RECENT COMPARATIVE TRENDS IN TECHNOLOGY INDICATORS IN THE OECD AREA

L. Soete and *B. Verspagen*
University of Limburg, MERIT

I. INTRODUCTION

The purpose of this paper is to provide a broad review of technological indicators and their shortcomings, with a particular focus on trends and possible biases linked to the emergence of new technologies. From this perspective the aim of the paper is twofold: to shed some light on technology "measurement" problems and to provide some broad technological evidence with respect to the productivity paradox. We will not address the issue here of the relationship between such technological evidence and the actual trends in "measured" total factor productivity growth. That issue is addressed in detail in Workshop 2.

When presenting technological evidence within the framework of its consistency with growth in productivity, whether at the macroeconomic or sectoral level, it is of course important to recognise that the *economic* impact of technical innovations does vary significantly and might not reflect in any way the scientific or technological importance of such innovations. It is useful in this context, to make at least two distinctions.

First of all, it is essential to recognise that there are many innovations which have very widespread societal effects, but whose measurable economic effects are small or at best indirect in terms of macroeconomic growth and efficiency. Examples abound. The innovation of an oral contraception device had a major impact on sexual behaviour in the 60s and 70s in most OECD countries, giving rise to some fundamental debates about medical and social ethics. Its economic impact was at best indirect through greater participation of women in the labour market. Genetic fingerprinting – more recent technological advance in biotechnology – is said to be of great importance in forensic medicine, crime detection and the judicial process, especially in cases of rape, assault and murder. It could also have major implications for medical prognosis and life insurance, which will raise fundamental questions of medical and social ethics. Again though, the economic significance of this technical advance is unlikely to be large.

The fact that for some innovations, the societal impact may be very great while the direct measurable economic impact might be small, has important implications for any analysis looking at technological change from an economic perspective. In line with other contributions to this and the other three Workshops we are concerned here primarily with those new technologies whose "measurable" *economic* impact is significant.

A second distinction which is of equally great importance is the difference between innovations which find applications in only one sector and those which effect many or all sectors of the economy. In some of the technological taxonomies suggested in some of our previous writings (Pavitt, 1984; Patel and Soete, 1987; and Soete, 1988), technological advances were identified as either "localised" or "pervasive" in terms of their impact. Again, an illustrative example will serve to clarify this distinction. The "float glass" process introduced by Pilkington's in the 1960s was certainly of enormous economic importance for that firm and for the glass industry generally, as it was licenced to almost all the major glass manufacturers in the world over the next few years. However, it had no applications outside the glass industry and its *macro*economic significance was therefore relatively small. The microprocessor or the electronic computer by contrast have found applications in practically every single sector of the economy, with one suspects a major economic impact on the efficiency and growth performance of the economy.

In our discussion of technological indicators and presentation of evidence and trends based on such indicators, it is important to be aware of this wide variance in economic impact of technological advances. The problem has undoubtedly become more severe over the recent period. Whereas, most empirical studies in this area, in order to at least eliminate some of the more societal technical advances, limit the analysis to the industrial sector, either as "purveyor" of technological advances, or as funding such advances, such an approach becomes increasingly laborious, as we will see below, because it ignores large parts of the service sector as contractor of major new technologies.

A systematic inclusion of services in the analysis, means on the other hand, that one will be increasingly confronted with questions about the "direct" economic impact of such technological advances. In many service sectors the separation between economic "measurable" impact and "societal", quality of life impact of technological change is difficult to make. The task before us is, as it stands, difficult enough.

By its nature, technological change is difficult to measure directly. None of the traditional indicators are without conceptual and measurement problems. Available measures of inputs into the technological generation process are expenditures on R&D and numbers of R&D personnel such as scientists and engineers. Given the limited space available we limit the analysis in the first section of this paper to the – from an international perspective – somewhat more reliable R&D *expenditure* indicator. Whether such data still represent an accurate picture of all technological inputs is increasingly doubtful and a question which will be addressed in the second part of Section II.

Among the available proxy indicators of the output of technological efforts one has at one's disposal unfortunately even more unreliable indicators: "number" indicators such as number of patents (granted or applied for) or innovation counts; international performance data such as trade in high-technology products or technological balance of payments receipts or expenditures, and best-practice productivity measures. To the extent that some of these output indicators are being discussed in the ensuing contributions of Schankerman (on patents) and Grupp's group (on technometrics), we discuss only briefly in Section II some of the recent trends and measurement problems with respect to the new emerging technologies within the context of the one indicator, we ourselves have been keen users of, namely patents statistics. In Section III we conclude with a couple of ideas for further research and improvement of data collection, in which the OECD could play a major role.

II. R&D MEASUREMENT AND THE NEW TECHNOLOGIES

Aggregate R&D statistics

Over the past thirty years, R&D statistics have become established as the most widely used direct measure of technical change. The OECD itself can claim a large slice of the credit for this. In the early 1960s, it developed the so-called *Frascati Manual*, setting out agreed definitions of R&D activities, that then became the basis of surveys in the Member countries. Since then, it has become the internationally recognised centre for discussions and experience on such measurement difficulties as the distinction between research and teaching in higher education, the boundary between development and testing of prototypes and pilot plant, and international comparisons when input costs differ. Improvements in definition, detail and practice, coupled with time series now extending back more than twenty years, have made R&D statistics an irreplaceable tool for policy-makers, analysts and practitioners. So much so that R&D has become increasingly used as a synonym for technical change.

The rapid growing trends in R&D expenditures since the thirties seemed, at least in the United States, to lend ample support to some of the results of the early growth accounting exercises (Abramovitz, 1956; Solow, 1957; Denison, 1962). Consequently the concept of R&D seemed also to fit perfectly the concept of technical change. In the other OECD countries similar trends in R&D expenditure over the post-war period appeared to illustrate well the process of "technological" catching up to the United States technology frontier.

In Figure 1 the trends in industrial R&D intensity over the period 1956 to 1986 have been represented graphically in relation to trends in output per man hour over the same period, for each of the five major OECD countries. The United States reached an absolute peak in industrial R&D intensity in the early-sixties, since then growth in real R&D expenditures first slowed down, but picked up substantially in the 80s. Industrial R&D intensity is, however, only now back to its peak of the early-sixties. With respect to the catching up countries both the Japanese and German trends illustrate how catching up to United States (labour) productivity levels has required over the 60s and 70s a significant increase in industrial R&D intensity.

Figure 1a

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND LABOUR PRODUCTIVITY

GERMANY 1956-1985

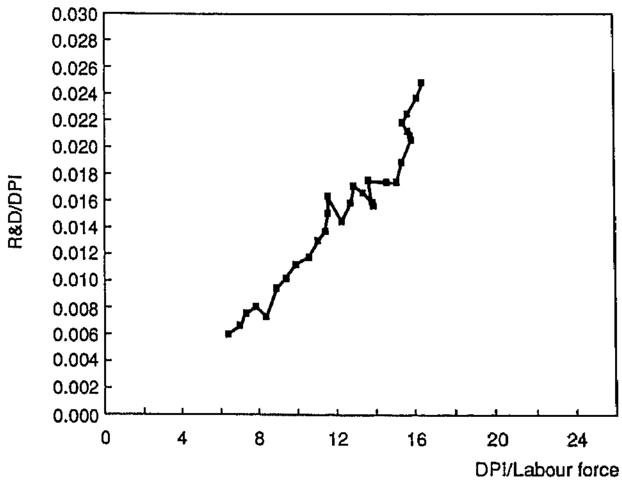


Figure 1b

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND LABOUR PRODUCTIVITY

FRANCE 1956-1986

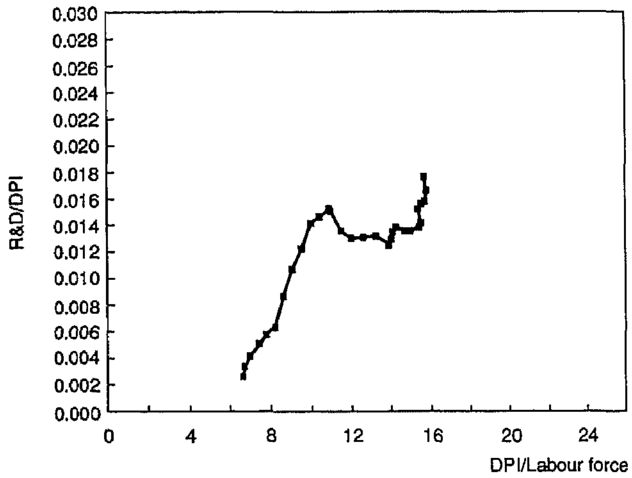


Figure 1d

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND LABOUR PRODUCTIVITY

UNITED KINGDOM 1956-1985

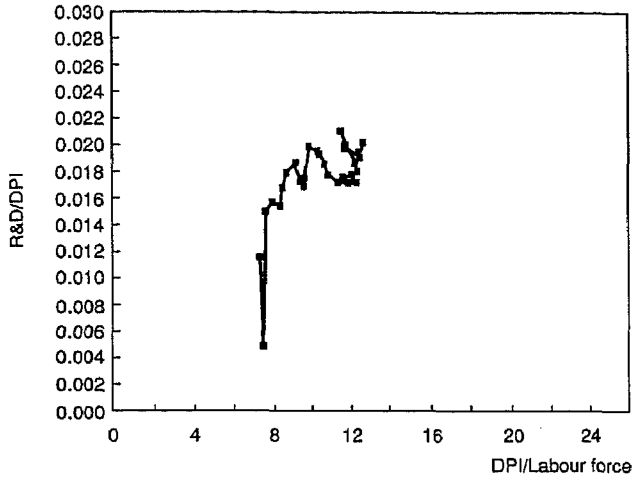


Figure 1c

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND LABOUR PRODUCTIVITY

JAPAN 1956-1986

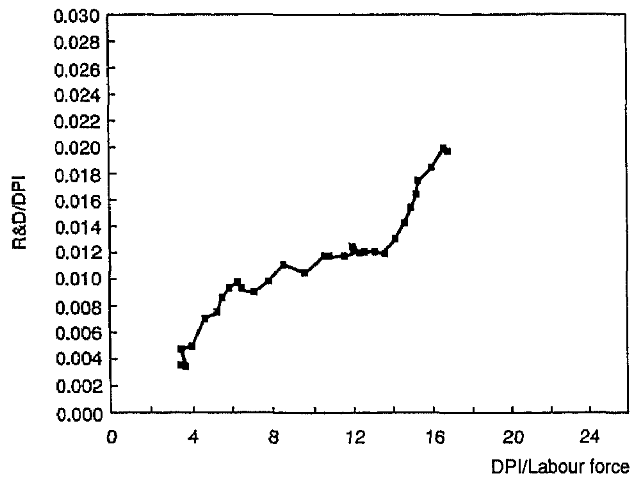
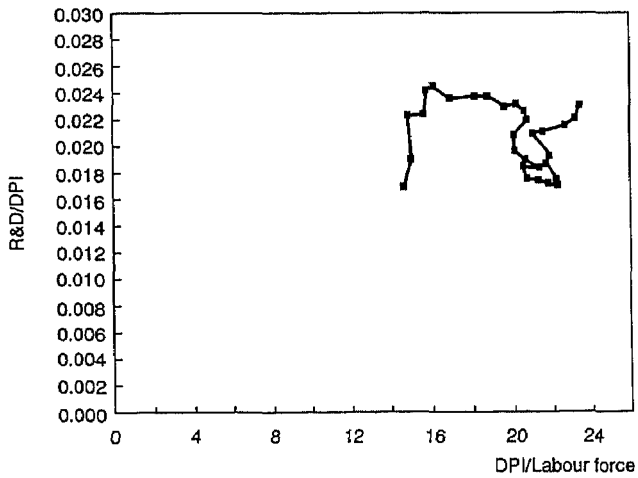


Figure 1e

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND LABOUR PRODUCTIVITY

USA 1956-1986



However, the significant uptake in R&D intensity over the 80s is clearly unrelated to any continuing catching up process. The latter has by and large come to an end; both Japan and Germany have now privately-funded R&D intensities above the corresponding levels of the United States. The trends for France and the United Kingdom are less clear. The technological catching up process of France was more rapid than in the German and Japanese case; the uptake in R&D intensity over the 80s is however less pronounced. The United Kingdom R&D intensity levels on the other hand despite significant fluctuations, have remained more or less constant.

