R&D, patenting and innovative activities

A statistical exploration

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Better understanding of, and policies towards, technical change, requires better measurement of technical change. No single measure is perfect. Taken together, statistics on R&D and on patenting activities give important clues about the rate and direction of innovative activities, and also show the dangers of too hasty interpretation based on one measure. They both show a heavy concentration of innovative activities in chemicals and engineering (electrical, electronic and non-electrical) sectors; relatively rapid growth of innovative activities in drugs, scientific instruments and food products, and slow growth in aerospace and electrical products, in the USA between 1963 and 1974. They both show relatively high levels of innovative activities in Germany, Sweden and Switzerland, and relatively rapid rates of increase in Japan and Sweden between 1967 and 1975. They also show the strong association in the chemicals and engineering industries between the levels of innovative activities and of export competitiveness.

On the other hand, taken together they suggest that patent statistics underestimate innovative activities in large firms, and that R&D statistics do so in small firms. This casts doubt on widely held assumptions about diminishing rates of innovative activity in very large firms, and about the non-electrical machinery and fabricated metal products sectors as "traditional" and "non-innovative" industries. Four factors are put forward to explain differences in what is shown by the patent and by the R&D measures: first, competitive behaviour, with smaller firms making a relatively greater use of patents, and bigger firms of R&D activities; second, different degrees of specialisation and formalisation of innovative activities in and around R&D departments; third, variation across sectors in the degree to which patents measure an increment of technical improvement: fourth, institutional factors in aerospace and other defence-related sectors, and in motor vehicles, where patenting is low and the proportion of routine testing in R&D comparatively high.

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1. Introduction

It has become commonplace to say how important technical innovation and diffusion are in industrial competition, economic growth and social change. Ever since the work in the 1950s and the 1960s, showing their contribution to US economic growth and to international competitive advantage, there has been a renewed theoretical interest in technical change, perhaps the most notable consequence of which has been the development of the so-called "neo-technology" theories of international trade, that put technical change and skills at the centre of explanations of the industrially advanced countries' trading advantage (see [22]). Much remains to be done, however. The conventional theory of the firm has very little to say that is relevant to our understanding of technical innovation and, as Nelson and Winter have pointed out, our knowledge of the process of technical innovation and the factors affecting it is balkanised amongst many disciplines and subdisciplines [9].

If anything, the interest of policy-makers in technical change has grown in the 1970s, when the belief that high rates of economic growth could be sustained simply through macro-economic demand management has been found wanting. "Structural adaptation", or "positive adjustment", to changing patterns of demand, to high energy costs, to emerging competition from the newly industrialised countries, and to emerging technological opportunities, has become the rallying cry for the 1970s and the 1980s, and the associated policies

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either assume or prescribe an elastic supply of innovations in the industrially advanced countries.

The development of both theory and policy suffer from at least one common problem, namely, the insufficient use of a range of measures of technical innovation and diffusion. With a few notable exceptions [1], applied economic analysis continues to treat technical change as what is left over when conventional analysis has been tried but does not explain very much: for example, the very large "residual" left over in evaluating measured contributions to economic growth, or the "non-price factors" explaining differences in export competitiveness when measured prices do not. The gaps in our systems of measurement are all the more disquieting if one accepts that the rate, direction and productivity of innovative activities will have a major influence on patterns of investment and employment and that – together with the international diffusion of technology – they will have a major influence on patterns of national competitiveness and structural change. Under such circumstances, micro-studies, partial measurements, and expert opinion cannot be a substitute for the collection of systematic evidence – both quantitative and qualitative – on technical innovation and its diffusion.

The problem is not simply one of lack of data, although more data are certainly needed. There is also a problem of the disciplinary and institutional balkanisation mentioned earlier. In the OECD countries, statisticians and scientists in government have been collecting statistics on one major aspect of innovative activities – research and development (R&D) – for at least fifteen years. In addition, major initiatives have been taken in the past ten years to widen the range of measures, the most notable example being the *Science Indicators* publications in the USA [6]. These new initiatives have generated both considerable interest and considerable controversy, the latter tending to be concentrated on problems of interpretation.

However, an effective bridge has yet to be built between mainstream economic analysis of technical change, and the whole range of statistical measures of innovation and diffusion that are now being compiled. There are several possible reasons for this. Statisticians and government officials have naturally been cautious in interpreting what these new statistics might mean. There has perhaps been insufficient recognition that all statistical measures are imperfect, and that policy analysis inevitably requires the use of a variety of imperfect measures. Perhaps, also, the reward systems for those involved in both economic theory and economic policy do not encourage strongly enough the analysis of technical change.

The objectives of this paper in bridge-building are modest, limited and prosaic. [2] It explores the use of R&D and patenting statistics as indicators of innovative activity, in making comparisons amongst firms, industries, countries and time periods. It also explores the links between innovative activities and export performance. It is not a comprehensive review of what is known and not known about patent statistics. It does not review and systematically build upon the important work of earlier writers, in particular, Machlup, Schmookler, Kuznets, Freeman, and Taylor and Silberston [2,4,5,16,20] nor does it review or comment upon more recent empirical work, like that of Schiffel and Kitti [15].

2. Underlying assumptions

The basic assumption of this paper is that both R&D and patent statistics show different aspects of the same process of industrial *innovation*. This is somewhat different from the assumption that, since patents by definition involve novelty, and since invention is defined as novelty, patents capture and measure the earlier stages of a process that leads from novelty/invention, through development, testing and engineering, to full-scale innovation. It is also different from the assumption that numbers of patents measure one of the primary outputs of R&D activities.

Such views of the innovation process neglect that, as Schumpter pointed out, the essential process for the industrial firm is *innovation*, not invention [17]. Patents can therefore be viewed as one of the means by which entrepreneurs protect

[1] See in particular [2,9,18,20,21,23].

[2] In a recent book, this writer and his colleagues at the Science Policy Research Unit at the University of Sussex used a variety of measures and methods of analysis to assess the role of technical innovation in British industrial performance [14], and we intend to pursue this work in future.

their *innovations*. Or, to put it another way, patents are means by which entrepreneurs try to augment the monopoly profits from innovation by making it more difficult for potential competitors to copy or imitate. Other methods of discouraging imitation involve secrecy, further technological advance based on firm-specific R&D and skill, influence over suppliers or marketing outlets, and manipulation of standards. Patenting activity may extend over the whole of the product life-cycle: from the patents protecting the basic invention, through those related to product and process engineering, to a myriad of improvement and blocking patents. What concerns us here are the relationships amongst industrial R&D activity, patenting and innovation. In interpreting the data, we shall have two working hypotheses in mind.

First, in spite of the many perversities (real and imagined) of imperfect and oligopolistic competition, it is implausible that a firm would commit resources to R&D and to patenting activities in order not to innovate. It might not wish to be the first to innovate, it might even wish to control or to delay the innovation process. But eventually it knows that it will have to innovate. In other words, I shall assume that R&D activities and patenting activities are positively related to innovative activities.

