)** | | | 0.38 t(7.50)** | 0.40 t(7.73)** |
| D(IR(–3)) | 0.001 t(0.44) | 0.001 t(0.59) | 0.001 t(0.73) | 0.002 t(0.95) | –0.003 t(–3.10)** | –0.003 t(–3.18)** | –0.002 t(–1.73)* | –0.001 t(–1.12) |
| D(GDP) (–1) | 0.26 t(2.21)** | 0.14 t(1.39) | 0.33 t(2.82)** | 0.29 t(2.56)** | 0.11 t(1.31) | 0.07 t(0.83) | 0.17 t(2.35)** | 0.14 t(1.78)* |
| D(GOV)(–1) | 0.05 t(1.69)* | 0.10 t(3.89)** | 0.01 t(0.29) | 0.06 t(2.12)** | 0.02 t(2.10)** | 0.02 t(2.00)** | 0.01 t(1.11) | 0.01 t(0.90) |
| D(STRUC) (–1) | | | 0.33 t(3.07)** | 0.27 t(2.62)** | | | 0.19 t(3.29)** | 0.21 t(3.60)** |
| D(IR(–3)) (–1) | –0.001 t(–0.59) | 0.000 t(0.22) | –0.002 t(–1.06) | –0.001 t(–0.30) | –0.003 t(–3.17)** | –0.003 t(–3.19)** | –0.003 t(–3.10)** | –0.003 t(–2.60)** |
| D(RD)(–1) | 0.14 t(1.78)* | 0.00 t(0.02) | 0.03 t(0.41) | –0.06 t(–0.73) | 0.15 t(2.69)** | 0.16 t(2.78)** | 0.06 t(1.08) | 0.06 t(1.06) |
| R2 Adjusted | 33% | 38% | 39% | 45% | 25% | 25% | 31% | 33% |
| DW | 2.05 | 1.99 | 2.01 | 2.06 | 2.22 | 2.24 | 2.11 | 2.15 |
| Modified LM test | 0.03 t(0.14) | –0.09 t(–0.49) | 0.11 t(0.46) | –0.14 t(–0.71) | –0.22 t(–1.03) | –0.22 t(–1.08) | –0.03 t(–0.09) | 0.02 t(0.08) |
| Number of observ. | 140 | 140 | 140 | 140 | 274 | 274 | 274 | 274 |
| Model fit for the 90s[2] | –0.005 t(–0.62) | –0.003 t(–0.34) | 0.003 t(0.41) | 0.004 t(0.53) | –0.009 t(–1.30) | –0.009 t(–1.31) | 0.002 t(0.29) | 0.001 t(0.10) |

1. The response variable is the volume of R&D performed and financed by the business enterprise sector; GOV is the volume of R&D performed by the business enterprise sector but financed by government; STRUC is an indicator reflecting the industry structure of the economy; IR are real long term interest rates.
2. The residuals of each estimated model were tested against a dummy variable which is equal to 1 for 1990-96 and 0 elsewhere.

*Source:* OECD, *Economic Outlook 60,* STAN, ANBERD and *MSTI databases, 1998.*

elasticity of business R&D to GDP are not significantly different from unity, which means that business R&D does not overreact to fluctuations in GDP. In other words, the economic downturn of the 1990s has generated a slowdown in R&D, but it cannot explain by itself the decrease in R&D intensity that was observed in many OECD countries. It played a prominent role, but other factors must be taken into account when it comes to explain the levelling off of R&D expenditures.

Government funding of research is the second most important factor in the explanation of R&D fluctuations: it exhibits a long-run elasticity of about 0.3 to 0.6 in the basic equations, and around 0.2 when a time trend and structure variable are introduced. Over the short run, government funding seems to have a much weaker effect, around 0.1 in most equations (with a zero contemporaneous effect in all except one equation). Therefore the impact of government funding is mainly a long-term one. It takes years for firms to adjust their R&D expenditures to the change in conditions generated by a change in government funding. The delayed adjustment of private funding to subsidies may signal that government funding is rather concerned with projects of a long duration, or that the research generated by government funds may open new, long-lasting opportunities to firms.

The share of BERD which is financed by government varies widely across countries, from 1.5 per cent in Japan to 15 per cent in the United States in the mid-1990s. In almost all countries this share has experienced a decline over time, which has become more pronounced in the past 10 years. Indeed, government funded BERD has been reduced in real terms in most countries, notably in all G7 countries (except Japan where it is negligible) over the past decade or so. The reasons are presumably twofold: the end of the cold war reduced defence expenditures, which made up a large part of government R&D expenditure in some countries (especially the United States, the United Kingdom, and France); while the deterioration of budget deficits in most countries strengthened downward pressures on all types of expenditures, including R&D. The estimation results suggest that the reduction of government funding explains much of the reduction in R&D expenditures in some countries (and especially in those cited above).