Turning now to the more recent period and focusing also on the particular contributions of private and public funding in the increase in R&D intensity, Tables 1 and 2 indicate for a couple of years, the total and funded R&D intensity for all OECD countries. The

Table 1. **Trends in Industrial R&D as a Percentage of Industrial Output in the OECD Countries, 1967 to 1986**

	1967	1975	1979	1981	1985	1986
A. Countries with R&D/Output ratios above 1%						
Germany	1.51	1.75	2.06	2.14	2.49	n.a.
France	1.55	1.37	1.41	1.55	1.79	n.a.
Japan	1.00	1.25	1.32	1.55	2.05	2.03
UK	2.03	1.75	n.a.	2.13	2.04	n.a.
US	2.35	1.78	1.77	1.97	2.22	2.33
Belgium	0.76	0.99	1.13	1.20	1.32	n.a.
Netherlands	1.45	1.38	1.26	1.29	1.49	n.a.
Sweden	1.29	1.58	1.89	2.23	3.06	n.a.
Switzerland*	2.15	1.83	1.63	1.55	n.a.	n.a.
B. Countries with R&D/Output ratios between 1 and 0.5%						
Austria	n.a.	0.58	n.a.	0.82	0.85	n.a.
Canada	0.70	0.57	0.63	0.83	n.a.	1.00
Denmark	0.56	0.65	0.74	0.85	1.07	n.a.
Finland	0.40	0.61	0.78	0.90	n.a.	n.a.
Italy	0.50	0.62	0.60	0.71	0.92	0.87
Norway	0.61	0.87	0.90	0.90	1.33	1.63
C. Countries with R&D/Output ratios less than 0.5%						
Australia	n.a.	n.a.	n.a.	0.25	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	0.06	n.a.	n.a.
Iceland	n.a.	0.04	0.10	0.11	n.a.	n.a.
Ireland	n.a.	0.34	0.33	0.45	n.a.	n.a.
New Zealand	n.a.	0.20	0.21	0.26.	n.a.	n.a.
Portugal	n.a.	n.a.	n.a.	0.11	n.a.	n.a.
Spain	0.10	n.a.	0.22	0.23	0.36	n.a.
Yugoslavia	n.a.	n.a.	0.51	0.47	n.a.	n.a.

* R&D as a percentage of GDP.
n.a. = non available.
Source: OECD.

difference between the various countries in industrial R&D intensity levels, private-public contribution and trends over the last twenty years makes it difficult to draw in a couple of sentences general conclusions. For analytical purposes, we have grouped the various countries according to some arbitrary average R&D intensity "cut-off" ratios. Three groups of OECD countries can in this way be defined: high tech, medium tech and low tech industrial countries.

Let us first try to draw some conclusions from the R&D trends in the high tech countries. If we take these R&D data at their face value and synonymous for technological advance, the data in Table 2 suggest that there are now clearly, at least in terms of *privately* funded industrial R&D efforts, three "new" technological leaders: Japan, Sweden and Germany. These three countries have now industry-financed R&D/output ratios above or around two, well above any other OECD country. Ergas (1985, 1987) referred to these three countries as the diffusion-oriented countries in terms of technology policy. Leaving aside the detail of what particular policies were followed in these countries, Table 2 suggests that it would be more appropriate to describe these countries as countries with an increasing commitment from the private sector to R&D investment. In these three countries that commitment more or less doubled over the last twenty years. In the United States and France (and to a lesser extent Belgium) R&D intensity increased also substantially over the last twenty years, as a result of both increased public and increased private R&D efforts. However, the somewhat lower commitment to R&D from the private sector (about half the increase in Japan, Germany or Sweden) to increased R&D expenditure has meant that both the United States and France are now clearly lagging behind in terms of privately funded R&D intensity. This is even more clearly the case with respect to the Netherlands and the United Kingdom – with the United States and at least in terms of industry-financed R&D intensity the two "old" technological leaders – where the high levels of R&D efforts of the private sector in the sixties were not kept up, despite increased publicly funded R&D support. These countries have now been taken over by Japan, Germany, Sweden, the United States and France.

Within the medium R&D spending countries, there is a particularly rapid increase in R&D effort noticeable over the most recent period in the Scandinavian countries and in particular in Norway and in Finland.

Table 2. **Trends in Industry-Financed R&D as a Percentage of Industrial Output in the OECD Countries, 1967 to 1987**

	1967	1975	1979	1981	1985	1986
A. Countries with R&D/Output ratios above 1%						
Germany	1.24	1.38	1.64	1.75	2.07	n.a.
France	n.a.	0.95	1.16	1.26	1.54	n.a.
Japan	1.00	1.22	1.30	1.52	2.01	n.a.
UK	1.35	1.10	n.a.	1.49	1.34	n.a.
US	1.15	1.14	1.19	1.34	1.49	1.49
Belgium	n.a.	n.a.	1.06	1.13	1.25	n.a.
Netherlands	n.a.	n.a.	1.12	1.09	1.25	n.a.
Sweden	n.a.	1.30	1.62	1.88	2.66	n.a.
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
B. Countries with R&D/Output ratios between 1 and 0.5%						
Austria	n.a.	0.53	n.a.	0.73	0.75	n.a.
Canada	0.57	0.41	0.48	0.62	n.a.	n.a.
Denmark	0.53	0.60	0.64	0.74	0.93	n.a.
Finland	0.39	0.57	0.72	0.81	n.a.	n.a.
Italy	0.47	0.56	0.55	0.62	0.71	0.60
Norway	0.48	0.68	0.67	0.66	1.04	1.26
C. Countries with R&D/Output ratios less than 0.5%						
Australia	n.a.	n.a.	n.a.	0.20	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	0.04	n.a.	n.a.
Iceland	n.a.	0.04	0.05	0.06	n.a.	n.a.
Ireland	n.a.	0.31	0.29	0.37	n.a.	n.a.
New Zealand	n.a.	n.a.	0.17	0.22	n.a.	n.a.
Portugal	n.a.	n.a.	n.a.	0.10	n.a.	n.a.
Spain	0.10	n.a.	0.21	0.21	0.30	n.a.
Yugoslavia	n.a.	n.a.	0.39	0.35	n.a.	n.a.

n.a. = non available.
Source: OECD.

In Austria, Canada and Italy similar but less pronounced increasing trends can also be observed. While the increase in R&D is substantial in these latter countries and indicative of an effective industrial technology presence, the gap with the "new" technological leaders is widening, despite significant public R&D support over the most recent period in most of these countries. Particularly in terms of the relative international technology competitive position of these countries within their own regional trade blocks it appears that only the Scandinavian countries are keeping their mutual technology gaps constant. In the case of Italy with respect to the "older" European Community partner countries; or Canada with respect to the United States or Japan, such widening technology gaps might have negative implications in terms of these countries' future growth and international competitiveness.

Finally in the low tech industrial countries: Australia, New Zealand, Ireland, Spain, Yugoslavia, Greece and Iceland, a more diverging pattern exists. Some countries do carry out a relatively significant amount of industrial R&D, e.g. in Ireland and Yugoslavia, in other countries such as Greece or Iceland the industrial R&D base is practically not existent. It is clear that in all these countries, and particularly the larger ones such as Spain and Australia, the process of industrialisation will involve a significant increase in future R&D efforts both privately and publicly funded.

Figure 2 illustrates in a similar fashion to Figure 1, but for the United States, Japan and Europe (EC-9) as a whole, recent trends in industrial R&D intensity in relation to levels in GDP per capita. The contributions from the private and public sectors, have also been separated out. The following points emerge from Figure 2:

- First, as already illustrated in Figure 1, the break since the late 70s in the relatively flat trend of R&D intensity is particularly striking in the case of the United States and Japan. In both countries, the break is clearly the result of an increase in privately funded R&D. In the case of the United States, this is clearly in contrast with the decline in the ratio in the late 1960s, which was primarily due to a decline in the publicly funded R&D part.
- Second, the growth in the 80s in Japan's R&D intensity can best be described as a process of technological *leapfrogging* in contrast to the process of technological catching up in the 60s and early 70s. While *total* R&D/Industrial Value Added ratios in 1985 were at about the same level as the United States and Germany, *privately funded* ratios were above any of the other major OECD countries. In

Figure 2a

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND PER CAPITA GDP

9 EC Countries 1967-1985

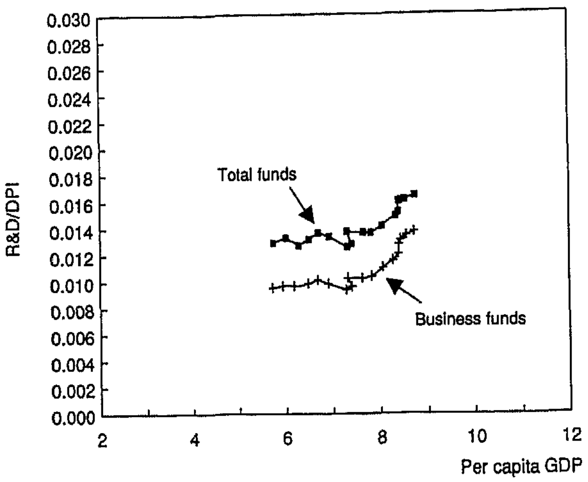


Figure 2c

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND PER CAPITA GDP

USA 1967-1986

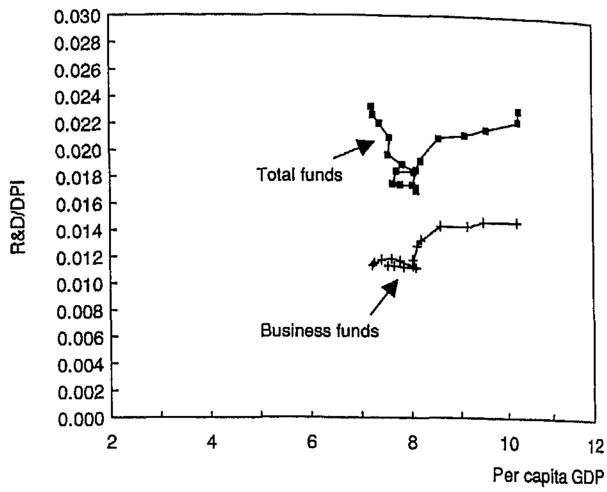
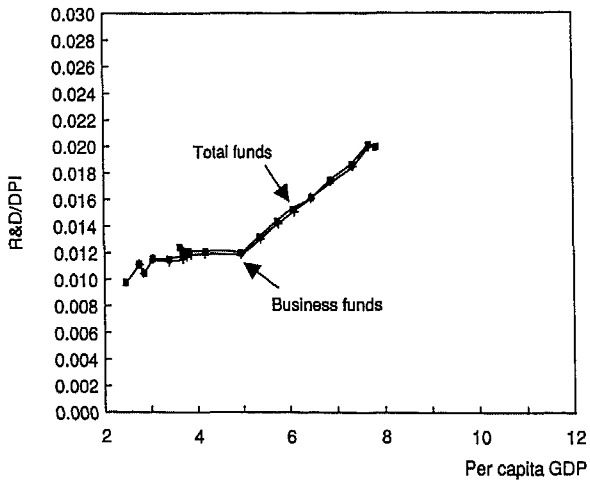


Figure 2b

R&D AS A SHARE OF DOMESTIC PRODUCT OF INDUSTRY AND PER CAPITA GDP

JAPAN 1967-1986



1977, ten years earlier, both ratios were still below the ratios of any of the other countries (with the exception of France).

- Third, the slower uptake in R&D-intensity in Europe over the recent period particularly compared to the United States and Japan. Here too, though, there is again a clear break noticeable in the R&D intensity, GDP per capita relationship over the most recent period.

Having established a clear break in the trends in R&D expenditures both for the "old" technologically leading country, the United States, and the newer technologically leading countries such as Japan, Germany and Sweden, one now must ask the question whether this growth is a general pattern, covering all sectors or whether it can be related to some of the new technologies.

Sectoral R&D data

The available sectoral R&D data does not provide one with a sufficiently detailed level of disaggregation to deduce readily a clearcut sectoral definition of some of the most significant new technologies.

Both with respect to new materials and biotechnology, it is impossible to derive from the OECD or national sectoral R&D data any useful information. The only information available is based on special surveys, such as the OTA report *Commercial Biotechnology: An International Analysis* and the more recent NSF special report on *Biotechnology Research and Development Activities in Industry.* According to such surveys, total industrial biotechnology expenditures amounted in 1985 in the United States to some $1.1 billion, an increase of some 20 per cent over the 1984 level. Table 3 contains details in terms of sources of funds and areas of application. While the estimated figure of $1.1 billion looks impressive, it amounts however to no more than 1.25 per cent of total industrial R&D spending in the United States in 1985. At the same time though its growth rate is well above the overall growth rate in R&D spending of 14 per cent.