Second, I assume that R&D and patenting activities are positively related to each other; in other words, that they are complementary activities in the sense that higher or lower R&D activities are reflected in higher or lower patenting activities. However, we must recognize that R&D and patent activities sometimes may not be perfect reflections of each other. R&D activity may not be patented because secrecy is felt to be a better protection than patenting, or because its results are in the form of unpatentable know-how (especially in relation to production and to systems design); in this case R&D will be a more reliable indicator of innovative activity than patenting. On the other hand innovative activities undertaken outside formal R&D institutions may not be measured in the R&D statistics, but may nonetheless result in patenting activity. In this case, patenting will be a more reliable indicator of innovative activities than R&D activities. Patenting and R&D may also be substitutable activities, at least at the margin. Firms may decide *between* more patenting and more R&D as alternative means of maintaining their temporary monopoly power.

In this paper, we shall not look at the evidence collected within individual firms on the relationship between their R&D activities and their patenting behaviour. We shall instead compare R&D and patenting amongst firms, industries, countries and time periods. The statistical information comes from a variety of sources, mainly in the USA: the *Science Indicators* publications; the regular series published by the National Science Foundation; the publications of the Office of Technology Assessment and Forecast, as well as information specially prepared by the Office for the Science Policy Research Unit: the figures on company R&D expenditure compiled and published by *Business Week*; and the recent comparison of industrial R&D expenditures in different countries made by the Science and Technology Indicators Unit at the OECD [1,6,7,8,10,11,12,13]. We shall begin by examining differences amongst firms.

3. Differences amongst firms

Recently published data has enabled a much more systematic examination of the relationship between patenting and R&D activities by individual US firms. *Business Week* has since 1976 published data on the expenditures of the largest US corporations on R&D activities, based on information submitted to the US Securities Exchange Commission. OTAF has provided data to the Science Policy Research Unit on the patenting activities of the major US corporations [13]. On this basis, Soete has recently carried out a thorough analysis of the way in which the relationship between patenting and R&D activities varies across size of firm and industrial sector [18]. Of the 532 R&D performing firms with sales greater than $100 million, identified from *Business Week*, Soete found that 96 firms had been granted less than ten patents between 1963 and 1976. He therefore eliminated these firms from his analysis, and concentrated on the 436 remaining.

He found that the coefficient of correlation (r) between numbers of patents and R&D spending in each firm, both as proportions of sales was 0.44, and both as a proportion of employment was 0.56. This was statistically highly significant, but Soete observed that the r was surprisingly low. The reason, he argued, is the way in which the balance between R&D and patenting activity varies as a function of size of firm. As the size of firm increases, the ratio of R&D expenditures to sales increases, but the number of patents per unit R&D expenditure decreases. This negative relationship between R&D/sales and patents/R&D holds for the 436 largest firms taken as whole ($r = -0.2$); it also holds in most industrial sectors, with greatest intensity in aircraft, drugs, office equipment, textiles, building materials and machinery, the one exception being personal care products.

This same phenomemon has been observed by Schmookler for the USA, and by Taylor and Silberston for the UK [16,20]. Soete explains it in terms of the propensity of larger firms to use greater R&D expenditures relatively more than more patents as a means of protection against, or discouragement of, actual or potential competitors. He goes on to suggest tentatively that the reduction since the late 1950s of US patenting per unit of industrial R&D can thereby be explained through increasing industrial concentration. In a time series regression of total US patenting per unit R&D since 1955 against industry concentration ratios, he found that about 60 percent of the reduction of the ratio of patenting to R&D until 1976 could be explained in terms of increasing concentration.

A number of other explanations have been put forward to explain this reduction over time in patenting per unit R&D. Some take patent numbers as a proxy for the 'output' of R&D activities, and conclude either that big firms are less efficient than small firms in performing R&D, or that the productivity of R&D has been declining steadily since the late 1950s. I find both these explanations to be implausible, although they merit further investigation. There is no thorough and systematic evidence of low R&D efficiency in large firms, or of diminishing R&D productivity. Indeed, the past trend towards increasing concentration of R&D in large firms, together with the growing proportion of industry's resources committed to R&D in most OECD countries until the mid-1970s, suggest otherwise.

There are two other explanations that I find more plausible. The first is the changing nature of industrial R&D as firms get bigger, with more emphasis on testing, applications engineering, and systems and production know-how, all of which are more difficult to patent. The second is the increasing formalisation and specialisation of innovative functions within the firm as it gets bigger or more R&D intensive, with the result that R&D statistics capture a higher proportion of all the firm's innovative activities, and the ratio of patents to observed R&D activity goes down.

Whatever the relative importance of these explanations, their operational significance for the interpretation of patent statistics is not inconsistent with the explanation put forward by Soete. They show clearly that R&D and patenting activities do not evolve in a linear relationship to each other over different ranges of firm size. They also suggest that R&D activities might be a better proxy for innovative activity in large firms, and patenting activity a better proxy in small firms. Similar problems of interpretation occur in making comparisons between industries, as we shall now see.

4. Differences amongst industrial sectors

In looking at the breakdown of R&D and of patenting activity by industrial sector, we shall be interested in answering at least three questions. First, to what extent do the two measures reflect the sectoral pattern of innovative activities? Second, to what extent do they reflect the varying innovation intensities of different sectors? Third, to what extent do they reflect changing patterns over time?

4.1. Sectoral patterns of R&D and of patenting

Table 1 shows the sectoral distribution of patenting activity in US 1973–5, by comparison with total industrial R&D, industry-financed R&D, the employment of qualified scientists and engineers, total employment, and sales. Table 2 shows that the correlation (r) between sectoral patenting on the one hand, and the three other measures of innovative activity in industry, on the other, are not very strong, the highest r being achieved for the total employment of qualified scientists and engineers. However, the correlation increases enormously for all three measures, when aerospace and motor vehicles are excluded. How

Table 1
Sectoral shares of US industrial patenting compared to other activities

Sector	Patents granted (1973) (%)	Total R&D expenditures (1973) (%)	Industry financed R&D (1974) (%)	Qualified scientists and engineers (1975) (%)	Manufacturing employment (1974) (%)	Manufacturing sales (1974) (%)
Food and kindred products	1.0	1.2	2.1	3.5	6.9	10.2
Textiles	0.9	0.3	n.a.	1.2	3.3	1.8
Chemicals (except drugs)	11.3	6.7				
			15.6	13.1	7.9	9.6
Drugs	1.3	2.9				
Petroleum and related products	1.3	2.3	4.4	3.1	3.4	(14.9)
Rubber	4.1	1.3	n.a.	3.0	2.7	2.3
Stone, glass, clay, concrete	1.9	0.8	1.3	2.3	2.5	1.6
Ferrous metals	0.7	0.7				
			2.2	4.9	7.8	7.8
Non-ferrous metals	0.6	0.6				
Fabricated metals products	11.2	1.3	2.0	7.3	5.1	3.4
Non-electrical machinery	25.9	10.2	15.3	12.5	11.2	8.5
Electrical and electronics	20.0	30.6	21.2	21.5	16.6	10.6
Motor vehicles	2.8	11.3				
			23.8	18.5	16.5	14.7
Aerospace	1.8	23.6				
Scientific instruments	9.8	4.2	5.8	4.9	3.6	2.5
Other manufacturing	5.5	2.0	6.4	4.2	12.5	14.1
Total	100.0	100.0	100.0	100.0	100.0	100.0

Sources [6,7,8].

