POLICY FORUM: SCIENCE PRIORITIES

The Scientific Investments of Nations

Robert M. May

Advances in science and technology have led to huge changes in our daily lives—changes that have been overwhelmingly positive, improving our economic prosperity and quality of life (*1*). Most financial support for research and development (R&D), both public and private, is generated in anticipation that such fruits will eventually be harvested.

So how much should nations invest in R&D? And what should be the apportionment among basic research, applied research, and development? There are no theorems, no basic principles, that answer these important questions. Instead, the world's leading countries exhibit diverse patterns of investment in R&D. Here I survey these patterns and draw some tentative conclusions.

Governments are the principal funders of basic research because the results are unforeseeable and unownable. They also fund applied research to inform public policy and operations. Additionally, governments seek to encourage business R&D to sharpen the competitive edge of their industries and increase national wealth. Governments in major and emerging industrialized countries claim to be placing increasing emphasis on the importance of R&D in all forms, from basic through applied.

To test these claims, I compare and discuss 12 countries' national investment in R&D between 1981 and 1995, using OECD data (*2*). The 12 countries include the G7 plus five others: Australia, Denmark, the Netherlands, Sweden, and Switzerland. This group of countries includes most of the top producers of papers in science, medicine, and engineering and of citations (*3*, *4*). A significant omission is Israel, which is not in the OECD and therefore not in its data set.

R&D Investment

These 12 countries together account for 80% of the world's total investment in R&D. On average, their gross expenditure on R&D (GERD) (*5*) grew as a proportion of gross domestic product (GDP) during the 1980s from 1.8% in 1981 to 2.2% in 1990 and has remained around 2.2% up to 1996 (Fig. 1) (*6*).

The author is Chief Scientific Adviser to the UK Government, based in the Office of Science and Technology, London SW1H 9ST, UK.

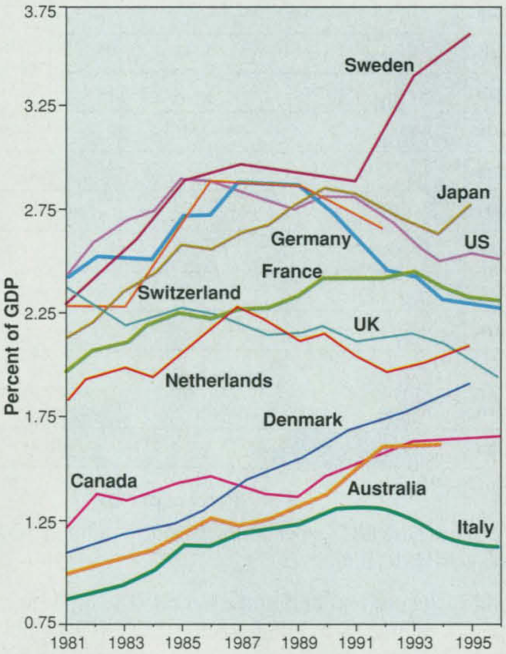

Fig. 1. Trends in GERD as percent of GDP (*2*, *5*).

Between 1981 and 1996, Sweden and Japan overtook the United States and Germany (*7*) as the top spenders on R&D relative to GDP. Sweden, Japan, Switzerland, France, and the Netherlands overtook the United Kingdom, which is the only country in which investment relative to GDP declined throughout the period.

These trends are clouded by important differences among countries in the balance of their R&D effort between civil and defense purposes. A substantial proportion of the R&D effort of the United States, United Kingdom and France has been defense-related (respectively, 18, 15, and 14% in 1995). Sweden spent 9% and Australia 7%; the remainder spent at most 1%.

The United States and the United Kingdom stand out among the group by showing a sharp decline in government-funded R&D (Fig. 2) (*8*) as a proportion of GDP; this decrease largely reflects cutbacks in defense spending after the end of the Cold War, combined with the tight expenditure control under Ronald Reagan and Margaret Thatcher. In essentially all 12 countries, nongovernment-funded R&D grew relative to GDP.

Investment in the Science Base

The 12 countries had very different investments in their science base. I use this term to describe all research and postgraduate training undertaken in universities, government-funded laboratories, and private nonprofit organizations (charities or foundations) funded both from public and nonpublic sources (*9*).