Table 3. **Biotechnology R&D Performance in Industry by Source of Funds, Major Application and Major Technique, United States, 1984-85**

Million $

	1984	1985	Annual % change
Source of funds			
Companies' own funds	670.6	792	18.1
Other industry	80.4	88	9.5
Foreign	24.5	33	34.6
Federal government	8.4	13.2	57.5
State or local governments	2.2	3.3	52.1
All other sources	114.0	171.6	50.5
Major application			
Health care	580.9	727.3	25.2
Plant agriculture	113.7	142.6	25.4
Chemicals/food additives	106.7	115.2	7.9
Animal agriculture	59.6	69.1	15.9
Energy/environment	10.7	12.8	19.9
All other applications	28.2	33.1	17.3
Major technique			
DNA/RNA	459.6	567.7	23.5
New bioprocess technology	163.7	198.8	21.5
Old bioprocess technology	132.3	140.5	6.2
Hybridoma development	91.8	127.2	38.5
All other techniques	52.7	65.9	25.0
Total	900	1 100	22.2

Source: National Science Foundation, Special Report, NSF 87-311.

With respect to new information technologies, it is easier to draw some estimates of levels and trends from the available sectoral R&D data for the electronics and computer industries. In both these sectors R&D investment is often more important than physical investment. As Table 4 illustrates, the share of electronics (including computers, but excluding instruments and other electronic user sectors such as robotics) in total industrial R&D varies somewhat from country to country but can be estimated at around 25 per cent.

For Canada and the United Kingdom the figure is nearer to 35 per cent; for some of the smaller R&D performing countries such as Denmark, Australia or Spain less than 20 per cent. Its growth has been consistently higher than that of overall manufacturing.

These estimates based on the available OECD sectoral R&D data underestimate significantly the importance of the new information technology sector. Estimates based, e.g. on the R&D data reported every year for the United States in *Business Week* and presented in Table 5 would bring the share in total R&D expenditure of the information technology in the United States to 33 rather than 25 per cent, with an average annual growth over the 80s around 18 per cent well above the 11 per cent for all sectors.

Trends in technological performance such as the ones presented in Tables 1 to 5 and Figures 1 and 2 are

Table 4. **R&D Employment and Expenditure Growth Electronics Group, 1975-85**

	Number of researchers				1985 Electronics share in manufacturing researchers	R&D expenditure				1985 Electronics share in manufacturing expenditure
	Growth 1975-81 1975 = 100		Growth 1981-85 1981 = 100			Growth 1975-81 1975 = 100		Growth 1981-85 1981 = 100		
	Electronics	Manufacturing	Electronics	Manufacturing		Electronics	Manufacturing	Electronics	Manufacturing	
United States	146	138	116	113	26.8	142	137	141[a]	129	22.7[a]
Japan	174	135	153	131	28.9	218	167	193	156	26.6
Germany	115[a]	126	126[a]	121	41.0[a]	125[a]	145	131[a]	124[a]	27.2[a]
United Kingdom	238	130	n.a.	n.a.	n.a.	220	130	113	107	36.7
France	133	117	131	125	36.7	137	130	123	121	28.3
Italy	106	133	157	140	31.4	98	128	167	154	23.4
Canada		149	176	129	45.9	178	171	190	122	42.7
Sweden	159[a]	114	n.a.	n.a.	n.a.	158[a]	130	123[a]	160[a]	20.6[a]
Belgium	364	150	n.a.	n.a.	n.a.	148	124	159	122	22.2
Spain			165	149	21.3			212	169	17.7
Austria	71	132	152	119	32.4	217	164	106	108	22.9
Finland			n.a.	n.a.	n.a.	188	168	111[a]	144	17.3[a]
Australia	37*	83*		166		120*	107*	n.a.	n.a.	n.a.
Norway		120	n.a.	n.a.	n.a.		110	144	151	30.6
Denmark	196	150	105[b]	145	8.0[b]	134	131	127[b]	137	9.6[b]
Ireland	232	153	829	188	45.9	296	177	184[b]	153	27.1[b]

a) Electrical engineering = ISIC 383.
b) Electronic equipment and computers.
* 1976-1981.
n.a. = non available.
Source: OECD and own calculations.

Table 5. **Shares of Total R&D Expenditure by Sector United States, 1980-85**

In percentage

Sector	1980	1981	1982	1983	1984	1985	Annual growth	In share 1980-85
Aerospace	7.29	7.36	7.04	6.57	6.45	6.13	7.60	–1.16
Appliances	0.60	0.50	0.44	0.49	0.28	0.25	–6.56	–0.35
Automotive, cars & trucks	16.04	14.16	12.66	12.51	12.49	13.08	6.98	–2.96
Automotive, parts	1.04	1.09	1.03	0.47	0.51	0.45	–5.73	–0.59
Building materials	0.57	0.55	0.46	0.44	0.40	0.42	4.76	–0.15
Chemicals	7.70	8.21	8.48	8.56	8.02	7.48	10.47	–0.22
Conglomerates	4.27	3.99	4.00	3.78	3.64	4.83	13.55	0.57
Containers	0.42	0.37	0.29	0.26	0.16	0.14	–10.27	–0.27
Drugs	7.69	7.63	8.33	8.73	8.41	8.19	12.32	0.50
Electrical	4.67	4.63	4.20	4.31	3.60	3.31	4.13	–1.37
Electronics	2.87	2.62	3.82	4.06	4.53	4.70	20.92	1.83
Food & beverage	1.86	1.80	1.87	1.68	1.47	1.22	2.69	–0.63
Fuel	5.37	7.04	6.59	6.04	5.24	4.51	7.58	–0.86
Information processing	15.20	15.32	16.61	18.30	19.18	20.01	16.56	4.81
Instruments	2.11	2.02	2.01	2.28	2.07	2.30	12.79	0.19
Leisure time	2.85	2.79	2.87	2.89	2.60	2.67	9.74	–0.18
Machinery	1.75	1.54	1.17	1.01	1.00	1.28	4.72	–0.48
Machines, farm construct	2.38	2.26	2.19	1.79	1.69	1.49	1.75	–0.89
Metals & mining	0.77	0.76	0.65	0.54	0.44	0.41	–1.54	–0.36
Misc manufacturing	3.31	3.63	3.55	3.34	3.17	3.17	10.15	–0.15
Oil services & supply	1.67	1.94	2.28	2.02	1.94	1.68	11.16	0.01
Paper	0.97	0.80	0.76	0.77	0.69	0.70	4.52	–0.27
Personnel & home care	1.87	1.84	1.99	2.01	1.99	1.58	7.69	–0.29
Semiconductors	2.20	2.22	1.57	1.87	2.17	2.39	12.71	0.19
Steel	0.59	0.56	0.54	0.44	0.33	0.28	–3.84	–0.31
Telecommunications	2.19	2.74	3.05	3.31	6.14	6.00	31.23	3.81
Textiles & rubber	0.18	0.15	0.15	0.19	0.18	0.15	7.01	–0.03
Tyre & rubber	1.48	1.40	1.38	1.32	1.25	1.13	5.72	–0.35
Tobacco	0.11	0.07	0.05	0.05	0.05	0.05	–6.86	–0.07
Total (percentage)	(100)	(100)	(100)	(100)	(100)	(100)		
Total	28 065	32 107	35 764	39 204	45 509	48 779	11.06	

Source: Business Week, various issues.

of course only as good as the underlying data. With respect to the particular technology proxy used the inherent limitations of R&D data need to be far better understood before any reliable assessment of such trends can be made.

R&D data and their limitations

To equate R&D expenditures with technical change as in the previous sections is not without dangers. As is well-known but quickly forgotten, R&D statistics measure inputs, not outputs, and therefore cannot detect variations in the efficiency with which R&D activities are carried out. This is one reason why considerable efforts have been made since the mid-1970s to improve measures of the output of R&D activities: in particular, counts of scientific papers, patents and citations; innovation counts; trade in so-called "high technology" products, etc.[1]. Once again, the OECD has played a crucial role in their development[2].

This is not the place to address the broad subject of R&D inputs and outputs. In Section II we discuss, albeit briefly, some of the output measurement problems of the R&D system with respect to the indicator patents. We shall instead concentrate here on inputs to the development of new technology that are not captured, or are captured only very imperfectly by R&D statistics, since these have major – although difficult to estimate – effects on the volume, composition and trends over time in technology-producing activities. Briefly stated, R&D is better at detecting such activities in the science-based technological paradigm, than in the production-based and the information-based paradigms.

As Freeman (1982), Mowery (1983) and Rosenberg (1982) have pointed out, R&D activities have grown in importance as sources of technical change as a consequence of both the growing contribution of professionalised science and scientists (particularly chemistry and physics) to industrial technology, and the spread of the functional organisational form, especially in the growing number of large firms. Mowery describes the spread of R&D laboratories in the United States in the inter-war period, from the most R&D intensive sector (chemicals) to other sectors, and from larger to smaller firms. Given the nature and determinants of this process, R&D has the following important limitations as a measure of inputs to technological activities.

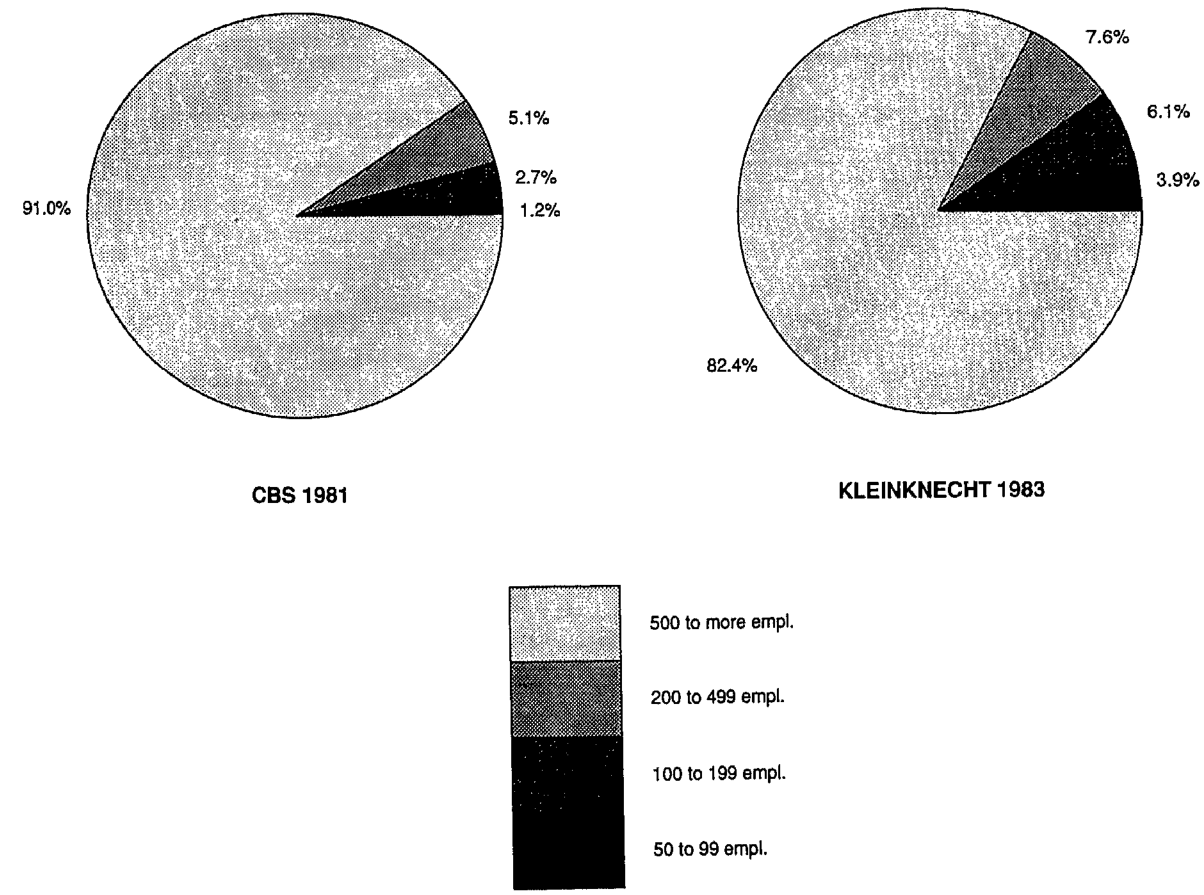
Production, technologies and small firms

As is well-known, but insufficiently acknowledged, R&D statistics underestimate the output of technology in production-based technologies, where much technical change takes place in and around the design, building and operation of complex capital goods and production systems. In such circumstances, technical change takes place in Design Offices and Production Engineering departments[3] *as well as* in R&D laboratories. As a consequence, R&D statistics are likely to underestimate the volume of technology in production-related technologies.

Furthermore, R&D statistics capture only imperfectly the output of technology in small firms, where technology-producing activities often do not have a separate functional and accounting identity. Nearly all manufacturing firms with more than 10 000 employees have R&D laboratories. Most manufacturing firms with fewer than 1 000 employees do not. A number of studies have shown that, although firms with fewer than 1 000 employees account for about 3 per cent of business enterprise R&D, they typically produce more than 30 per cent of the output of innovations (Kleinman, 1975; Feinman and Fuentevilla, 1975; Pavitt, Robson and Towsend, 1987).