Table 2
Results of correlations of shares of US patenting by different US industrial sectors, with their shares of other activities

Nature of activity		n	r	t coeff.	Significance (%)
Total industrial R&D	A	16	0.48	2.031	10
	B	14	0.71	3.552	1
Industry-financed R&D	A	11	0.57	2.041	10
	B	10	0.82	4.108	1
Employment of qualified scientists and engineers	A	13	0.66	2.969	2
	B	12	0.84	4.880	1
Total employment	A	13	0.48	1.793	20
	B	12	0.63	2.598	5
Total sales	A	12	0.17	0.590	n.s.
	B	11	0.30	0.921	n.s.

For basic data, see table 1.
A = including aerospace and motor vehicles; B = excluding aerospace and motor vehicles.

can we explain the differences between the sectoral patterns of R&D and those of patenting activities?

First, there is the explanation offered by Soete, namely that differing size and concentration structures across industries result in different trade-offs between R&D and patenting [18]. He found that just over a quarter of the variation amongst twenty-eight US industrial sectors in the ratio of patenting to R&D can be explained by the average size of manufacturing plant, or by the degree of industrial concentration: the higher the average size of plant, or of concentration, the lower the ratio of patents to R&D.

Second, there is the explanation that, the more R&D intensive the firm, the higher the proportion of innovative activities captured by R&D, and the lower the patenting to R&D ratio. Extending this explanation to differences amongst industries, we would expect a negative relationship across industries between R&D intensity, and the patent to R&D ratio. On the basis of data collected by Soete for 30 US industries for 1972, such a relationship does exist, albeit a weak one ($r = -0.46$, significant at the 2% level). However, it is very dependent on the inclusion of a number of heavily defence-related sectors with high R&D intensities and low patenting (ordnance, engines, communications and office machinery equipment, aircraft and guided missiles). When these sectors are excluded, the relationship disappears.

Perhaps more convincing evidence of the importance of innovative activities outside R&D laboratories in the less R&D-intensive industries is the data in tables 1 and 2, where the total number of qualified scientists and engineers in industrial sectors reflect patenting activity more satisfactorily than do the R&D measures. The relatively high levels of patenting compared to R&D activity in fabricated metal products and non-electrical machinery are particularly important to note.

Third, there is the explanation that patents are not homogeneous units in different industrial sectors, because the ease with which patentable inventions can be made varies considerably from sector to sector. One measure of this ease of invention could be the proportion of patents in each sector taken over by individuals rather than institutions [6, 1976, table 4-14]. Two factors could influence the ease of invention: the level of skill, and the level of resources required for invention. In order to examine this hypothesis, I correlated the proportion of individuals in total patenting in each sector (a measure of ease of patenting) against sectoral R&D intensity (a meaure of skill requirements), and then against average plant sales in the sector (a measure of level of resources required). In the former case, the correlation was negligible and statistically insignificant: skill requirements do not appear to influence the accesss that individuals have to patenting activity in different sectors of industry. In the latter case, the correlation was -0.49 and significant at the 2% level: scale of resources required may influence to some extent the degree to which individuals contribute to sectoral patenting activity.[3] This suggests another explanation of the inverse relationship between size of firm and R&D intensity, on the one hand, and the patent to R&D ratio on the other. Smaller firms gravitate to sectors, and within sectors to products, where the costs of making innovations are somewhat lower than those of big firms.

Finally, there is the group of US sectors where the patent to R&D ratio is very much smaller than in other sectors: guided missiles, aircraft, motor vehicles, communication equipment, office machinery, ordnance and engines [18]. With the exception of motor vehicles, all these sectors receive a considerable proportion of their R&D funds from the Federal Government. One can think of at least three reasons why they might as a consequence tend to patent less than other sectors: the nature of the R&D work done, military security, and company policy towards patenting (or, rather, non-patenting) of government-funded R&D work. Quite why the same relationship holds in the motor vehicle industry is less clear. It certainly is *not* the result of government regulation, since the patenting to R&D ratio has been low in motor vehicles since at least the early 1960s. Does recorded R&D in motor vehicles include a relatively very large proportion of relatively routine testing activities? Could the same be true for the defence-related sectors?

[3] These correlations left out sectors with large amounts of defence R&D activity, for reasons to be explained below.

4.2. Sectoral patterns of R&D-intensity and patent-intensity

Soete showed that, across thirty sectors in 1972, the measure of R&D intensity (applied R&D expenditures as a proportion of value added), gave very different rankings from the measure of patent intensity (number of patents divided by value added). He found a Spearman rank correlation coefficient of 0.27 between the two measures, and the *r* to be negligible and non-significant [18]. However, the data show that the level of patenting activity in heavily government-funded sectors does not capture the rate of technological advance. For example, the number of patents divided by value added in both the aircraft and the guided missiles sectors is about the same as in non-ferrous metals, and is nearly eight times less than in farm machinery.

The exclusion of heavily government-funded sectors and of motor vehicles once again changes the pattern considerably. The Spearman rank correlation coefficient between the two measures increases to 0.59, and the *r* to 0.64 (significant at the one percent level). The remaining unexplained variance results largely from the differences in the measurement of relative innovation intensity of the chemical and non-electrical machinery sectors. With the exception of agricultural machinery and of office machinery, the patent measure ranks the non-electrical machinery sectors more highly, whilst the R&D measure gives higher rank to the chemicals sectors.

4.3. Sectoral trends over time

To what extent do trends in R&D expenditure and in patenting activity in different sectors reflect trends in innovative activity? Table 3 shows for the USA the increase between 1963 and 1974 in R&D expenditures and in US patenting. The two indicators show roughly the same trends. The Spearman rank correlation coefficient is 0.52, and the *r* is 0.57, which is significant at the 10 percent level. Both measures suggest unambiguously that the highest rates of increase of innovative activity have been in drugs, scientific instruments and food products, and the lowest in aerospace and electrical products. The greatest variance between the two measures exists in fabricated metal products and non-electrical machinery, where the R&D measure gives a considerably higher rate of increase than the patent measure; and the chemicals, ferrous metals, and stone, clay, glass and concrete sectors, where the reverse has been the case.

Of the explanations put forward above to explain variance between the two measures, I would guess that, in non-electrical machinery and fabricated metal products sectors, three of the factors leading to reduced patent to R&D ratios have been at work: greater firm size and concentration of industry; increasing formalisation of innovative activities in R&D laboratories; and the tackling of more difficult and more ambitious R&D problems. In the sectors where patents have increased faster than R&D (and all of which are process industries), I would guess that there has not been a reduction in size or concentration, but the R&D programmes have shifted in balance from radical product and process innovations to good environmental housekeeping (i.e. input conservation) and application research; in other words, to technically easier tasks.