High real interest rates are usually taken to have contributed to the reduction in physical investment experienced by European countries in the 1990s. When interest rates are introduced in the R&D equation the results differ across the panels. In the G12 countries, they have a strong impact on business R&D: a rise in real interest rates of 100 basis points reduces the level of business R&D by 3 per cent in the long run (when a time trend and a structure variable are introduced); but the effect is significant in only one equation in the G6 panel. The short-term impact across both panels is weak or nil. Moreover, the effect of interest rates is lagged by three years in the estimates. Such a delayed response is broadly in line with the literature on monetary policy (central bankers use the rule of thumb of 18 months for the effect of changes in interest rates on economic activity to become significant). A delayed response of the impact on R&D is consistent with the idea that interest payments, rather than expectations, are the mechanism through which the shock is transmitted to R&D: as they have to reimburse higher service on their debt (which they have incurred for funding research or other expenditures), firms have less cash available to spend on R&D. These effects are additional to the indirect negative impact of interest rates on business R&D through GDP (which is also negatively affected by interest rates). The estimated effects imply that the high level of real interest rates from the early 1980s on (they rose from zero or negative values to 4-6 per cent in a few years) played a substantial role in the levelling off of R&D.

Changes in the cross-industry structure of the economy also seem to play an important role in R&D fluctuations. In order to capture these multi-dimensional changes quantitatively, an indicator (STRUC) which - basically - reflects the share of high-technology sectors in GDP is constructed. More precisely, it is defined as the weighted average across sectors of their shares in GDP, where the weights are the sectors' respective R&D shares at a specific point in time.[4] For the G12, the long-term elasticity of this factor is around 2, whether there is a time trend or not and its short-term elasticity (contemporaneous plus one year lag) is close to 0.6. For the G6, the long-term value is 1 without a time trend, 0.6 with a time trend, and the short-term value is 0.7 to 0.8.

When introducing this structural variable, the effect of government funding on BERD weakens substantially. The role of government funding is partially integrated in the structural variable. This suggests that an important part of the effect of government funding is to push high-technology sectors of the economy to above-average growth. Most R&D in high-technology industries is financed for government objectives, such as defence (in aerospace or electronics) or space exploration.

High-tech industries in OECD countries grew faster than the rest of the economy in 1975-85, but slower thereafter (Figure 3). More specifically, the growth of technology-intensive sectors was little affected by the recession of the early 1980s, but was strongly influenced by the recession of the 1990s, a period during which their share in the economy declined. Moreover, the share of services (which on average are much less R&D intensive than manufacturing) in GDP surged in the 1990s. Thus, overall, changes in industry structure contributed substantially to the acceleration of R&D expenditures in the early 1980s and to the slowdown of the 1990s.

In order to test whether the model adequately explains the levelling off of R&D in the 1990s, the residuals of the estimated equations were regressed on a dummy variable, which equals 1 for the 1990s and 0 before. The coefficient for this variable is not significantly different from zero in any of the estimates. Hence the model gives a fair account of the levelling off, although it probably does not capture all the complex factors at work.

## CONCLUSION

The levelling-off of business R&D expenditures in the 1990s is satisfactorily accounted for by the economic downturn of this period, by the reduction in government funding, by high interest rates and by a structural shift from high-tech to service industries. The main contributing factor varies across countries. In the case of Japan and Germany, large macroeconomic shocks (caused by the burst of the financial bubble and unification respectively) had a very detrimental effect on all forms of investment including R&D. For the United States and the United Kingdom, the reduction in government funding and the shift to services were major factors. This is also the case for France, although at a later point in time.

There is no evidence, in the results presented here, of an increase in the cyclicality of R&D. The influence of GDP was masked in the past by anti-cyclical behaviour of other variables such as government funding. The conjunction of adverse macro-economic conditions and of shrinking government funding deepened the levelling-off in the 1990s, creating this impression of stronger cyclicality.

The reduction in R&D expenditures has probably also had effects on the type of research conducted by firms. R&D managers and government sources often claim that R&D has become more short-term oriented and more applied (less basic) than it was before (see OECD 1998*b*). Moreover, according to R&D managers, research activities would also have become more efficient, in that they give now "more value for money". In the line of the model presented above, these changes are more likely consequences than causes of the levelling-off. It is likely that when firms reduce their investment expenditure they will first cut projects with the lowest expected returns. This will have a positive impact on the average and marginal efficiency of the remaining projects, contributing to the increase in the efficiency of R&D as perceived by managers. In economic downturns, firms tend to retain investments that have a direct impact on their short-term situation. Basic research will therefore be reduced before applied research, which may lead to a perception that R&D has become more applied in recent years.

It has been shown that government funding affects business R&D in the long run, which supports the idea that the government-funded component of business R&D has a longer term, or more basic, nature than the business-funded component. Since government reduced their funding over the past decade, this may have affected long-term, basic R&D more than applied R&D.