Relative to GDP, the top three spenders in 1988 and 1995 were Japan, Sweden, and the Netherlands (Fig. 3). The bottom four—Italy, the United Kingdom, the United States, and Canada—were the same in both years. Denmark showed the most improvement over the period, moving from eighth to fourth and overtaking Switzerland, Australia, Germany, and France.

In most countries, government is the main funder of the science base; other contributions typically amount to less than 10%. However, nongovernment sources of funding have been substantial in the United Kingdom (around 25% throughout 1988–1995) and also, to an increasing extent, in the United States and Canada. Business and charities fund proportionately more of the science base in the United Kingdom and in Sweden than they do in the United States or Canada; overseas contributions are small but increasing in the United Kingdom and to a lesser extent in Denmark, Sweden, and the Netherlands. Nongovernment sources fund almost 40% of Japan's science base, and their business contributions (in relation to GDP) are higher than for any other of the 12; the relative contribution of government and nongovernment sources to higher education in

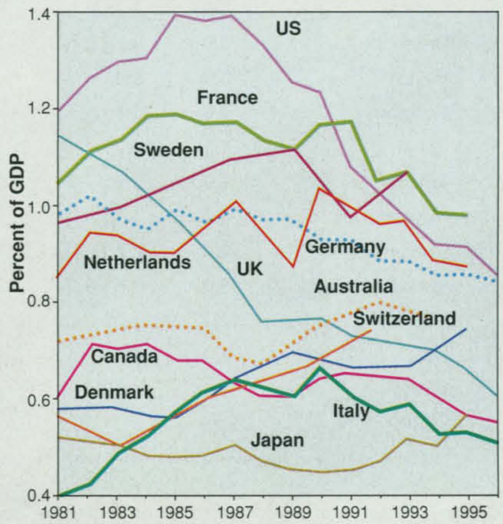

Fig. 2. Trends in government-funded GERD as percent of GDP (*2*, *8*).

Japan is, however, unclear (*10*).

The patterns based on population are similar to those shown in Fig. 3, although wealthier countries tend to move up. For example, between 1988 and 1995, Japan and Switzerland moved past Sweden. Per capita comparisons, however, can be distorted by differences among countries in the average salaries of researchers relative to other groups (*11*). In absolute terms, the U.S. investment in basic science, at around $41 billion in 1995, is 1.5 times that of the next largest investor (Japan, at $28 billion) and almost exceeds the $45 billion total for the other 10 countries (*12*).

Private Sector R&D

There are also marked differences in industry-financed business enterprise R&D (IFBERD) (*13*) for the 12 countries. In contrast to government expenditures (Fig. 2) over this period, IFBERD increased or held roughly constant as a percentage of GDP for most countries; the recession in the early 1990s had a dampening effect, but company investment in R&D is now climbing back [except in the United Kingdom and Germany (*7*)].

The United Kingdom and the United States, along with Australia, Canada, and Denmark, have seen particularly large shifts to private sector funding (Table 1). Japan, Switzerland, and Sweden have the highest ratios of private to public investment; these three countries also have the highest levels of IFBERD as a proportion of GDP; Germany and the United States are also in the upper part of this range. The United Kingdom, by contrast, has a relatively low level of IFBERD as a proportion of GDP and also saw its level fall relative to that of most of the other countries (even though it rose in absolute terms) during the period. The high ratio of private- to public-sector R&D in the United Kingdom is thus more a reflection of the low level of government support than of the buoyancy of UK business R&D investment.

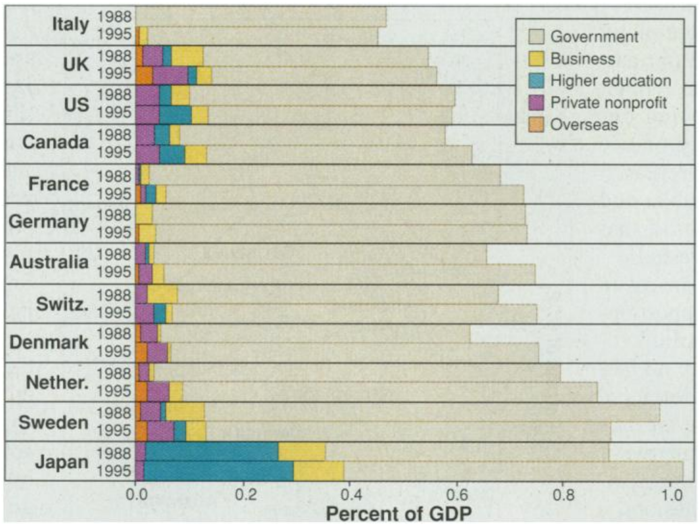

Fig. 3. Science base R&D expenditure by source of funds as percent of GDP for 1988 and 1995 (*2, 9*).