Evidence regarding the underestimation by official (OECD) statistics of R&D activities in small firms is presented by Kleinknecht (1987). In his 1983 innovation survey in Dutch manufacturing, Kleinknecht used a very simple R&D indicator (i.e., man-years) and explicitly asked for informal R&D (i.e., R&D outside the R&D department). The R&D definition used was the one in the *Frascati Manual.* This resulted in finding

Figure 3
SIZE DISTRIBUTION OF R&D, MAN-YEARS
THE NETHERLANDS 1981-1983



a considerable larger amount of R&D in small firms compared to the official survey (i.e., the 1981 survey by the Dutch Central Bureau of Statistics), while the results for larger firms were more or less equal among the two surveys. These results are presented in Figure 3.

The Kleinknecht survey also includes firms with less then 50 employees, which are not covered by the official survey. It appears, however, that these firms do have a substantial part in national R&D statistics: 6.6 per cent of the R&D done by firms with more then 50 employees.

On the basis of a recent United Kingdom study Table 6 compares the characteristics of innovation firms in three size categories. It shows that, in contrast to large innovating firms, small ones depend mainly on in-house knowledge sources other than R&D, they are technologically specialised within mechanical and instrument engineering rather than diversified within chemicals and electronics, and they tend to remain functionally unspecialised.

Finally, as illustrated in Table 7, studies of the United States Small Business Administration Unit have shown the importance of small firms in high tech sectors, particularly in services. We come back to this issue below.

Software and services

Finally, just as R&D underestimates technological activities in the largely mechanical paradigm developed before the rise of science-based technology, so it also underestimates the importance of the information-based paradigm that is now expanding so rapidly. Whilst R&D statistics reflect accurately the technological activities (hardware and software) of IT equipment suppliers, they capture far less well the very rapid expansion of software development in software houses, and in Systems Departments of large users of often complex IT[4]. The detailed study of Arossa (1987) for the OECD estimates the total value added of software, including hardware manufacturers at $22.5 billion in the United States, $3.4 billion in Japan, $2 billion in France, $1.9 billion in Germany and $1.8 billion in the United Kingdom. Table 8 compares Arossa's estimates including and excluding hardware manufacturers with total R&D expenditures for 1985.

We leave the more difficult issue about the precise inclusion of software to Arossa's contribution to Workshop 2. Here, it is worth noticing that the major difficulty with respect to the official R&D expenditures surveys is that they concentrate on manufacturing and hardware, whilst the most rapid growth in technology is in services and software. The *use* of computer hard-

Table 6. **Comparison of Sources, Composition and Organisation of Technological Activities in Innovating Firms of Different Sizes**

	Firm size (number of employees)							
	1 – 999		1 000 – 9 999		10 000+		Total	
% Age distribution of business enterprise R&D expenditure (1975)		3.3		16.4		80.3		100.0
% Age distribution of significant innovations (1970-79)		34.9		18.1		47.1		100.0
Top three sources[a] of in-house knowledge for the innovations (% age of total)	Design (27.5) Development (27.5) Operating staff (15.7)		Development (42.1) Design (30.3) Research (14.5)		Development (40.3) Research (36.3) Design (17.0)		Development (39.0) Research (26.0) Design (23.0)	
Top three sectors of principal production of innovating firms (% age of total)	ME IN EE	(40.1) (11.7) (10.7)	ME CH EE	(28.9) (15.0) (13.7)	EE CH ME	(29.9) (14.1) (11.8)	ME EE CH	(27.2) (18.7) (10.2)
Degree of[b] technological specialisation (% age of total)	S ND BD	(65) (13) (22)	S ND BD	(47) (23) (30)	S ND BD	(24) (27) (49)	S ND BD	(46) (20) (34)
% Age of innovations made by divisionalised firms		23.7		45.8		91.5		60.0

a) Identified sources are Research, Development, Design, Production Engineering, Operating Staff, Other.
b) See Table 5 for definitions of S, ND, BD, S + ND + BD = 100 per cent.
Source: Pavitt, Robson and Townsend (1988); SPRU Innovation Survey (1984).

Table 7. **Employment in High-Technology Industries, by Size of Firm and Industry, 1980-84**

Industries	Small firms[a] 1980	Small firms[a] 1984	Large firms 1980	Large firms 1984	Small firms' share of total employment 1980 (Per cent)	Small firms' share of total employment 1984 (Per cent)	Distribution of employment by small high-technology firms 1980 (Per cent)	Distribution of employment by small high-technology firms 1984 (Per cent)
High-technology manufacturing industries[b]	591 332	710 421	2 930 019	3 195 418	16.8	18.2	52.5	51.0
Guided missiles & spacecraft	991	1 485	88 839	100 388	1.1	1.5	0.1	0.1
Communications equipment & electronic components	65 358	317 882	965 324	1 108 090	21.6	22.3	23.4	22.8
Aircraft & parts	44 558	47 147	507 756	498 352	8.1	8.6	3.9	3.4
Office, computing & accounting machines	49 898	86 888	347 548	472 815	12.6	15.5	4.4	6.2
Drugs & medicines	31 154	35 228	196 762	181 299	13.7	16.3	2.7	2.5
Industrial inorganic chemicals	7 074	5 437	54 382	53 138	11.5	9.3	0.6	0.4
Professional & scientific instruments	160 134	184 079	380 934	440 763	29.6	29.5	14.1	13.2
Engines & turbines	6 066	6 813	172 659	158 304	3.4	4.1	0.5	0.5
Plastic materials & synthetics	26 099	25 462	215 815	182 269	10.8	12.3	2.3	1.8
Technology-rated service industries[c]	542 032	682 055	542 755	589 622	50.0	53.6	47.8	49.0
Computer & data processing services	150 019	242 643	156 037	241 646	49.0	50.1	13.2	17.4
Engineering, architectural & surveying services	357 529	403 944	264 174	288 799	57.5	58.3	31.5	29.0
Non-commercial educational, scientific, and research organisations	34 484	35 468	122 544	59 177	22.0	37.5	3.0	2.5
All technology-related industries	1 133 364	1 392 476	3 472 774	3 785 040	24.6	26.9	100.0	100.0

a) Firms with less than 500 employees.
b) Industries whose products meet the DOC-3 criteria for high-technology products. See U.S. Department of Commerce, International Trade Administration, *An Assessment of U.S. Competitiveness in High Technology Industries* (February, 1983), pp. 33-37.
c) Service industries classified the Small Business Administrational high technology, but excluding "Business Services, N.E.C." and "Service Industries, N.E.C.".
Source: NSF, *Science Indicators*, 1987.

ware – around which much applications software is developed – is, as Table 8, also hints at, less and less concentrated in manufacturing. This is particularly clear from the data with respect to computer installations, an issue highlighted by a.o. Gonenc (1985) and Baily and Gordon (1988). For example, in Japan just 32 per cent of general purpose computer installations by value in 1982 was in manufacturing, whilst 35 per cent was in financial service industries (Gonenc, 1985). Similar data has been presented for the United States by Baily and Gordon (1988) and is developed further in Baily's contribution to Workshop 2.

R&D statistics do, in other words not satisfactorily reflect these non-manufacturing sources. In most OECD countries, the official R&D surveys show more than 90 per cent of total R&D located in manufacturing firms and products; services on average represent little more than 2 to 8 per cent of total R&D. Figure 4 *a* to *e* represents trends in the service share over the last twenty years in a number of OECD countries.

While no particularly significant trend appears to emerge from Figure 4 *a* to *e*, it is nevertheless, possible to distill out of some national surveys a couple of potentially more significant trends. In the United Kingdom, e.g. between 1975 and 1981, and in apparent contrast to Figure 4*d*, the proportion of business enterprise R&D performed by non-manufacturing firms increased from 8.6 to 14.6 of the total, and on manufacturing products from 3.5 to 7.4 per cent (*Business Monitor*, 1979, 1985). And in Canadian surveys of business enterprise R&D, a separate category has been identified as "computer services", classified separately from "engineering and scientific services" (Statistics Canada, 1988). Between 1979 and 1987, R&D expenditures in such computer services increased in real terms by a factor of 16 from 0.6 to 5.1 per cent of all business enterprise R&D, and from 4.7 to 20.8 per cent of all R&D in services. They are mainly in Canadian ownership (more than 90 per cent of R&D expenditures), concentrated in Ontario (about two-thirds of R&D expenditures), and in firms with fewer

Table 8. **Software Development as a Percentage of BERD, 1985**

	Million $		% of BERD	
	totsoft	nhwsoft	% nhs[a]	% ts[b]
France	2 158.7	1 616.9	22.1	29.5
Germany	1 864	1 110.9	7.9	13.3
Italy	1 071	677.9	19.9	31.5
UK	1 830.9	1 094.9	14.0	23.4
Austria	188	102.1	22.8	42.0
Belgium	300.3	180.2	17.1	28.5
Denmark	209	132.9	35.5	55.8
Finland	186	133.0	n.a.	n.a.
Netherlands	575.1	408.9	24.9	35.0
Norway	188	121.1	24.7	38.3
Spain	305	162.0	20.9	39.3
Sweden	344	211.9	11.8	19.1
Switzerland	341	214.1	n.a.	n.a.
Ireland	71.4	49.4	55.2	79.8
Portugal	25	14.0	27.4	49.2
Turkey	6.8	4.8	n.a.	n.a.
Greece	5.9	4.9	n.a.	n.a.
US(*)	22 500	n.a.	n.a.	34.3
Japan(*)	3 001.8	n.a.	n.a.	13.5

a) % nhs: software developed by non-hardware producers.
b) % ts: total software.
(*) non-hardware-producers-software not available.
n.a. = non available.
Source: BERD: OECD. Software: Arossa (1987).

than 50 employees (more than 90 per cent of R&D employees). This "eclectic" evidence clearly fits the data presented above (Table 7) with respect to the importance of small high tech firms in services.

A similar picture emerges with respect to the United States in the study of the OTA on R&D expenditures in the United States service sector. Contrary to the "official" data, R&D expenditure in services was estimated here at about one third of total manufacturing R&D: for 1985 an amount of no less than $26 billion (about ten times the NSF and OECD estimate of $2.3 billion). As Table 9 illustrates, precisely the computer using and processing sectors, such as the "other business and professional services sector", including many small firms in a.o. computer and data processing services, engineering, other scientific, etc., sectors are the most important R&D spending sectors.

Total technology-producing activity

These imperfections in R&D statistics have considerable implications for our estimates of the total volume of technology-producing activities, and the way in which they change over time. Let us first consider by how much R&D expenditures in manufacturing need to be increased to cover small-firm technological activities and activities in Production Engineering departments. An approximate middle estimate emerges from

Table 9. **Research and Development Spending in the United States, by Sector: Reported Data and OTA Estimates**

Sector/industry	R&D spending Billions of dollars	R&D as a percentage of sales
	A. Reported figures (1986)	
Manufacturing	83.0	–
Non-manufacturing	2.3	–
Total	85.3	–
	B. Estimates by Office of Technology	
Goods-producing sector	69.9	2.15
Services sector	26.0	0.73
Trade	3.4	0.44
Real estate	0.2	0.44
Residental construction	1.6	0.60
Non-residential construction	1.4	0.60
Finance and insurance	1.2	0.50
Educational Services	1.4	0.60
Other business and professional services	4.2	2.50
Total	98.5	1.36

Source: United States Congress, Office of Technology Assessment, *International Competition in Services* (Washington, D.C., United States Government Printing Office, 1987).