Table 3
Increases in US patenting and R&D: 1963–1974

Sector	US patenting 1974/1963	US R&D expenditures 1974/1963
Food and kindred products	1.52	1.39
Textiles	1.28	1.38
Chemicals (except drugs)	1.36	0.99
Drugs	1.54	2.00
Petroleum and related products	1.17	1.16
Rubber	1.14	1.15
Stone, clay, glass, concrete	1.40	1.16
Ferrous metals	1.22	0.95
Non-ferrous metals	1.27	1.21
Fabricated metals products	1.03	1.15
Non-electrical machinery	1.03	1.60
Electrical products	1.06	1.14
Electronic products	1.30	1.20
Motor vehicles	1.33	1.37
Aerospace	1.10	0.69
Scientific instruments	1.53	2.18

Source: [6] 1976: The patenting ratio was calculated assuming compound rates of increase over the eleven years at the rate shown in [6, Appendix Table 4.12].

Table 4
US shares of world innovative activity, 1975: industrial R&D expenditures and US patents

Sector	Measure	US share [a]	Share compared to industry average [b]
All manufacturing	R&D expenditures	50.4	100.0
	Patents	64.9	100.0
Electrical and electronic products	R&D expenditures	51.0	101.2
	Patents	66.4	102.3
Chemicals	R&D expenditures	39.3	78.0
	Patents	58.6	90.3
Aerospace	R&D expenditures	73.5	145.8
	Patents	56.3	86.8
Non-electrical machinery	R&D expenditures	50.0	99.2
	Patents	63.5	97.8
Other transport	R&D expenditures	46.1	91.5
	Patents	60.0	92.5
Metals	R&D expenditures	36.8	73.0
	Patents	69.1	106.8

Sources: [10,12].
[a] US share of OECD expenditures in industry on R&D (BERD), or US share of all patenting in the US.
[b] US share in each sector (preceding column), divided by US share for all manufacturing.

5. Differences amongst countries

The use of patent statistics in international comparisons of scientific and technological activities has been widely discussed elsewhere (see, for example, [15]). It is often argued that comparisons of patents issued in different countries are unsatisfactory, given the considerable variation across countries in the ease with which patents can be obtained. I regressed per capita national patenting in eight countries against per capita industry-financed R&D.[4] The correlation coefficient was 0.66, significant at the ten percent level. Patenting clearly underestimated R&D activities in the Netherlands and overestimated them in France. National patenting is a relatively crude measure of scientific and technological activity.

[4] These countries were Belgium, Canada, France, F.R. Germany, Netherlands, Switzerland, UK, USA. Statistics were from [10] and [11].

I shall therefore concentrate here on the potential uses, for international comparisons of innovative activities, of the US patent statistics supplied by OTAF. Three problems merit particular attention. First, the validity of including the US in any international comparisons, given that US firms are patenting in their home country, whereas firms from other countries are not. Second, the problems of using patents to compare aggregate innovative activities amongst countries. Third, the problem – for similar reasons – of making international comparisons in specific sectors.

5.1. Evaluating US innovative activities

Table 4 shows, for 1975, the US share of OECD industrial R&D, and the share of patents from US sources in all US patents. In all cases except aerospace, the US share of patents was greater than its share of industrial R&D. This is not unexpected, given that firms in all countries are probably more discriminating about what they patent in foreign countries than what they patent domestically. It means, however, that US patenting in the USA overestimates the relative importance of innovative activities in the USA, by comparison with those of other countries.

The second column in table 4 compares for six major sectors, the US share of all major countries' patenting and R&D activities, with US shares for manufacturing industry as a whole.[5] Both the patent and R&D measures show unambiguous conclusions for four out of the six sectors: compared to other countries, the USA is relatively weak in innovative activities in chemicals and in other transport equipment, and is at the international norm in electrical and electronic products, and in non-electrical machinery (including scientific instruments, but excluding computers). Quite contradictory indications are given, however, by patents and by R&D statistics in the aerospace and metal products sectors.

For aerospace, the contradiction is yet another sign that levels of patenting activity do not reflect anything very much in this sector. For metals, there is probably quite another explanation, namely, the lumping together of two sectors with very different propensities to patent: ferrous and non-ferrous metals, on the one hand, and fabricated metal products on the other. As table 1 shows, R&D expenditures in metals and in metal products are roughly the same, yet nearly more than ten times the number of patents are granted in metal products than in metals. The apparent contradiction in table 4 in fact reflects, in terms of patenting activity, a comparative US advantage in metal products and a disadvantage in ferrous and non-ferrous metals.

Thus, the pattern of US patenting activity, and particularly the relative share of activity from foreign and from US sources, may give a good indication of the relative strength of US innovative activities when compared to other countries, provided that the aerospace sector is excluded, and that attention is directed to sufficiently disaggregated and homogeneous sectors to eliminate any distortions arising from high variability in the propensity to patent.

5.2. Industrial R&D and US patenting

Turning now to a more thorough examination of the US patenting activities of countries other than the USA, table 5 shows, for the same six major sectors as in table 4, the share of ten OECD countries in industrial R&D activities, and in US patenting activity. Table 6 shows the results of correlating these patent shares against the R&D shares. In the chemical, non-electrical machinery, and electrical and electronics sectors, and for the manufacturing sector as a whole, the correlations are very high (in all but one cases more than 0.9), and the results are highly statistically significant. For these sectors, where the bulk of industry-financed R&D and patenting activity is concentrated, both patents and R&D statistics show the same international differences, and this probably reflects innovative activity pretty accurately.

For aerospace, the relationship between the two indicators is very weak; given the earlier results of our analysis, this is not entirely surprising. For other transport and for metals and metal products, the relationship between R&D and patenting shares is stronger than for aerospace, but weaker than for the other sectors. The particularly glaring disparities involve F.R. Germany, Japan and (for other transport) Italy. For both sectors, Germany has a much higher share of patents than R&D whilst the reverse is true for Japan.

This writer can think of three possible explanations for these differences. First, Japanese R&D could be imitative and absorptive, involving few patents; however, as table 5 shows, this is not the case for the more R&D intensive sectors of chemicals, electrical and electronic, and non-electrical machinery. Second, there is the difficulty with the R&D statistics in accurately attributing R&D expenditures amongst sectors; however, since some of the greatest problems of attribution exist between other transport and metals, one would expect a relatively high R&D total in one sector to be compensated by a low figure in the other, and this is clearly not the case for either F.R. Germany or Japan. Finally, there is the problem of aggrega-

[5] This is a widely used method in international trade analysis of measuring the sectors of comparative advantage and disadvantage of each country. The basic formula is $(s_{ij}/\Sigma_i s_{ij}) \div (\Sigma_1^j s_{ij}/\Sigma_1^{ij} s_{ij})$ where s_{ij} is the patenting of the ith country in the jth sector.