The United Kingdom's *R&D Scoreboard* (*14*) presents data on relative R&D intensity (RDI, measured by the ratio of R&D expenditure to sales) for the 300 companies that top the world league for R&D investment (Table 1). Denmark, Canada, Sweden, and Switzerland have the highest average RDI, although for the first two the sample size is 1 and 2, respectively (*15*). The United Kingdom and Italy are well below the average RDI, but the UK's relative position improves if oil companies (all of which have low RDIs) are excluded (*16*). The United Kingdom stands up well in terms of RDI in pharmaceuticals and the electronic and electrical equipment sector but is well below par in chemicals, engineering, and telecommunications.

Discussion

What conclusions can we draw? First, total investment in R&D is on a rising trend. Second, public investment in R&D is at best holding level relative to GDP (despite rhetoric about its importance), as governments worldwide struggle to keep public expenditure under control. Third, in countries with relatively high investment in defense R&D, public funding has fallen steeply; the peace dividend seems to have gone into the general coffers, not into increasing civilian R&D. Fourth, worldwide nongovernment sources (principally businesses but also charities) are accounting for a higher pro-

Country	Private/public funding of GERD		Number of firms in top 300	RDI (average)	Percent of patents in 1995		U.S. human genetic patents (%)	
	1981	1995			U.S.	European	Owner	Origin of citations
Australia	0.4	1.1 ['94]	1 (15)*	1.0	0.4 (0.33)*	1.3 (1.07)*	–	
Canada	1.0	1.7	2 (16)	10.8	2.1 (0.93)	1.5 (0.66)	1.7	2.3
Denmark	0.9	1.7 ['93]	1 (51)	15.1	0.2 (0.55)	1.0 (2.77)	–	
France	0.9	1.4	19 (89)	4.0	2.8 (0.71)	6.9 (1.74)	1.8	2.9
Germany	1.5	1.7	21 (73)	4.7	6.5 (1.22)	17.2 (3.24)	2.5	2.5
Italy	1.1	1.1	7 (3.5)	2.3	1.1 (0.29)	3.2 (0.86)	1.0	
Japan	3.0	3.9	72 (149)	4.9	21.5 (2.41)	13.5 (1.51)	12.3	4.8
Netherlands	1.1	1.3 ['94]	5 (91)	5.3	0.8 (0.79)	2.1 (2.08)	–	
Sweden	1.4	2.2 ['93]	8 (264)	7.4	0.8 (1.43)	2.5 (4.52)	–	
Switzerland	3.0	2.5 ['92]	10 (313)	6.2	1.0 (1.69)	2.3 (3.90)	1.2	
UK	1.1	2.0	19 (96)	2.3	2.4 (0.66)	6.7 (1.84)	2.8	6.4
US	1.0	1.8	127 (100)	4.3	55.0 (2.34)	34.3 (1.46)	71.2	62.2
World	–	–	–	4.0	–	–	–	–
Others	–	–	–	–	5.5	7.5	5.5	19.0

*Values in parentheses are scaled to the countries' share of global GDP.

Table 1. Patterns of R&D investment in regard to ratios of private/public funding in 1981 and 1995 (unless otherwise indicated) (*2*); companies' investment in R&D (*14*), given by a country's number of top-300 firms and their average RDI; ownership of U.S. and European patents (*6*); and ownership of U.S. patents and papers cited therein for human cell and molecular technology (*21*).