Figure 4a
SHARE OF THE SERVICE SECTOR IN TOTAL R&D
GERMANY 1967-1983

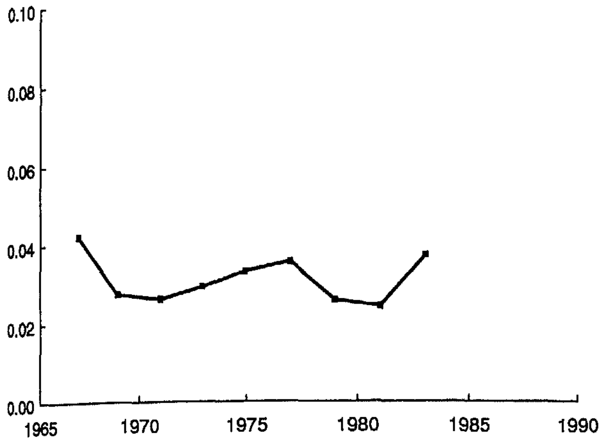


Figure 4b
SHARE OF THE SERVICE SECTOR IN TOTAL R&D
FRANCE 1970-1985

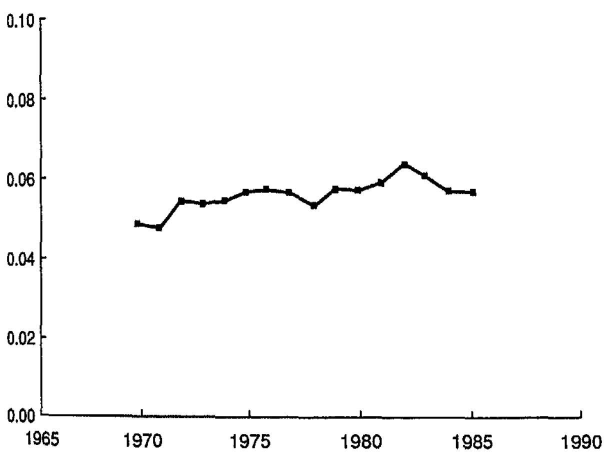


Figure 4c
SHARE OF THE SERVICE SECTOR IN TOTAL R&D
JAPAN 1967-1985

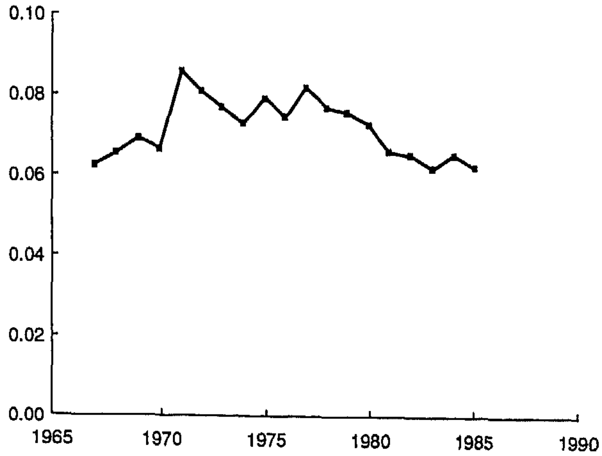


Figure 4d
SHARE OF THE SERVICE SECTOR IN TOTAL R&D
UNITED KINGDOM 1967-1985

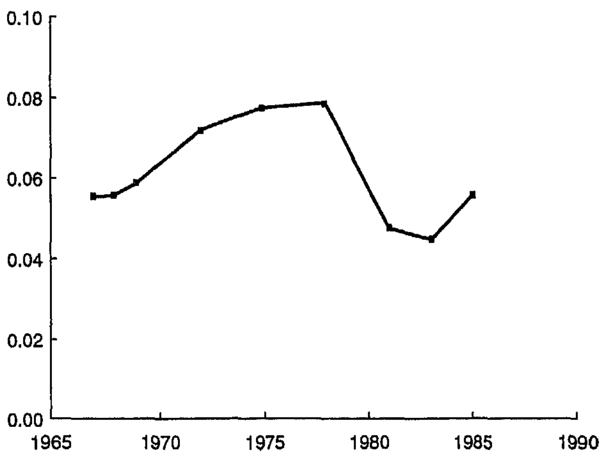


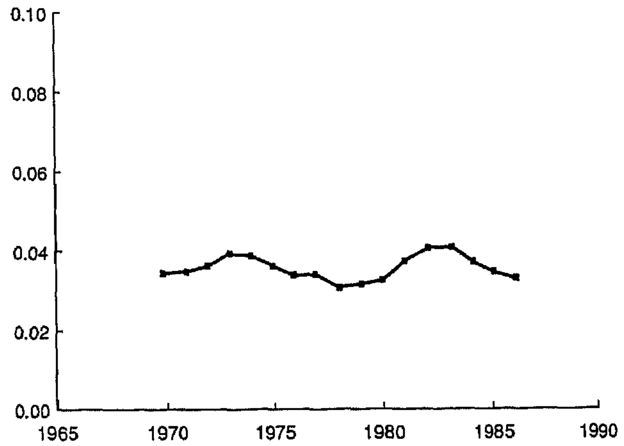
Table 6, which shows that R&D accounts for 65 per cent of all the knowledge sources for innovation. An upper estimate would be based on the assumption that Production Engineering expenditures are just as productive as R&D expenditures in developing new technology, *and* that R&D expenditures miss nearly all technological activities in firms with less than 1 000 employees; on this basis, we would estimate that the R&D figure would only account for 45 per cent of total technological activities.

Second, if we accept some of the estimates of R&D expenditures in services as reported in Table 9, or the estimates with respect to software expenditures in Table 8, one might reasonably assume that R&D expenditures in services, including software technology, would amount to about 20 to 30 per cent of all business enterprise R&D. Total expenditures on the production of technology could therefore amount to anything between 2 and 3 times the officially measured expenditures on R&D activities. And this is still a low

Figure 4e

SHARE OF THE SERVICE SECTOR IN TOTAL R&D

USA 1970-1986



estimate, excluding e.g. expenditures related to improvements in technology through "learning by doing", for which no reasonable estimate can be made[5].

These imperfections in the measured R&D indicator will also influence the estimates of trends over time in technology-producing activities, since there is no reason to assume that R&D remains a constant share. Given contradictory trends, it is difficult to judge whether the share has been increasing or decreasing. However, the difference in timing of the increasing and decreasing biases allows us to draw some general conclusions.

On the one hand, given the wider diffusion of the organisational innovation that is the R&D laboratory, the increasing relative importance of large firms, and the growth of science-based compared to production technologies, we would expect R&D to increase its share of the total technology-producing activities since the 1950s. Under such conditions, R&D will overestimate trends in total technology production. In our view it is likely that such an overestimation bias might have been behind the rapid growth in R&D intensity in the 50s and 60s in most OECD countries, as illustrated e.g. in Figure 1.

On the other hand, and particularly with respect to the more recent period, with the rapid growth of software development independent from related hardware development, and the increased research and technology efforts of a growing number of service sectors, it is likely that officially measured R&D expenditures more and more underestimate trends in total technolology production.

In other words, while overall R&D expenditures might well represent only 35 to 45 per cent of the overall resources devoted to technology production, trends in R&D expenditures over the 50s and 60s are likely to have overestimated the "true" rate of *domestic* technical change in most OECD countries, while trends in the late 70s and 80s are likely to have underestimated the actual rate of technical change.

If, in other words, there is talk of an acceleration of technical change over the eighties on the basis of the officially measured R&D expenditure data, that acceleration is likely to have been even more significant than the figures we have presented in Figures 1 and 2 and Tables 1 to 5, might lead one to believe.

Let us now turn to trends and measurement issues with respect to patents as technology *output* indicator. In contrast to our discussion on trends and biases in R&D expenditures, the analysis will be limited to the identification of a couple of recent trends. A more detailed analysis of the patent concept can be found in Schankerman's contribution to this workshop.

III. PATENTING STATISTICS AND THE NEW TECHNOLOGIES

Aggregate trends in number of patents: problems of measurement and definition

Economists helped pioneer the development and use of patenting statistics as an indicator of technological activities[6]. In general, they treat patents (since they are a record of invention) as an intermediate output of R&D activities. While this assumption has its potential uses, it also leads to puzzles and anomalies. Thus, the most sophisticated econometric analyses have detected no time-lag between R&D "inputs" and patenting "outputs" at the level of the firm (Pakes and Griliches, 1984; Hall, Griliches and Hausman, 1984, 1986; Griliches, Pakes and Hall, 1986; Griliches and Lichtenberg, 1987).

More importantly, there are persistent and major variations across sectors in R&D "productivity" as measured by patents granted per unit R&D spent. Thus, in the United States, such "productivity" in 1985-86 was more than seven times the industry average in fabricated metal products, 55 per cent higher in instruments, 25 per cent higher in machinery, a third of the average in motor vehicles, and only 6 per cent of the average in aerospace (see *Science and Engineering Indicators,* 1987; similar conclusions for the United Kingdom are reached by Silberston, 1989).

As between countries similar anomalies exist. The number of patents per million dollars R&D spent varies from 3 to 2 in the United States, to 15 in Japan. To a large extent such inter-country differences are only a reflection of the intersectoral differences mentioned above. Differences in national procedures for examination and national patent propensity are, however, also important factors in explaining such inter-country differences.

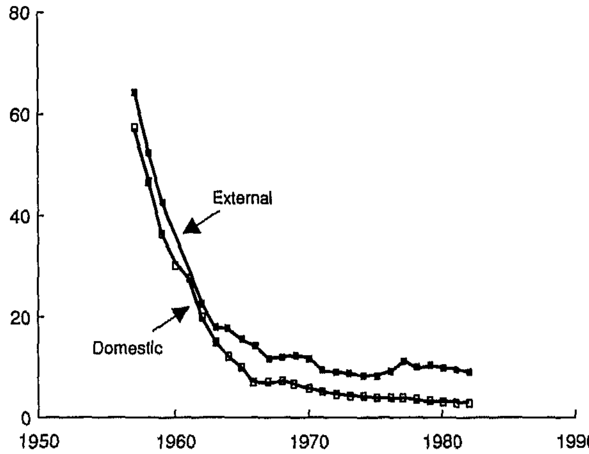
These intersectoral and intercountry variations reflect in part intersectoral differences in the imperfections of R&D measurement discussed above. They also reflect intersectoral variety in another major characteristic of patenting activities, namely, their relative importance as a barrier against imitation.

Considerable progress has been made in the past five years in our understanding of the nature and determinants of these barriers in different industries (see, in particular, Levin *et al.*, 1987; Bertin and Wyatt, 1988). They confirm that intersectoral variety in the ratio of patents applied for or granted, per unit spent on R&D, reflect less the productivity of R&D than innovators' perceptions of the effectiveness of patents as a barrier against imitation.

In spite of these drawbacks, statistics on patenting have found numerous uses in comparative analyses of technological activities in countries and firms[7]. Given the intersectoral variety in the propensity to patent the results of R&D described above, such comparisons usually involve normalisation by sectoral totals. Given the international variations in the patenting procedures mentioned above measurement has also tended to concentrate on one national patenting system or on international patenting (see a.o. Pavitt and Soete, 1980; Soete, 1981; Fagerberg, 1987). The intercountry differences in numbers of "international" patents applied for or granted per domestic unit of R&D spent remains however significant. Figure 5 provides information on the trend in number of domestic and "international" patents applied for per million dollars of R&D spent over the period 1957-85 for the five largest OECD countries[8].

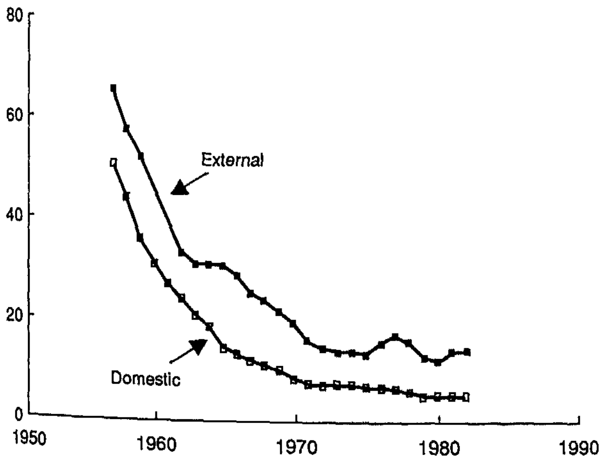
Apart from the variation across countries in the patents/R&D ratio, Figure 5 also illustrates the pitfalls of interpreting the decline over time in most countries (the trend in the Japanese external patent/R&D ratio

Figure 5b
DOMESTIC AND EXTERNAL PATENTS PER $ R&D
FRANCE 1957-1982



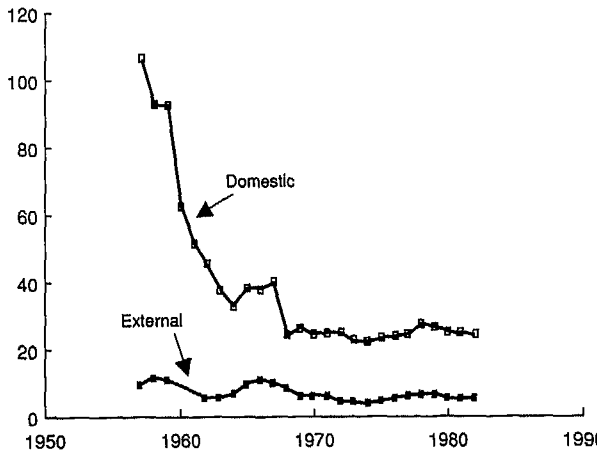
Values are calculated using current R&D and 3 year anticipated patent applications.

Figure 5a
DOMESTIC AND EXTERNAL PATENTS PER $ R&D
GERMANY 1957-1982



Values are calculated using current R&D and 3 year anticipated patent applications.