Table 5
The percentage distribution of industrial R&D expenditures and of US patenting amongst selected OECD countries in 1975

	Belgium	Canada	France	Federal Republic of Germany	Italy	Japan	Netherlands	Sweden	Switzerland	United Kingdom	Total
Total manufacturing											
US patents	1.2	5.9	10.2	25.8	3.3	27.5	2.6	4.2	6.2	13.2	100.0
Total industrial R&D	1.8	2.2	14.1	24.0	3.4	26.9	4.6	3.2	2.6	17.4	100.0
Industry-financed R&D	2.0	2.1	10.5	22.0	4.9	31.1	3.6	2.9	2.9	12.8	100.0
Industrial R&D manpower	1.9	2.3	12.8	19.6	4.3	32.8	2.9	2.4	1.9	19.1	100.0
Chemicals											
US patents	1.5	3.0	9.9	29.4	3.9	26.3	2.1	1.4	10.6	11.9	100.0
Total industrial R&D	3.3	1.6	11.2	28.7	4.8	24.2	4.9	1.3	5.9	14.0	100.0
Industrial R&D manpower	3.2	1.7	10.5	24.4	4.7	30.9	4.7	1.0	3.5	15.5	100.0
Non-electrical machinery											
US patents	1.5	6.2	10.9	28.7	3.4	29.9	n.a.	5.5	n.a.	13.8	100.0
Total industrial R&D	1.0	3.0	7.9	35.5	3.7	28.1	n.a.	6.7	n.a.	14.3	100.0
Industrial R&D manpower	2.4	2.6	7.3	31.8	3.9	31.8	n.a.	4.5	n.a.	15.5	100.0
Electrical and electronic products											
US patents	0.9	4.7	10.4	23.9	2.6	36.6	5.0	2.7	n.a.	13.4	100.0
Total industrial R&D	2.0	2.9	20.2	25.3	3.3	25.3	4.7	3.0	n.a.	13.3	100.0
Industrial R&D manpower	1.6	2.1	13.5	22.6	3.2	34.3	2.7	1.8	n.a.	18.1	100.0
Aerospace											
US patents	n.a.	4.8	19.0	43.[illegible]	n.a.	n.a.	n.a.	3.5	n.a.	28.8	100.0
Total industrial R&D	n.a.	1.7	29.7	23.3	n.a.	n.a.	n.a.	2.9	n.a.	42.4	100.0
Other transport											
Patents	0.5	5.4	12.8	31.8	2.1	25.8	n.a.	3.4	n.a.	17.8	100.0
Total industrial R&D	0.1	0.4	12.4	22.0	n.a.	39.8	n.a.	n.a.	n.a.	11.7	100.0
Industrial R&D manpower	0.3	0.6	14.2	20.4	10.2	48.0	n.a.	3.8	n.a.	11.5	100.0
Metals											
US patents	1.3	8.6	10.6	26.7	2.8	25.2	n.a.	7.5	n.a.	16.6	100.0
Total industrial R&D	5.3	4.5	10.6	13.3	3.5	46.0	n.a.	5.4	n.a.	12.0	100.0
Industrial R&D manpower	4.4	5.2	10.4	13.1	n.a.	48.1	n.a.	4.9	n.a.	13.6	100.0

Source: For data on R&D see [10]. For data on US patenting see [12].
Method: The categories used for the patent data and the R&D data are not always strictly comparable. They are as follows: *Chemicals*: For R&D data, ISIC 351-354. For patent data, US SIC 28. *Non-electrical machinery*: For R&D data, ISIC 382 and 385. For patent data, US SIC 35 and 38 (except 3825). *Electrical and electronic*: For R&D data, ISIC 383. For patent data, US SIC 36 and 3825. *Aerospace*: For R&D data, ISIC 3845 plus missiles and rockets. For patent data, US SIC 372 and 376. *Other transport*: For R&D data, ISIC 384 less 3845. For patent data, US SIC 371, 373-375, 379 less 3795. *Metals*: For R&D data, ISIC 371, 372 and 381. For patent data, US SIC 33, 34 less 348.

Table 6
Results of correlations of shares of patenting activity in the US against shares of industrial R&D expenditures, for selected OECD countries

Sector	Measure of R&D activity	r_{xy}		t coeff.	Significance (%)
Total manufacturing	Total industrial R&D	0.96	10	9.597	1
	Industrial financed R&D	0.97	10	10.920	1
	Industrial R&D manpower	0.93	10	7.079	1
Chemicals	Total industrial R&D	0.97	10	12.517	1
	Industrial R&D manpower	0.94	10	7.755	1
Non-electrical machinery	Total industrial R&D	0.97	8	10.400	1
	Industrial R&D manpower	0.98	8	14.527	1
Electric and electronic products	Total industrial R&D	0.89	9	5.315	1
	Industrial R&D manpower	0.97	9	12.098	1
Aerospace	Industrial R&D manpower	0.70	5	1.687	20
Other transport	Total industrial R&D	0.77	8	3.012	5
	Industrial R&D manpower	0.77	6	2.377	10
Metals and metal products	Total industrial R&D	0.72	8	2.548	5
	Industrial R&D manpower	0.70	7	2.176	10

Source: For basic data, see table 5.

tion. "Other transport" includes motor vehicles along with other sectors with much higher propensities to patent R&D activities; and as we have seen, metals includes fabricated metal products, where patenting is high, and ferrous and non-ferrous metals, where it is low. The disparity in Italy between low patenting and high R&D can probably be explained by a lesser concentration of innovative activities on high patenting branches within the sectors; equipment other than motor vehicles in "other transport"; fabricated metal products in "metals". The reverse could be true in Japan.

5.3. Per capita innovative activities

Table 7 shows measures of per capita patent shares and industry-financed R&D shares per ten OECD countries. The association between the two measures of per capita innovative effort is very close, with a correlation of 0.82, significant at the 1% level. With both measures, F.R. Germany, Sweden and Switzerland emerge as the strongest countries in per capita terms. At the same time, the data bring out more clearly the structural differences amongst countries. The higher shares of R&D than of patenting for Belgium probably reflects the relative importance of low-patenting ferrous and non-ferrous metals; and for Italy low patenting probably reflects motor vehicles. For similar reasons, the higher shares of patenting than of R&D in Germany and Sweden may reflect the greater importance of fabricated metal products and mechanical engineering, and in Switzerland reflect the drug sector.

Part of the high patenting figure for Switzerland may also reflect R&D activities undertaken in other countries, but patented from Switzerland, for tax or other reasons. And the relatively high patenting share for Canada – and which is clear in all sectors (see table 5) – probably reflects the particular Canadian closeness to, and dependence on, the US market. However, I am unable to find satisfactory explanation for the relatively low US patent share of the Netherlands. I can only speculate that it might have something to do with the policies for the location of R&D, and for patenting, of the five large firms that are dominant in industrial R&D in the Netherlands.