Country	1990	1993	1996
UK	22.15	19.58	18.83
Denmark	21.00	18.28	16.35
Sweden	16.93	15.22	15.69
Switzerland	20.14	16.62	15.60
Canada	20.24	16.55	13.94
Australia	15.17	12.95	12.13
Netherlands	15.53	11.66	11.12
US	17.52	12.23	10.10
France	10.46	9.29	8.86
Italy	8.84	7.76	8.78
Germany	11.86	9.82	8.10
Japan	5.62	4.98	4.25

Table 2. Papers published in science (including medicine and engineering) in 1990, 1993, and 1996 per £1 million of science base expenditure in 1987, 1990, and 1993, respectively (*26*).

portion of total R&D investment, not just in applied activity but also in basic research. Fifth, as governments seek to control their own investment in R&D, they will continue to look to the private sector for growth. It is interesting that countries that introduced tax credits over the past decade—Australia, Canada, and the United States—have all seen strong growth in industry-financed R&D investment.

To investigate the relative effectiveness of different countries' investment in R&D, I compared countries' relative investment in basic research (Fig. 3) with their relative output of scientific research papers (Table 2). On this basis, the United Kingdom is at the top and Japan is at the bottom, opposite to their positions in Fig. 3. Denmark, Switzerland, and Sweden, which, unlike the United Kingdom, are large investors in basic research relative to GDP and population size, also come out well. Germany, Italy, and France come out near the bottom, possibly reflecting a bias in the Institute of Scientific Information (ISI) data or other social and institutional factors (*17*). But insofar as the output of papers is a measure of effective scientific activity, these countries, together with Japan, appear to have relatively low productivity in relation to their investment in basic research (*18*, *19*).

Patent data are one indicator of a country's relative capacity for commercial exploitation of advances in basic research. As seen in Table 1, the 12 countries' proportionate ownership of U.S. patents differs considerably, and understandably, from their ownership of European patents. The eight European countries plus Australia have roughly the same relative rankings for both U.S. and European patents in relation to GDP; Sweden, Switzerland, and Germany are at the top. By contrast, Japan and the United States occupy first and second places in the ranking by U.S. patents but fall dramatically to eighth and ninth for European patents.

A more detailed analysis (*20*, *21*) is produced by comparing a country's authorship of the literature cited in patents [predominantly university research (*22*)] with its ownership of the patents themselves. Narin *et al.* (*23*) showed that citations of basic research papers are increasing in U.S. patents in all sectors. A study of U.S. patents in "human molecular and cell technology" (*21*) revealed that the United Kingdom is a clear second to the United States in authorship of cited research papers but a poor third to the United States and Japan in owning the patents (*24*).

In short, as I observed in a previous paper (*4*), the strong UK science base does more than its share in helping to create wealth around the world. It is also arguably a primary factor in the United Kingdom's good record in attracting inward investment (*25*). But this science base strength is not consistently translated into strong industrial performance within the United Kingdom itself.