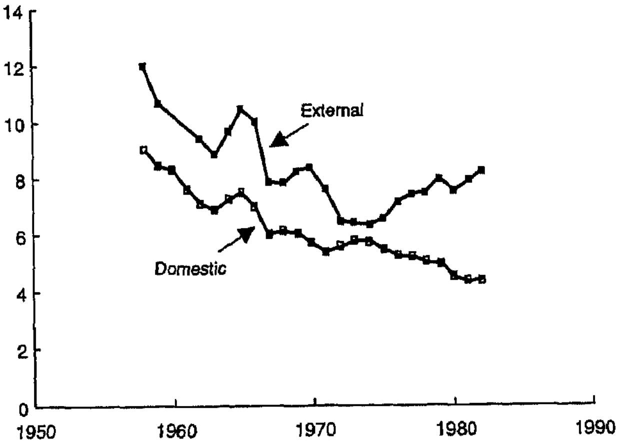
Figure 5c
DOMESTIC AND EXTERNAL PATENTS PER $ R&D
JAPAN 1957-1982



Values are calculated using current R&D and 3 year anticipated patent applications.

Figure 5d
DOMESTIC AND EXTERNAL PATENTS PER $ R&D

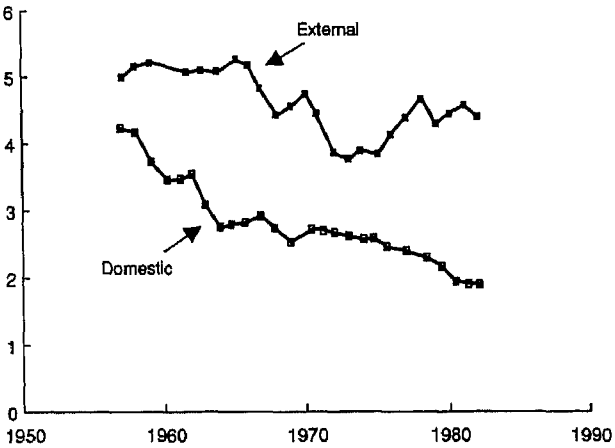
UNITED KINGDOM 1957-1982



Values are calculated using current R&D and 3 year anticipated patent applications.

Figure 5e
DOMESTIC AND EXTERNAL PATENTS PER $ R&D

USA 1957-1982



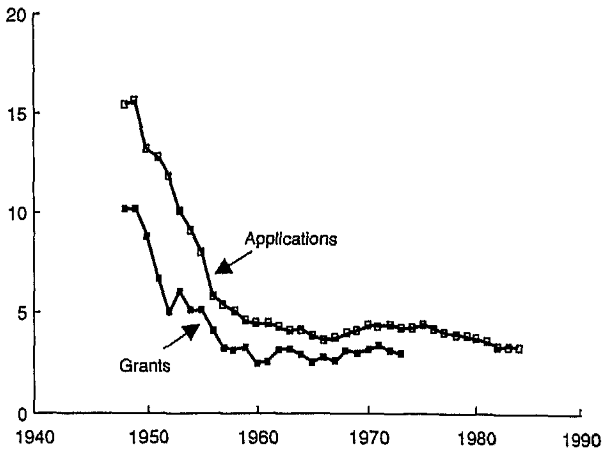
Values are calculated using current R&D and 3 year lagged patent applications.

is the exception) in the volume of patenting per unit of R&D spent as a decline in R&D "productivity" (Evenson, 1987; OECD, 1988). In most countries the decline in the numbers of patents per million dollars of R&D spent is a reflection of a general post-war trend set in motion before the sixties with little relationship to any particular trend in the efficiency of R&D.

This is also supported by Figure 6, which represents for the United States the number of domestic patents applied for and granted per million dollars R&D spent over the whole of the post-war period. The decline in the United States in this ratio in the 50s is actually comparable to the declines which occurred in the 60s in France, Germany and Japan, as illustrated in Figure 5.

Figure 6
PATENTS PER $ R&D

USA 1948-1985



Values are calculated using current R&D and 3 year anticipated patents (grants) resp. 1 year anticipated patents (applications).

There are at least two better explanations for the decline in the patent/R&D ratio:

i) An increase in the proportion of total technology development activities measured by R&D statistics (see our discussion at the end of the previous Section). This explanation is actually strongly supported by both Figures 5 and 6. The dramatic decline in number of patents per unit of R&D in Germany and France in the 60s, and in the United States in the 50s suggests that in these "early" periods the "measured" increase in R&D expenditure probably overestimated total technology development effort and thus the "true" rate of technological advance. On the other hand, the levelling off in the patent/R&D ratio over the 70s and 80s seems to suggest that this tendency of R&D growth to overestimate technological development efforts might have come to an end in the 70s.

ii) A decline in the importance of patenting as a barrier to imitation, compared to other possible barriers. Patent attorneys in large firms judge that patenting is as important now as it was ten years ago

(Bertin and Wyatt, 1988). On the other hand, there have been considerable difficulties and ambiguities in establishing an acceptable degree of protection of invention in the new technologies of software[9] and biotechnology.

Having established that trends in aggregate numbers of patenting whether in absolute terms or relative to R&D inputs are unlikely to provide one with much information of trends in the output, let alone efficiency of the technology production system, we now turn to some of the disaggregated patent information with respect to new emerging technologies.

Disaggregated patent data

One of the major practical advantages of patent data as technology output indicator resides in the fact that patent data are generally available at a very high level of disaggregation (in the United States some 110 000 classes) and are, in contrast to R&D data, classified in terms of technology rather than sectors. Bearing in mind what has been said above with respect to the particular difficulties the patent system has encountered in dealing with some of the most important new technologies, it remains surprising how available disaggregated patent data can shed light on trends and performances in particular new technology areas.

As in previous work (Pavitt and Soete, 1980; Soete, 1981; Soete and Wyatt, 1983), our interest is in trends in number of patents granted in a common major "third" technology market: e.g. the United States. Detailed comparisons of the number of foreign patents granted in such a common third market will allow us to make a number of international comparability claims to the extent that all patents have undergone a similar screening process and that the US market is sufficiently important in order to attract all patents of a certain quality. We refer the interested reader to some of our previous writings to get an impression of the insights one may gain using such patent data (see a.o. Pavitt and Soete, 1980; Soete, 1981;, Patel and Pavitt, 1987, 1988, etc.).

Here we limit the analysis to a closer look at the number of patents granted in some of the major new technology areas as identified in the Technology Profiles prepared by the United States patent and trademark office. Table 10 indicates such trends in a number of new technology areas over the period 1973-86 (the specific patent classes corresponding to each of the technologies mentioned in Table 10 are identified in Table 13). Also indicated are the number of patents granted by country of origin: the United States, Japan, OECD-Europe, and other countries.

The trends given in Table 10 are indicative of the rapid rise of patenting activity in some of the new technology areas. Overall these sectors have grown an average of 2.7 per cent a year well above the total

Figure 7a
SHARE OF BIOTECHNOLOGY IN TOTAL PATENTING

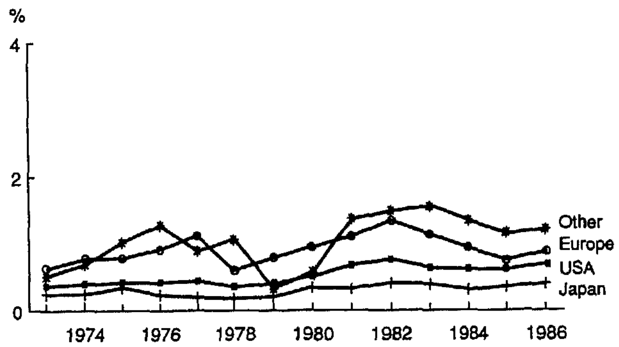


Figure 7b
SHARE OF INFORMATION TECHNOLOGY IN TOTAL PATENTING

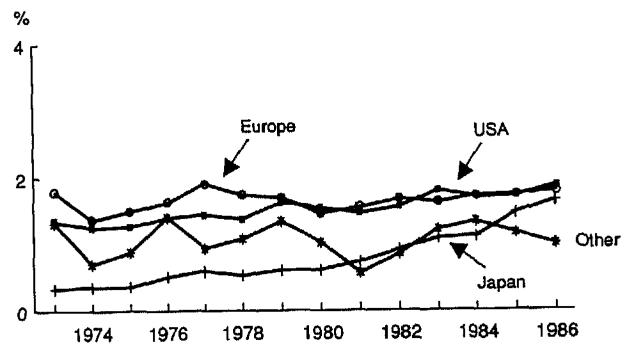
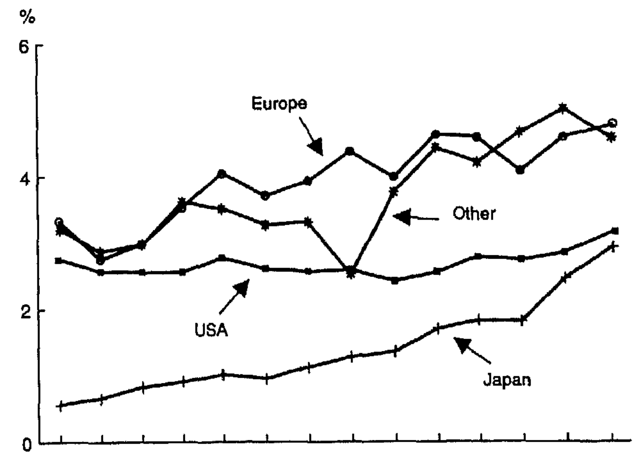


Figure 7c
SHARE OF TELECOMMUNICATIONS IN TOTAL PATENTING



average growth in United States patenting of 0.0 per cent. Growth in the biotechnology sphere has been highest with an average growth rate of 6.6 per cent a year. Growth in computers and electronics was 2.4 per cent a year, and in communications 2.3 per cent a year. The "new technologies" share of total patents granted in the United States as identified in Table 10 increased consequently from 6.6 per cent in 1973 to 10.5 per cent in 1986. It goes without saying that the list of technologies in Table 10 represents only a small fraction – probably the most well-known "core" technologies – of new information and biotechnologies.

In Figure 7, the trends in the patent share of the United States, Japan, OECD-Europe and all other countries in each of the three broad technology areas (Biotechnology, Computer and Electronics technology and Telecommunications technology) identified in Table 10 is represented graphically. The growth in the Japanese share in telecommunications and computer and electronics technology is impressive as is the growth of the United States in biotechnology.

Finally, Figure 8 represents for 1986 the "Revealed Technology Advantage Index[10]" (Soete, 1980) for the United States, Japan and a number of European countries in each of the nine technology fields identified in Table 10.

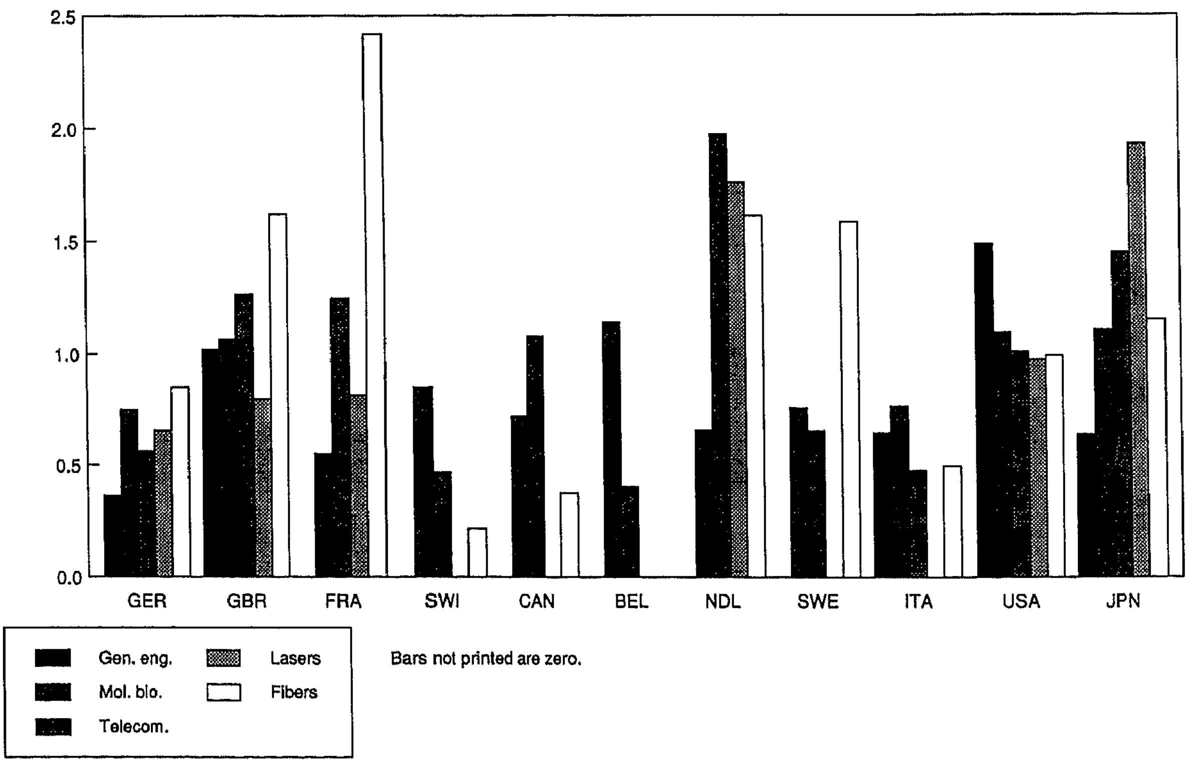
Again the strong comparative technological advantage of Japan in the electronics and telecommunications fields emerges quite strongly from Figure 8. With respect to the other countries the relatively strong technological comparative advantages of France in telecommunications and particularly fibers, the Netherlands in telecommunications and semiconductor electronics, and the United States in genetic engineering and computers is also worth noting.