5.4. Trends in innovative activities

Table 8 compares, for nine OECD countries, the rate of increase of US patenting and of industry-financed R&D between 1967 and 1975. It shows that, in all countries except Sweden, US patenting increased faster than R&D, which is consistent with the view of Schiffel and Kitti that increasing foreign patenting in the USA reflects in part growing economic interdependence in addition to increasing R&D activities. However, differences in the rate of increase of US patenting amongst non-US countries reflect quite accurately differences in the rate of increase in industry-

Table 7
Indices of industry financed R&D expenditures per head and patenting per head in ten countries, 1975

	Index of patents per head	Index of industry-financed R&D per head
Belgium	12.2	20.4
Canada	26.2	9.3
France	19.4	20.0
Federal Republic of Germany	41.6	35.5
Italy	6.0	8.8
Japan	25.1	28.4
Netherlands	19.3	26.7
Sweden	51.2	35.4
Switzerland	96.9	45.3
United Kingdom	23.6	22.9

Note and sources: Patent Index = Shares of patents in table 5, per 100 million population.
Population data from: *UN Statistical Yearbook*.
Results of Regression: $r = 0.82$, $t = 4.131$, significant at 1% level.

Table 8
Increases in industry-financed R&D expenditures and of US patenting, 1967–1975

	Industry-financed R&D expenditures, 1975/1967	US patenting 1975/1967
Belgium	1.40	1.64
Canada	0.94	1.38
France	1.27	1.54
Federal Republic of Germany	1.39	1.62
Italy	1.46	1.57
Japan	1.91	4.50
Netherlands	1.08	1.22
Sweden	1.75	1.71
United Kingdom	0.88	1.10

Sources: [10,11].
Results of regression: $r = 0.74$, $t = 2.941$, significant at 10% level.
Spearman rank coefficient = 0.93.

financed R&D over the same period. The correlation between the two measures is 0.74 (significant at the 10% level), and the Spearman rank correlation coefficient is 0.93. In other words, it is very clear from both measures which countries have been increasing their innovative activities faster than others. Japan has increased fastest, followed by Sweden, and then by three countries – Belgium, Italy, F.R. Germany – and then closely by France. Three countries have seen hardly any real increase, and perhaps even a real decrease. This has certainly been the case for the UK, and perhaps also for Canada and the Netherlands.

6. Innovative activity and export shares

One of the attributes of patent statistics, when compared to R&D statistics or innovation counts, is the degree to which they can be disaggregated, and traced back over relatively long periods. This is a very considerable advantage for economic analysis. Together with Soete and other colleagues, I have recently tried to take advantage of this attribute in an analysis of the role of innovation in international trade performance [14]. There is not much point in reproducing in full here what has been published elsewhere. I shall instead describe briefly why the OTAF patent statistics were critical for this work, the method that we used, and the conclusions that we reached.

The basic model that we implicitly set out to test was a simple one, based on developments in the so-called "neo-technology" theories of international trade [22]. These attempt to explain international competitive advantage and trade patterns in terms of the ability to exploit new technology and gain a temporary ability to exploit new technology and gain a temporary monopoly advantage. Work by Vernon and others about ten years ago showed that the pattern of US exports and imports reflected comparative advantage in the R&D intensive industries. It is now demonstrated and widely accepted that, by comparison with the less developed countries, the industrial advanced ones have a comparative advantage in R&D intensive industries. And a considerable effort in the past few years has been devoted to examining whether or not other countries have a more or less "R&D intensive" structure of exports than the USA [3]. The results of these studies have been unsatisfactory in two respects. First, they apply US patterns of R&D intensity to other countries, which may not be justified. Second (and more important), they do not attack an essential question, namely, the degree to which, in specific sectors, differences amongst the industrially advanced countries in innovative activities affect their international competitiveness.

The difficulty faced in answering this second question has resulted in large part from the lack of statistical data enabling reliable international comparisons of innovative activity, sector by sector. R&D statistics are difficult to compare across countries, given that exchange rates do not reflect accurately R&D costs. The Science and Technology Indicators Unit of the OECD has recently made a major step forward in assembling and analysing industrial R&D data for the OECD area [10]. But the price of comparability has been greater aggregation, which makes economic analysis more difficult.

In this context, the data made available by OTAF on patenting by source in more than forty industrial sectors from 1963 to 1976 is of great potential usefulness [12]. On the basis of the analysis above, it is reasonable to assume that, aerospace apart, patenting activity is a good proxy for R&D activity and innovative activity: the relationship between the measures is likely to be particularly close in chemicals, non-electrical machinery, and electrical and electronic products; there may, however, be problems of aggregation in metals and in other transport.

The basic model that we tested is as follows. Other things being equal, a greater flow of successful innovative activities by a firm are likely to result in greater competitiveness, and greater competitiveness to an increased share of world exports. Eventually this share will stabilize as the greater export competitiveness works back through the balance of payments to push up the exchange rate, and to dampen the rate of increase of shares of world exports. The net effect will be higher real income levels and a bigger share of world exports in those countries that have relatively more success-innovative activities.

We then assume that the volume of patenting activity reflects the volume of innovative activity, and that problems of specifying lags between "invention" and "innovation" are spurious ones. In fact, we found that the results of our analysis were

Table 9
Regression results for 40 industries relating per capita exports to per capita US patents

Industry	US SIC	Equation	
		t-value b coeff.	r^2
I. Significant results [a]			
Special industrial machinery	355	12.13	0.89
Drugs	283	12.12	0.89
Metalworking machinery	354	11.99	0.88
Engines and turbines (incl. aero)	351	8.40	0.79
Instruments	38-3825	8.24	0.78
Electrical transmission and distribution equipment	361, 3825	7.88	0.77
Ordnance, guided missiles	348, 376, 3795	7.50	0.75
Electrical industrial apparatus	362	7.30	0.74
Industrial inorganic chemicals	286	5.86	0.64
Office and computing machinery	357	5.42	0.61
Communications and electronic eq.	366, 367	4.49	0.52
Electrical lighting, elec. eq.	365	4.17	0.48
Construction machinery	353	4.13	0.47
Soaps, cleaning products, etc.	284	4.07	0.47
Miscellaneous chemical products	289	3.68	0.42
General industrial machinery	356	3.52	0.40
Fabricated metal products	34 - 3462 3463	3.48	0.39
Industrial organic chemicals	281	2.92	0.31
Motor vehicles	371	2.81	0.29
Petroleum products	13, 29	2.79	0.29
Railroad equipment	374	2.71	0.28
Miscellaneous machinery	359	2.67	0.27
Refrigeration and service machinery	358	2.51	0.25
II. Non-significant results			
Aircraft	372	2.34	0.22
Miscellaneous electrical eq.	369	2.24	0.21
Plastic materials	282	2.21	0.20
Radio and tv receiving eq.	365	2.20	0.23
Electrical household appliances	363	2.16	0.20
Rubber products	30	1.82	0.15
Farm machinery	352	1.62	0.12
Textiles	22	1.59	0.12
Misc. transportation eq.	379-3795	1.53	0.11
Nonferrous metal products	333-336-3398, 3463	1.33	0.09
Stone, clay, glass products	32	1.32	0.08
Ferrous metal products	331, 332, 3399, 3462	1.30	0.08
Agricultural chemicals	287	1.08	0.06
Food	20	0.99	0.05
Motor and bicycles	375	0.61	0.02
Paints and allied products	285	0.52	0.01
Ship and boat building	373	0.47	0.01

[a] Significant at the 2% level.
Source: [18].

insensitive to the lag chosen. For reasons of convenience, we therefore chose to use accumulated patent data for the period 1963 to 1976. For the OECD countries (excluding the USA), we then regressed per capita exports in 1974 against per capita patents in the forty sectors for which the US patenting data are available.