References and Notes

1. See, for example, J. Stiglitz *et al.*, *Supporting R&D to Promote Economic Growth: The Federal Government's Role* (Council of Economic Advisors, Washington, DC, October 1995). These authors suggest that the social rates of return on R&D investment are around 50%, and the private rates are around 20 to 30%. D. Coe and E Helpman [*Eur. Econ. Rev.* **39**, 859 (1995)] show that although there are large spillovers, substantial benefits accrue preferentially to the country or business performing the research. See also B. R. Martin *et al.*, *The Relationship Between Publicly Funded Basic Research and Economic Performance* (HM Treasury, London, 1996).
2. Organization for Economic Cooperation and Development, *OECD Basic Science and Technology Statistics* (OECD, Paris, 1995 and 1997). The OECD ensures that member countries' data comply with standard practices and definitions of R&D spending, as published in the *Frascati Manual 1993* (OECD, Paris, 1994).
3. *Australian Science: Performance from Published Papers* (Australian Government Publication Service, Canberra, 1996); *Analysis of the Quality of the UK Science Base* (Office of Science and Technology, London, 1997).
4. R. M. May, *Science* **275**, 793 (1997).
5. GERD is total intramural expenditure on R&D during a given calendar year. It includes R&D performed within a country and funded from abroad but excludes payments made abroad for R&D (*2*).
6. *2nd European Report on S&T Indicators 1997* (European Commission Publication EUR 17639, Brussels, 1998).
7. Up until 1990, the numbers are for the former West Germany; since 1991, they are for the new unified Germany.
8. The GERD data (*5*) distinguish among several sources of funding: government, business enterprise, private nonprofit (that is, charities), higher education's own funds, and money from overseas.
9. The GERD data (*5*, *8*) also give information about the sectors performing the R&D (*8*). Using this, the UK Office of Science and Technology has developed a measure of basic research or "science base" R&D activity. This gives a rough indication of the underpinning, precompetitive scientific activity of a nation, taking account of national differences in the organizational structures of research facilities. This science base figure sums funds for all R&D performed (i) by government (in government-owned research laboratories and Research Council or equivalent institutions), (ii) by higher education institutions, and (iii) by private nonprofit institutions. It includes all "Frascati" categories of such R&D (*2*). The higher education category in Fig. 3 represents expenditure by universities, directly from their own endowed or other funds; the detailed accounting, however, varies somewhat from country to country.
10. The higher education–funded R&D in Fig. 3 is for research supported by the sector's own funds (such as endowment income) (*9*). For Japan, however, all R&D carried out in private universities has its funding attributed to this source (regardless of the actual funder).
11. An international comparison of salaries of scientists/researchers found (indexed against 100 for Australia): France, 149; Germany, 215; Japan, 267; UK, 111; US, 148. See *Science System: International Benchmarking* (Aust. Gov. Publ. Service, Canberra, 1996), Table 7.12.
12. National currency data have been converted to U.S. dollars, using purchasing power parities developed by the OECD. See *National Accounts Vol. I, 1960–1993* (OECD, Paris 1995), sections VII and VIII.
13. IFBERD represents that part of R&D carried out within and funded by the business enterprise sector.
14. *The UK R&D Scoreboard 1997* (Department of Trade and Industry, London, 1997).
15. Other measures of relative investment in R&D, for example, expressed as a ratio to profits rather than sales, give rankings similar to those in Table 1 (*14*).
16. There are 10 "oil, integrated" companies among the 300 companies, two of which are UK companies. These 10 account for 14% of all sales in the *Scoreboard*, and the two in the United Kingdom account for 50% of its sales total. If all integrated oil companies are excluded, the global average RDI increases to 5.0, and the UK average increases to 4.3. This gives a rather different picture from Table 1.
17. See discussion in (*4*) (notes 6 and 8), and G. R. Barreto, *Science* **276**, 882 (1997); P. C. White, *ibid.*, p. 884; S. Herskovic, *ibid.*
18. See also J. Grant and G. Lewison, *Science* **278**, 878 (1997); R. M. May, *ibid.*, p. 879.
19. A recent study [S. and R. Rousseau, *Scientometrics* **42**, 75 (1998)] measures outputs by various combinations of publications and European patents, and inputs by combinations of R&D expenditure in relation to GDP and size of labor force. Switzerland, with its strengths in both publications and European patents, now tops all these league tables, but the broad patterns remain as in Table 2.
20. F. Narin, K. S. Hamilton, D. Olivastro, *Res. Policy* **26**, 317 (1997).
21. J. Anderson, N. Williams, D. Seemungal, F. Narin, D. Olivastro, *Technol. Anal. Strat. Manag.* **8**, 135 (1996).
22. Publicly funded research, predominantly in universities, accounted for 73% of all papers (46% U.S., 29% foreign) cited in U.S. industrial patents in 1993–1994. Corresponding sectoral figures are 79% for patents for drugs and medicines and 76% for chemicals, to a low of 49% for electrical components (*20*).
23. See (*20*), figure 1 and table 1.
24. There is a marked national component to the link between basic science and its technological application, in that a country's patents tend to cite papers from that country at rates significantly above "background" [see (*20*), figure 3]. This observation relates broadly to my opening discussion (*1*).
25. The United Kingdom receives more than a third of all inward investment into the EU, including roughly 40% of all such investment from the United States and Japan.
26. Bibliometric data are from ISI [see (*4*), notes 2 through 4]. Science base expenditure was estimated from OECD data (*2*, *9*, *18*) (Fig. 3).

27. I thank R. Dowdell, K. Root, S. Sarson, H. Williams, J. Anderson, B. Martin, and K. Pavitt for comments and advice.