## NOTES

1. In this view, changing market structures (strengthened competition in product and capital markets), increasing codification of knowledge (which eases imitation by competitors) and reduced government support may have led firms to adopt a more cautious innovation strategy.
2. Data for R&D (business performed research and government funding) are collected by national surveys, then gathered and harmonised by the OECD Secretariat (Directorate for Science, Technology and Industry). All the R&D data used in the econometric work are from the DSTI data base, and are published bi-annually in the Main Science and Technology Indicators (OECD 1998*a*).
3. The similar evolution of R&D and physical investment is confirmed by a simple regression of the annual growth rate of business investment on BERD funded by business (with country specific fixed effects), which gives a coefficient of 0.65, with a t-statistic of 7 and R-squared of 0.15.
4. This indicator is defined as:

$$\ln\left[STRUC(t)\right] = \sum_j w_j(t_0)\ln\left[V_j(t)\big/V_+(t)\right],$$

where $R_j$, $V_j$ denote the R&D and the value added of a sector "*j*", $R_+$, $V_+$ the R&D and the GDP of the economy of a specific country and $w_j(t_0) = R_j(t_0)/R_+(t_0)$ the R&D share of a sector "*j*" in the economy at a specific time point (here: $t_0$= 1985).

In the case of a hypothetical economy with two sectors, where all R&D is conducted in the first sector, the variable STRUC would represent the GDP share of this sector.

## BIBLIOGRAPHY

ABRAMOWITZ, M. and P. DAVID (1996), "Technological Change and the Rise of Intangible Investments: The US Economy's Growth Path in the Twentieth Century", in OECD: *Employment and Growth in the Knowledge-based Economy*, Paris.

GEROSKI, P. A. and C.F. Walters (1995), "Innovative Activity Over the Business Cycle", *Economic Journal 105* (July), pp. 916-928.

HALL, B.H. (1992), "Investment and R&D at the Firm Level: Does the Source of Financing Matter?" *NBER Working Paper* No. 4096, Cambridge, MA.

HALL, B.H. and J. MAIRESSE (1995), "Exploring the Relationship between R&D and Productivity Growth in French Manufacturing Firms", *Journal of Econometrics*, 65, pp. 263-293.

HIMMELBERG, C. and B. PETERSEN (1994), "R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries", *Review of Economics and Statistics*, 76(1), pp. 38-51.

MINNE, B. (1996), "Expenditures in Relation to the Knowledge-based Economy in 10 OECD Countries", presented at the Conference on "New Science and Technology Indicators", OECD, Paris.

OECD (1996), *The Knowledge Based Economy*, Paris.

OECD (1998*a*), *Main Science and Technology Indicators*, 1998-1, June, Paris.

OECD (1998*b*), *Technology, Productivity and Job Creation - Best Policy Practices* , Paris.

SAINT-PAUL, G. (1993), "Productivity Growth and the Structure of the Business Cycle", *European Economic Review*, 37, pp. 861-883.

*Annex*

## THE MODEL

The econometric model which is estimated is of the "Error correction" type (ECM):

$$\Delta \ln[Y_i(t)] = a_0 * \Delta \ln[X_i(t)] + a_1 * \Delta \ln[X_i(t-1)] + \rho * \{\ln[Y_i(t-2)] - \gamma * \ln[X_i(t-2)]\} - \delta_i + \varepsilon_i(t)$$

where $Y_i$ is BERD financed by the business sector in country "i" and deflated by the GDP-deflator (here in log-difference, *i.e.* in growth rates), and $X_i$ denotes the vector of independent variables of country "I". As such are taken: GDP of the business sector, BERD financed by government (both deflated by the GDP-deflator), real long-term interest rates and a structure variable.

In this kind of model it is assumed that:

- a shock in the factors is transmitted to the dependent variable (R&D) partly within the same (or the next) year: this is the "short-run effect", represented by $a_0$ and $a_1$;
- there is a long-term equilibrium relationship between the levels of the dependent variable and the factors: *i.e.* $\ln[Y_i(t)] - \gamma * \ln[X_i(t)]$ is stationary. This relation may be thought of as an economic equilibrium relation between the variables: when R&D "over- or under-shoots" (the term above is bigger or smaller than 0), it will be pushed back to the long-term equilibrium, *i.e.* towards 0 (it is multiplied by the adjustment factor $\rho$, which is smaller than 1). The vector-parameter $\gamma$ is the long-run elasticity of R&D with respect to the independent variables and $\delta_i$ are the country specific intercepts.

The above equation differs from some of the literature in the field by relating the levels (in logarithms) of R&D with the level of GDP, whereas some other studies rather relate the level of R&D to the growth of GDP (or, which is the same, the "stock of R&D" to the level of GDP). Our approach is analytically justified by cointegration properties of the series (the tests are available upon request to the authors). Moreover, it is more convenient not to rely on "R&D stocks" which are calculated under strong and hard to verify assumptions (regarding especially the depreciation rate).

We made further assumptions in the estimation procedure:

- The elasticity of R&D with respect to explanatory factors is the same across countries and time (in the short and long run).
- Each country is allowed to have its proper intercept: the model does not explain cross countries differences in R&D levels.
- The one-period lag which is used for the short-run effects is sufficient to make the residuals independent in time (this assumption is verified with the LM test).
- As residuals appeared to be correlated across countries, we used the seemingly unrelated regression procedure (SUR).