The results of these regressions are shown in

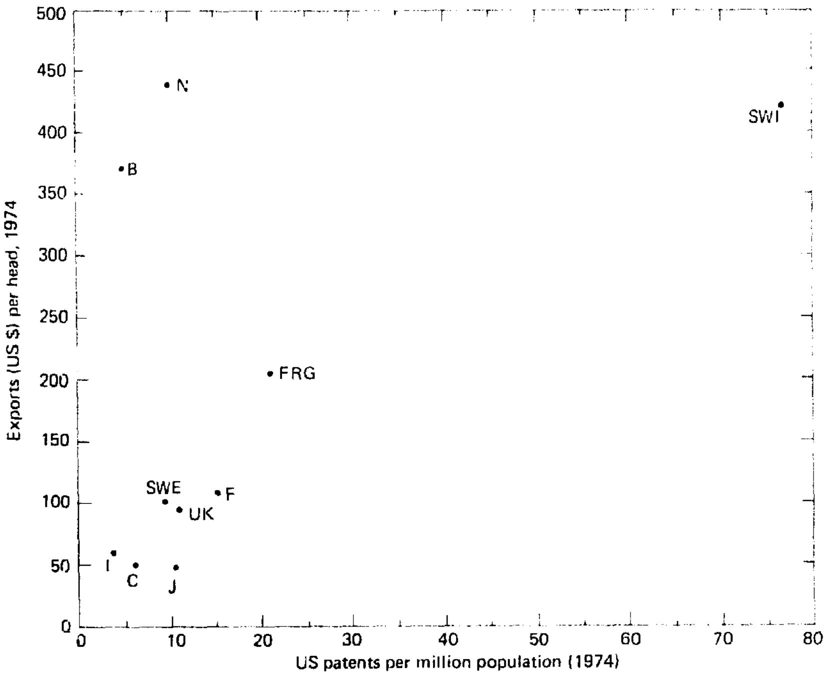

Fig. 1. Export performance and US patenting: chemicals (US SIC Code 28). *Source*: [14].

US patents per million population (1974)
Key: B = Belgium/Luxembourg; C = Canada; F = France; FRG = F.R. Germany; I = Italy; J = Japan; N = Netherlands; SWE = Sweden; SWI = Switzerland; UK = United Kingdom.

Findings:
$r^2 = 0.28$ for all 10 countries (significant at 0.20 level).
$r^2 = 0.94$ excluding Belgium/Luxembourg and The Netherlands (significant at 0.01 level).
$r^2 = 0.76$ excluding Belgium/Luxembourg, The Netherlands, and Switzerland (significant at 0.01 level).

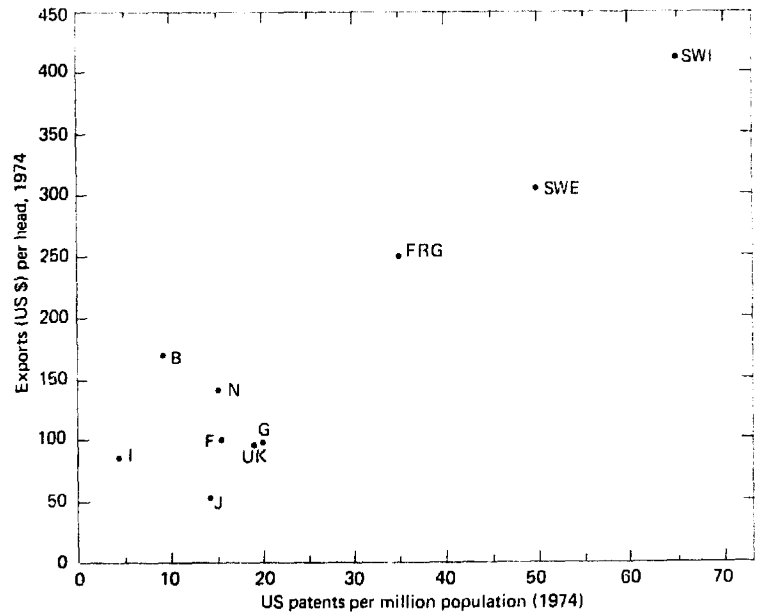

Fig. 2. Export performance and US patenting: non-electrical machinery (US SIC Code 35). *Source*: [14].

US patents per million population (1974)
Key: see Fig. 1.
Finding:
$r^2 = 0.85$ for all 10 countries (significant at 0.01 level).

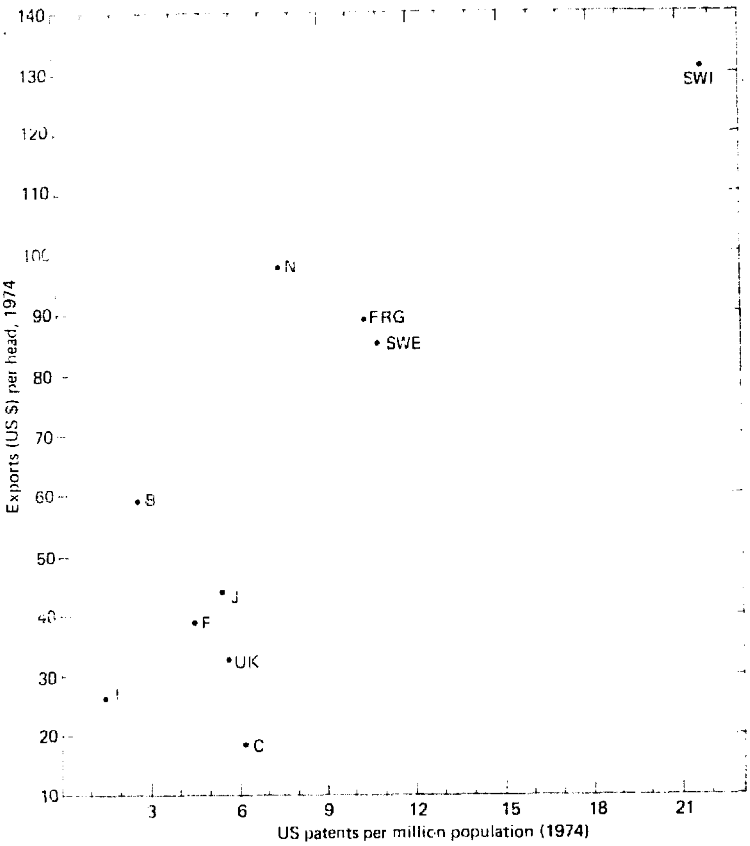

Fig. 3. Export performance and US patenting: electrical products (US SIC Codes 361, 364, 369, 3825). *Source*: [14].

US patents per million population (1974)
Key: see Fig. 1.
Findings:
$r^2=0.66$ for all 10 countries (significant at 0.01 level).
$r^2=0.43$ excluding Switzerland (significant at 0.10 level).