Patents statistics offer many more possibilities for detailed analysis of country or company technological performance. Given space and time constraints we present in Tables 11 and 12 some other patenting data which illustrate other possible uses of patent data. Table 11 presents trends in number of patents granted in the fastest growing patent classes over the 1963-86 period, and is based on some ongoing research (Patel and Soete, 1989). The analysis in Table 11 is, given the space constraints, only at the 3-digit patent class level. The Table lists all patent classes which have witnessed

Figure 8a

REVEALED TECHNOLOGY ADVANTAGE — BIOTECHNOLOGY AND TELECOMMUNICATIONS

11 Countries 1986



Bars not printed are zero.

the largest increase in *absolute* number of patents in the United States – both domestic and foreign – over the whole period 1963-86. More disaggregated and detailed analyses can be found in Patel and Soete (1989). Table 12 shows first results of the renewal rate of patents following the introduction in 1982 of a renewal system in the United States. At this stage, given the average high renewal rate, it is impossible to use this data to analyse the extent to which patents granted in new technologies areas are more or less systematically renewed, pointing to a possible higher or lower quality level. Comparative analysis with trends in Europe will be extremely useful here.

IV. CONCLUSIONS

A number of conclusions emerge from the previous analysis. Let us briefly summarise them:

First, there has indeed been a clear acceleration over the late seventies and eighties in the rate of technological effort, measured e.g. in terms of industry-financed R&D expenditures in most OECD countries. This increase has been most noticeable in Japan, Sweden, Germany and the United States. However, the pattern of an acceleration in R&D spending is a feature of the eighties, common to practically all OECD countries.

Second, the observed "officially measured" acceleration in R&D expenditures is to a large extent related to the emergence of some radical and pervasive new technologies such as information technologies over this same period. In countries where the acceleration has been small or non-existent, the share in total industrial R&D of electronics R&D remained constant or fell, in other countries such as the United Kingdom, Canada and Japan a large part of the acceleration in aggregate industrial R&D expenditure over the 80s was the result of increased spending in electronics and information technologies.

Third, official R&D expenditure data represent according to our "best" estimates a mere 35 to 45 per cent of total efforts devoted to technological advance. Officially reported R&D expenditures tend to significantly underestimate the actual technological effort in such areas as production engineering, software and design; in small firms and in services. Particularly in

Figure 8b

REVEALED TECHNOLOGY ADVANTAGE — COMPUTER-RELATED SECTORS

11 Countries 1986

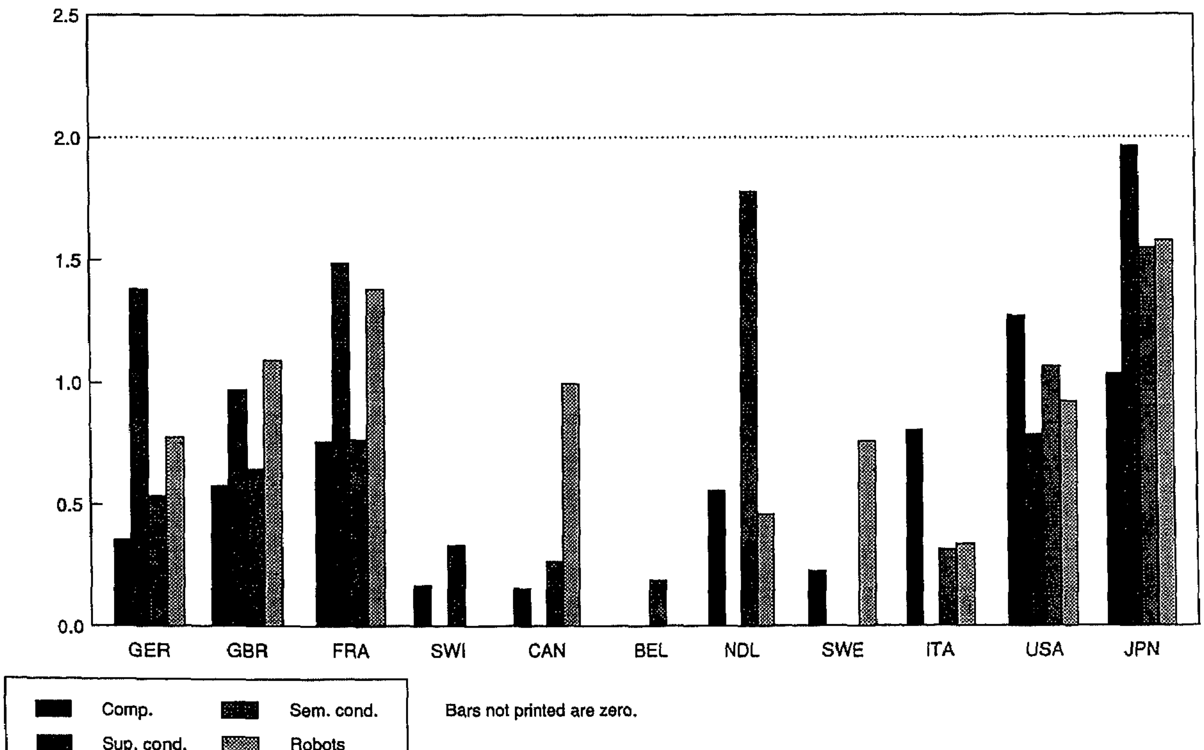


Table 10. **Patenting in New Technologies**

In percentages of total

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Genetic engineering														
TOT	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.06	0.19	0.11	0.10	0.12	0.16
USA	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.07	0.21	0.12	0.14	0.17	0.24
JPN	0.00	0.02	0.05	0.02	0.02	0.04	0.00	0.00	0.04	0.20	0.14	0.08	0.08	0.10
EUR	0.01	0.02	0.03	0.03	0.04	0.01	0.03	0.05	0.04	0.14	0.08	0.04	0.05	0.07
OTHER[a]	0.04	0.00	0.00	0.04	0.04	0.04	0.06	0.09	0.08	0.20	0.10	0.04	0.00	0.04
Molecular biology and microbiology														
TOT	0.65	0.72	0.84	0.82	0.87	0.65	0.73	0.99	1.17	1.27	1.14	1.02	0.99	1.10
USA	0.51	0.57	0.64	0.67	0.71	0.59	0.66	0.87	1.12	1.18	1.06	1.01	1.02	1.17
JPN	2.39	2.02	2.44	1.48	1.34	1.04	1.18	1.88	1.54	1.68	1.43	1.12	1.15	1.18
EUR	0.59	0.75	0.76	0.89	1.11	0.60	0.78	0.92	1.09	1.24	1.09	0.93	0.75	0.87
OTHER[a]	0.50	0.70	1.02	1.25	0.85	1.06	0.28	0.52	1.30	1.32	1.50	1.34	1.20	1.22
General purpose programmable digital computer systems														
TOT	0.33	0.27	0.20	0.32	0.36	0.36	0.36	0.35	0.34	0.41	0.53	0.62	0.50	0.50
USA	0.37	0.33	0.24	0.35	0.39	0.44	0.45	0.45	0.43	0.53	0.70	0.80	0.65	0.64
JPN	0.28	0.08	0.11	0.20	0.35	0.39	0.36	0.27	0.36	0.40	0.38	0.47	0.49	0.51
EUR	0.20	0.18	0.15	0.33	0.33	0.20	0.20	0.19	0.15	0.17	0.25	0.31	0.20	0.22
OTHER[a]	0.21	0.04	0.04	0.04	0.00	0.04	0.06	0.09	0.00	0.05	0.21	0.35	0.16	0.15
Superconductors														
TOT	0.12	0.08	0.09	0.08	0.09	0.07	0.08	0.06	0.05	0.08	0.10	0.08	0.09	0.08
USA	0.08	0.07	0.06	0.08	0.07	0.07	0.08	0.06	0.05	0.08	0.10	0.09	0.09	0.07
JPN	0.12	0.08	0.09	0.02	0.06	0.04	0.10	0.06	0.04	0.16	0.05	0.09	0.16	0.17
EUR	0.25	0.09	0.16	0.11	0.14	0.09	0.06	0.05	0.06	0.05	0.09	0.06	0.07	0.08
OTHER[a]	0.12	0.12	0.08	0.00	0.04	0.00	0.22	0.17	0.04	0.05	0.05	0.04	0.00	0.00
Semiconductor devices and manufacture														
TOT	1.53	1.41	1.50	1.70	1.77	1.63	1.88	1.73	1.73	1.85	1.97	1.88	2.08	2.24
USA	1.49	1.44	1.58	1.73	1.75	1.63	1.98	1.91	1.81	1.90	2.12	1.92	2.10	2.38
JPN	2.81	2.58	2.22	2.98	3.28	2.53	2.80	2.48	2.75	2.88	3.17	2.91	3.36	3.47
EUR	1.32	1.05	1.13	1.16	1.35	1.35	1.34	1.10	1.20	1.31	1.01	1.20	1.26	1.21
OTHER[a]	0.96	0.55	0.65	1.33	0.81	0.97	1.06	0.61	0.42	0.66	0.52	0.78	0.84	0.57
Robots														
TOT	0.04	0.06	0.07	0.04	0.08	0.06	0.09	0.10	0.12	0.13	0.19	0.13	0.25	0.30
USA	0.03	0.04	0.07	0.05	0.06	0.04	0.09	0.08	0.11	0.12	0.16	0.11	0.21	0.28
JPN	0.20	0.24	0.16	0.12	0.16	0.12	0.11	0.17	0.17	0.21	0.22	0.21	0.44	0.48
EUR	0.03	0.04	0.04	0.01	0.09	0.09	0.09	0.09	0.10	0.13	0.23	0.10	0.20	0.23
OTHER[a]	0.04	0.00	0.08	0.04	0.09	0.04	0.00	0.13	0.08	0.05	0.41	0.13	0.12	0.23
Telecommunications														
TOT	3.61	3.40	3.52	3.67	4.11	3.76	3.81	4.03	3.85	4.42	4.56	4.38	5.04	5.51
USA	3.60	3.54	3.56	3.65	4.02	3.74	3.72	3.84	3.63	4.07	4.41	4.33	4.78	5.36
JPN	5.41	5.01	5.45	5.52	6.35	5.40	5.92	6.38	5.89	6.53	6.25	5.81	7.16	7.78
EUR	3.15	2.50	2.75	3.09	3.57	3.21	3.26	3.66	3.40	4.11	3.90	3.52	4.08	4.24
OTHER[a]	3.12	2.84	2.78	3.03	3.24	2.83	2.78	2.26	3.24	3.95	3.72	4.02	4.77	4.44
Laser light sources and detectors														
TOT	0.11	0.10	0.11	0.14	0.13	0.11	0.12	0.13	0.12	0.13	0.11	0.11	0.10	0.16
USA	0.12	0.10	0.11	0.12	0.10	0.10	0.10	0.13	0.10	0.09	0.09	0.10	0.09	0.15
JPN	0.24	0.25	0.17	0.26	0.40	0.22	0.32	0.20	0.19	0.39	0.30	0.21	0.20	0.30
EUR	0.05	0.05	0.10	0.09	0.11	0.06	0.07	0.12	0.12	0.06	0.06	0.07	0.05	0.09
OTHER[a]	0.04	0.04	0.08	0.42	0.09	0.30	0.22	0.00	0.08	0.15	0.00	0.13	0.04	0.04
Light transmitting fiber, wave guide or Rod														
TOT	0.24	0.26	0.28	0.31	0.29	0.38	0.41	0.43	0.41	0.33	0.47	0.46	0.43	0.44
USA	0.27	0.26	0.30	0.30	0.27	0.39	0.37	0.39	0.38	0.27	0.41	0.46	0.41	0.42
JPN	0.22	0.51	0.49	0.34	0.23	0.27	0.23	0.28	0.41	0.29	0.41	0.39	0.46	0.48
EUR	0.16	0.20	0.16	0.32	0.38	0.43	0.60	0.63	0.47	0.48	0.66	0.52	0.49	0.48
OTHER[a]	0.08	0.00	0.12	0.21	0.21	0.17	0.33	0.30	0.46	0.35	0.52	0.52	0.24	0.19

a) All countries outside Europe, except Japan and the USA.
Source: "Technology Profile Reports", Office of Documentation, US Patent and Trademark Office, April/May 1987.

Table 11. **US Patent Classes with the Largest Numeric Increase Over the Period 1963 to 1986**

US Patent Class		1963-68	1969-74	1975-80	1981-86	(1981-86) minus (1963-68)
514	Drug, Bio-Affecting & Body Treating Comp.[a]	3 066	4 508	10 305	11 872	8 806
128	Surgery[b]	2 848	5 507	6 196	8 321	5 473
364	Electrical Computers & Data Proc. Equipment	1 905	3 627	4 099	6 671	4 766
123	Internal-Combustion Engines	1 807	2 547	4 607	6 183	4 376
428	Stock Material or Misc. Articles	3 353	5 814	5 483	7 712	4 359
525	Synthetic Resins or Natural Rubbers[c]	6 189	8 629	9 905	9 851	3 662
350	Optics, Systems & Elements	938	3 155	3 461	4 227	3 289
358	Pictorial Communication: Television	1 065	2 748	2 719	4 258	3 193
430	Radiation Imagery Chemistry	2 337	5 053	3 762	4 534	2 197
204	Chemistry, Electrical & Wave Energy	2 633	4 967	4 703	4 627	1 994
156	Adhesive Bonding etc.	2 745	5 439	4 072	4 651	1 906
435	Chemistry Molecular Biology & Microbiology	837	1 647	1 934	2 648	1 811
355	Photocopying	750	1 683	1 877	2 544	1 794
427	Coating Processes	1 824	3 038	2 652	3 438	1 614
502	Catalyst, Solid Sorbent, or Support Thereof	799	1 306	2 095	2 380	1 581
210	Liquid Purification or Separation	2 346	3 801	3 920	3 829	1 483
360	Dynamic Magnetic Info. Storage or Regrieval	1 185	2 109	1 821	2 630	1 445
252	Compositions	3 550	4 995	4 649	4 947	1 397
356	Optics, Measuring & Testing	809	2 538	2 035	2 200	1 391
340	Communications, Electrical	3 234	5 432	4 210	4 610	1 376
126	Stoves & Furnaces	1 032	942	2 002	2 297	1 265
73	Measuring & Testing	5 336	6 151	5 791	6 376	1 040
219	Electric Heating	3 018	4 543	2 911	3 977	959
370	Multiplex Communications	335	817	860	1 253	918
250	Radiant Energy	2 589	4 306	3 298	3 504	915
357	Active Solid State Devices	838	1 769	1 828	1 706	868
436	Chemistry: Analytical & Immunological Testing	224	762	1 104	1 088	864
354	Photography	1 641	2 771	2 424	2 442	801
280	Land Vehicles	2 340	3 419	3 396	3 130	790
346	Recorder	923	864	948	1 699	776
71	Chemistry, Fertilizers	1 028	1 016	1 671	1 780	752
273	Amusement Devices, Games	1 795	2 775	2 982	2 521	726
372	Coherent Light Generators	234	1 149	763	946	712
375	Pulse or Digital Communications	310	717	611	997	687
400	Typewriter Machines	614	708	918	1 281	667
433	Dentistry	485	786	847	1 144	659
530	Chemistry, Peptides or Proteins, Lignins	197	383	703	792	595
422	Process Disinfecting, Deodorizing etc.	1 197	1 846	1 888	1 768	571
405	Hydraulic & Earth Engineering	1 020	1 667	1 643	1 581	561
371	Error Detection/Correction and Recovery	262	555	478	815	553
369	Dynamic Information Storage or Retrieval	649	609	1 002	1 205	556
623	Prothesis (i.e. Artificial Body Members)	89	353	560	642	553
429	Chemistry, Electrical Current Producing	997	1 627	1 757	1 529	532
426	Food or Edible Material: Proc. & Products	2 141	3 183	3 009	2 680	539
318	Electricity, Motive Power Systems	1 769	2 764	1 844	2 297	528
29	Metal Working	3 824	5 566	4 186	4 291	467
208	Mineral Oils: Processes and Products	1 464	1 889	1 774	1 919	455

a) Contains classes 424 and 514.
b) Contains classes 128 and 604.
c) Contains classes 525, 521, 523, 524.
These classes all have the same title.
All classes have been ranked according to the difference between the number of patents granted in 1981-86 and 1963-68 (last column).
Source: Patel and Soete, 1989.

Table 12. **Patent Classes with the Highest Rate of Renewal in Chemical, Electrical and Mechanical Technologies, 1983**

Chemical Class	Number eligible for renewal	Number renewed	% renewed
430 Radiation Imagery Chemistry	46	45	98
65 Glass Manufacturing	35	22	96
501 Compositions Ceramics	38	36	95
560 Organic Compounds	76	72	95
530 Chemistry, Peptides or Proteins, Lignins	35	33	94
162 Paper Making and Fibre Liberation	32	30	94
75 Metallurgy	47	44	94
525 Synthetic Resins or Natural Rubbers	78	73	94
260 Chemistry, Carbon Compounds	92	86	93
502 Catalyst, Solid Sorbent, or Support ther.	137	127	93
521 Synthetic Resins or Natural Rubbers	191	177	93
136 Batteries, Thermoelectric & Photoelec.	66	61	92
All Chemical Classes	**5 941**	**5 221**	**88**
Electrical			
371 Error Detection/Correction and Recovery	23	23	100
370 Multiplex Communications	37	36	97
330 Amplifiers	31	30	97
455 Telecommunications	51	48	94
313 Electric Lamp and Discharge Devices	30	28	93
358 Pictorial Communication, Television	147	136	92
All Electrical Classes	**2 635**	**2 286**	**87**
Mechanical			
152 Resilient Tyres and Wheels	28	28	100
118 Coating Apparatus	74	70	95
339 Electric Connectors	88	83	94
57 Textiles, Spinning, Twisting and Twining	52	48	92
415 Rotary Kinetic Fluid Motors or Pumps	23	21	91
350 Optics, Systems and Elements	121	110	91
374 Thermal Measuring and Testing	21	19	90
All Mechanical Classes	**7 010**	**5 434**	**78**

Source: Manchuso, S.E., Masuck, M.P., and Woodrow, E.C., (1987), *An Analysis of Patent Expiration for Failure to Pay Maintenance Fees*, Worcester Polytechnic Institute, USA, October.

services, officially reported R&D expenditure data seem to represent only a fraction (10 per cent in the United States) of actual technological research activities.

Fourth, over time the underestimation of industrial R&D expenditures of actual technological efforts has not remained constant. Whereas in the fifties and sixties trends in industrial R&D expenditures tended to overestimate the actual trend in technological effort in most OECD countries, over the eighties the reverse has occurred with the increase in importance of such research activities as software, and increased research activities in a growing number of service sectors.

Fifth, over the whole of the post-war period there has been a decline in the aggregate number of patents (applied for or granted, domestic or international) per unit of R&D spent in practically all OECD countries. This "pervasive" trend illustrates probably better changes in the propensity to patent and changes in the share of total technological effort covered by R&D expenditures, than a real decline in the efficiency or productivity of R&D.

Sixth, "new" technology areas have been areas of rapidly expending number of patents particularly in the genetic engineering, computer and electronics, and telecommunications technology areas. Here too Japan seems to have been taken the technological lead particularly in the hardware information technology areas. The United States technological position is comparatively strong in biotechnology and computer technology.

To substantiate some of these sometimes tentative results, far more research is, however, needed in the area of technology indicators. As we have hinted at above that research will need to be directed to the following priority areas:

1. The need for a better R&D indicator. The present definitions used in the *Frascati Manual* are too old, too much directed towards industrial research activities and too much biased towards "formalised" R&D.
2. Better disaggregated R&D data particularly with respect to the new technologies. It is paradoxical that with the exception of a couple of highly partial

Table 13. **The New Technology Areas have been Defined in Terms of US Patent Classes as Follows:**

Genetic Engineering:	
Class	935
Molecular Biology and Microbiology:	
Class	435
General Purpose Programmable Digital Computer Systems:	
Class	364/200
Superconductors:	
Class	29/599
Class	174/15CA; 15S; 126S; 128S
Class	204/192.24
Class	307/245; 277; 306
Class	323/360
Class	324/248
Class	331/107S
Class	333/99S
Class	335/216
Class	336/DIG.1
Class	338/32S
Class	357/5; 83
Class	361/19
Class	365/160-162
Class	374/176
Class	420/901
Class	427/901
Class	427/62
Class	428/930
Semiconductor Devices and Manufacture:	
Class	148/1.5; 171-191; 33; 33.1-33.6
Class	29/569-591
Class	427/80-99
Class	156/643-662
Class	357/all subs
Robots:	
Class	901
Telecommunications:	
Class	379/all subs
Class	381/71; 73-74; 76-124; 29-59; 1-28; 150-205; 61-66
Class	350/96.1-96.34
Class	357/17; 19
Class	370/1-4; 5-124; 125
Class	372/43-50; 75
Class	455/600-619; 1-355
Class	178/all subs
Class	329/104-109
Class	332/9R-15
Class	340/347R-347DF; 853-861; 870.1-870.44; 425
Class	371/1-6; 30-71
Class	375/all subs
Class	358/1-304; 903-905
Class	33/267; 363R-363Y
Class	73/146.4
Class	128/903-904
Laser Light Sources and Detectors:	
Class	357; 19
Class	372/43-50; 75
Light Transmitting Fiber, Waveguide or Rod:	
Class	350/96.1-96.34

surveys, we have no R&D data on any of the new technologies which are so much at the core of present policy debates, and plenty of detailed sectoral R&D data on some of the older technology sectors.

3. The need to survey and integrate software expenditures in the present R&D concept and start collecting and analyzing such R, D & S data. A sufficient amount of private and public preliminary surveys exist, to make the step now to incorporate questions with respect to software expenditures formally in the R&D surveys.

The OECD could undoubtedly play a major role in inciting member countries to improve the presently most used technology input indicator: R&D statistics. However, some Member countries such as the United States and Japan which have been at the forefront of the use and development of the R&D indicator in the past, could well take the lead in bringing a major revision under way of the R&D concept and the way such data are being collected. As to Europe, the question must be raised whether R&D data based on "national" statistics, with all its disclosure problems – at the level of disaggregation required to study trends in new technologies – and in the final instance little bearing on the "domestic" rate of technical change, let alone "domestic" productivity growth, should not be replaced by R&D data collected directly at the EC level.

The emergence of some radical new technologies over the seventies and eighties does not only have a major impact on the social and economic framework of society. It is also a major challenge to some of the statistical concepts and categories we have relied upon in the sixties and seventies.

NOTES

1. The best source is *Science and Engineering Indicators*, published every two years by the US National Science Foundation, and the National Science Board.
2. See, for example, C. Freeman (1987), *Essays in Honour of Yvan Fabian.*
3. A number of studies suggest the following average distribution of innovation costs in large firms (excluding normal equipment costs): research-10%; development-40%; production engineering-40%; marketing-10%. See Kamin *et al.* (1982).
4. Most software development is untraded, being undertaken by users for their own special purposes (see Gonenc, 1985). For an analytical treatment of the role of users, see Barras (1986).
5. In early writings, it was often assumed that learning by doing was a costless and positive externality emerging automatically from production. It is now recognised that such learning is often related to the other technological activities that we have described above, and that its rate can be influenced by the expenditure of resources on organisation, communication and training.
6. See, in particular, the work of Scherer (1965) and Schmookler (1966). Computerisation of patent data in the 1970s and 1980s gave an additional stimulus (see Z. Griliches, 1984). Significant contributions are now being made by analysts from bibliometrics and from science and technology policy studies (see Narin and Olivastro, and Pavitt, in Van Raan, 1988).
7. In addition to Griliches (1984), see Soete and Wyatt (1983) and Patel and Pavitt (1987, 1988).
8. Given Griliches' recent analysis of patent statistics (1988, 1989), illustrating a.o. that trends in number of patents granted are largely "associated with differences in the procedures and resources of the various patent offices", we prefer to use here numbers of patents applied for, rather than granted.
9. Like R&D, patenting is a poor measure of technology development in software. Data on copyright protection might eventually be a better measure. In the meantime, it will be worth exploring any possible links between software development, and the development of related areas of IT hardware.
10. $$\text{RTA} = \frac{\dfrac{\text{patents country } i \text{ in sector } j}{\text{patents world sector } j}}{\dfrac{\text{patents country } i}{\text{patents world}}}$$

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