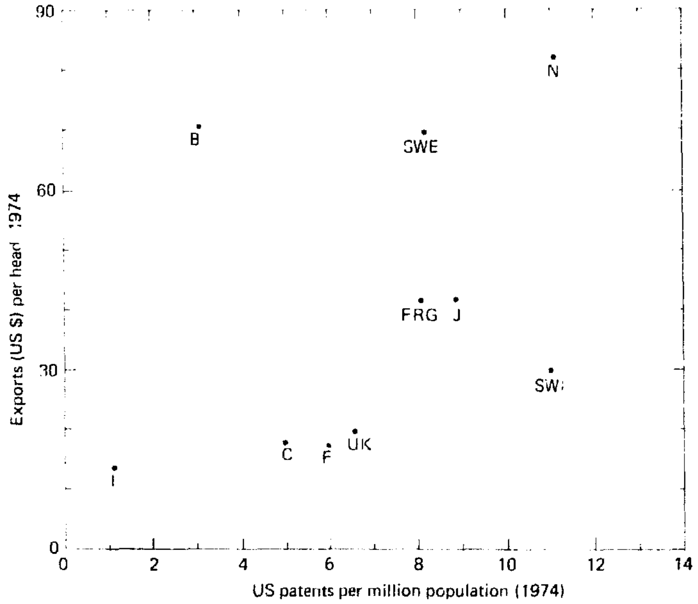

Fig. 4. Export performance and US patenting: electronic products (US SIC Codes 365–367). *Source*: [14].

US patents per million population (1974)
Key: see Fig. 1.
Findings:
$r^2=0.21$ for all 10 countries (significant at 0.20 level).
$r^2=0.56$ excluding Belgium/Luxembourg (significant at 0.05 level).

table 9. As we would expect from previous studies, significant r^2 were found for the chemicals, electrical and electronic sectors. More important, they were also found for most non-electrical machinery sectors. As we might also expect, non-significant r^2 were found for traditional non-durable consumer goods, and for traditional process industries.

However, some care must be taken in interpreting these regressions, given that smaller countries have a stronger propensity to export than bigger ones, and that their patenting and export activities are more heavily influenced by the behaviour of multinational firms. This is illustrated clearly in figs. 1 to 4 which show per capita export shares and patent shares for ten major OECD countries (other than the USA) in four more aggregated sectors: chemicals, electronics, mechanical engineering and motor vehicles. [7] After examining these influences, we have concluded that innovation is an important element in competitiveness in nearly all chemicals, capital goods and durable consumer goods. This covers a much wider range of products than has recently been assumed in analyses by Kelly and others to be "innovation-intensive" [3].

7. Conclusions

The above analysis confirms some widely held views, qualifies others, and challenges yet others. Its main conclusions can be summarised as follows.

Differences amongst firms: Small firms tend to patent more per unit R&D expenditure than do large firms. Previous work using patent statistics alone as a proxy measure for innovative activities, and concluding that there are diminishing returns in terms of innovative activities to increasing firm size, may well be mistaken. Using the R&D measure alone, Soete has recently arrived at very different conclusions [19]. In addition, the observable reduction over time in patenting activity may be a consequence not of diminishing R&D productivity, but of increasing industrial concentration.

Differences amongst industries: Both R&D and patent statistics show heavy concentrations of innovative activities in the chemicals and the electrical and electronics industries. However, R&D statistics also show heavy concentration in aerospace and motor vehicles, whilst patent statistics show heavy concentrations in non-electrical machinery and fabricated metal products. This is probably in part because patent statistics do not satisfactorily reflect innovative activities in aerospace and motor vehicles, nor R&D statistics in non-electrical machinery and fabricated metal products. It is also probably because R&D comprises a relatively high degree of routine testing in motor vehicles (and aerospace?), whilst a relatively high proportion of easy and trivial patents are made in mechanical engineering and fabricated metal products.

In any event, it is mistaken and misleading to treat (as is often done) non-electrical machinery and fabricated metal products as "traditional" or "non-innovative" industries. Their patenting intensity is high, and their R&D intensity has been growing rapidly in the USA since the 1960s. Their exclusion from many of the lists of R&D intensive products results in over estimations of the innovation-intensity of the exports of countries with big aerospace industries (i.e. the UK and the USA), and underestimations of export innovation-intensity in countries with strong mechanical engineering industries (i.e. F.R. Germany, Sweden and Switzerland).

Differences amongst countries: Available patent data do not enable R&D and patent statistics to be used together to asses the level of US innovative activities compared to other countries. However, together they show that, in the OECD area, the USA is at a comparative disadvantage in chemicals and transport equipment other than aerospace, and is at the international norm in engineering (electronic, electrical and non-electrical) industries, whilst the R&D data show a strong US comparative advantage in aerospace. Amongst the other countries, F.R. Germany, Sweden and Switzerland have relatively high innovative activities, whilst those of Japan and Sweden were growing most rapidly in the late 1960s and early 1970s.

[7] In chemicals, the position of Belgium and Netherlands reflect the geographical advantages of Antwerp and Rotterdam; in electronics, Belgium's position probably reflects investment by the Dutch Philips and other foreign electronics companies. In motor vehicles, the positions of Belgium and Canada reflect investment by foreign car manufacturers.

Innovative activities and export competitiveness: Analysis based on both R&D and patent statistics shows that innovative activity is an important determinant of export competitiveness in a wider range of industrial sectors than is commonly assumed: not only chemicals, electronic and electrical products, but also non-electrical machinery, fabricated metal products and motor vehicles.

Differences between the R&D and the patent measure: Four sets of factors can explain the different results reached when using the R&D and the patent measure: first, competitive behaviour, with smaller firms making relatively greater use of patents to protect their temporary, innovative monopolies; second, increasing specialisation and formalisation of innovative activities in and around R&D departments as firms get bigger and more innovation-intensive; third, the complexity and ambition of innovative tasks undertaken inside and outside R&D laboratories; fourth, the special circumstances of the aerospace and motor vehicles industries. Each of these explanations is consistent with the available data. Nearly all have an explanatory power that is statistically significant yet low. No one of the explanations dominates in most cases.

Further explorations: Further work along the above lines should be undertaken on a number of subjects:

(a) A better understanding of the relationships amongst R&D, patenting and innovations can be pursued in two directions: first, through comparisons of patent and R&D statistics with statistics on populations of innovations; second, through more detailed studies within industrial firms of the relationships amongst R&D, patenting and innovations. It is clear from the above analysis that many aspects of the relationships are industry-specific: compare, for example, chemicals with non-electrical machinery. Some may be of broader significance: for example, the general slowdown in patenting activity since the early 1970s.

(b) A more detailed knowledge of trends in innovative activities in the USA compared to those in other countries, is very necessary. Some headway can still be made using the OECD international comparisons of industrial R&D activities, and the detailed data published on patenting activity in the USA. The most promising new source of information is patenting statistics in Europe and other parts of the world. But tedious work needs to be done to convert these statistics to the standard classifications used in applied economic analysis.

(c) Further analysis needs to be done on the influence of innovation on international competitiveness and industrial location. More systematic data on investment, unit prices and the international diffusion of technology should be included in such an analysis, which should be dynamic in nature rather than static.

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