Economics of Innovation and New Technology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gein20

National Innovation Systems: Why They Are Important, And How They Might Be Measured And Compared

Parimal Patel [a] & Keith Pavitt [a]

[a] Science Policy Research Unit, University of Sussex, Falmer, Brighton, BN1 9RF, UK

Version of record first published: 28 Jul 2006

Econ. Innov. New Techn., 1994, Vol. 3, pp. 77–95
Reprints available directly from the publisher
Photocopying permitted by licence only

NATIONAL INNOVATION SYSTEMS: WHY THEY ARE IMPORTANT, AND HOW THEY MIGHT BE MEASURED AND COMPARED

PARIMAL PATEL and KEITH PAVITT*

Science Policy Research Unit, University of Sussex, Falmer, Brighton, BN1 9RF, UK

(Received 3 February 1994)

We shall argue that the notion of "national systems of innovation" is a useful one, since it treats explicitly what was ignored in earlier models of technical change: namely, deliberate "intangible" investment in technological learning activities that involve a variety of institutions (principally business firms, universities, other education and training institutions, and governments), links amongst them and associated incentive structures and competencies. Considerable diversity - indeed divergence - exists amongst OECD countries in the level and sectoral pattern of business investments in technological learning, and in the quality of support structures in basic research and workforce skills.

Some of this international "diversity" is not economically and socially desirable: in particular, persistently low investment in business R & D and related technological activities, and in associated workforce skills, which help determine both long-term economic growth rates, and the level of national demand for basic research and associated training activities. Other elements of international "diversity" can be seen as inevitable or desirable: in particular, differing national patterns of technological specialisation that reflect cumulative and localised paths of technological learning, and that strongly influence patterns of structural change and comparative advantage in trade.

KEY WORDS: Innovation, national systems, technological learning

1. WHY NATIONAL SYSTEMS OF INNOVATION ARE IMPORTANT

As is well known, policies and perceptions are influenced not only by events, experience and evidence, but also by mental models moulded in part by the concepts of theorists. Thus, in the 1960s and early 1970s, models of technical change and related policies were heavily influenced by the analyses of Arrow (1962a and b) and Salter (1966). Technical change comprised three elements:

- "embodied" technical change resulting from investment in better practice vintages of machinery;
- "disembodied" technical change resulting from the relatively costless diffusion of knowledge as codified "information";

*This paper draws heavily on research undertaken in the ESRC (Economic and Social Research Council) - funded Centre for Science, Technology, Energy and the Environment Policy (STEEP) in the Science Policy Research Unit, University of Sussex. A shorter version will be published in the OECD STI Review. We benefited greatly in its preparation from comments by Michel Quere, and from time spent by one of us (KP) at LATAPSES, CNRS - Universite de Nice, Sophia Antipolis.

- "disembodied" technical change with productivity increases resulting from "learning by doing" — a costless external benefit from production experience.

As a consequence, it was commonly assumed that the combination of buoyant demand and an open trading system would allow the rapid international diffusion of technology, in the form of easily transmissible information (e.g. blueprints and operating instructions), improvements embodied in machinery, and the learning benefits of production experience. The catching up of Western Europe and Japan to the levels of technology and efficiency of the world's leading country (the USA) would therefore be relatively smooth.

These expectations have not been fulfilled, since there has also been uneven development amongst countries. Some (e.g., the UK) have caught up only very partially, whilst others (e.g. FR Germany and Japan) have actually overtaken the world's technological leading country — the USA — in certain important sectors (Nelson, 1990a); these differences are reflected in the technological and competitive performance of companies (Patel & Pavitt, 1991a and b).

This is because the international diffusion of technology is neither automatic nor easy (Bell & Pavitt, 1993). Both material artefacts and the knowledge to develop and operate them are complex, involving multiple dimensions and constraints in performance, that cannot be reduced to codified "information", whether in the form of operating instructions, or predictive models and theories. Tacit knowledge — underlying the ability to cope with complexity — is acquired essentially through experience, and trial and error (Kline, 1991). But it is misleading to assume that such trial and error is either random, or a purely costless by-product of other activities like "learning by doing". As technological activities over time have become increasingly specialised, complex and roundabout, tacit (and other forms of) knowledge are increasingly acquired within firms through deliberate and often costly investment in what can be called "change-generating" activities, such as product design, production engineering, quality control, staff training, research, and/or the development and testing of prototypes and pilot plant (Bell & Pavitt, 1993).

Differences amongst countries in the resources devoted to such deliberate learning — or "technological accumulation" — have led to international technological gaps which, in turn, have led to international differences in economic performance. The "neo-technology" theories of trade and growth pioneered by Posner (1961) and Vernon (1966) in the 1960s have been amply confirmed in the OECD countries by the events of the 1970s and 1980s, by related econometric analyses of Soete (1981) and Fagerberg (1987; 1988), and by the company-based analyses of Franko (1989), Cantwell (1989), and Geroski *et al.* (1993): hence the growing interest in implications of international technology gaps for policy (Ergas, 1984) and for theory (Dosi *et al.*, 1990).

Given this historical experience, the notion of "national systems of innovation" must be welcomed as a serious attempt:

- to define and describe the nature and determinants of the explicit — though intangible — investments made by countries and companies in learning activities that promote and manage technical change;

- to measure and explain the important differences amongst countries in the levels and patterns of these investments.

2. HOW NATIONAL SYSTEMS OF INNOVATION MIGHT BE DEFINED

Efforts in the 1960s to explain differences in the rate and direction of technical change amongst sectors, firms and countries in terms of differences in the pattern of demand turned out to be unsatisfactory, because they neglected varying elasticities on the supply side.[1] Considerable progress has been made since then in conceptualising the supply side in terms of differences amongst *sectors* in the range of technological opportunities (Nelson & Winter, 1982), amongst *firms* in their dynamic competencies (Teece *et al.*, 1990), and amongst *countries* in their national systems of innovation.

Given that countries are more complex than either firms or sectors, the pioneering contributions to defining national systems of innovation — by Freeman (1988), Lundvall (1988) and Nelson (1993) — have been deliberately descriptive. However, in an earlier paper on the dynamics of capitalism, Nelson (1990b) made two important analytical points. First, he commended Schumpeter for stressing the importance of competition through innovation — and of the associated incentive of the prospect of temporary monopoly profits — in the growth of capitalist output and productivity. Second, he criticised Schumpeter for simplistic notions of how innovations are developed and commercialised, and in particular, for his neglect of networks of public and private institutions (such as universities) that support the development of innovations by business firms. In other words, he defined the importance of certain *incentives* and of certain *institutions* that are central to the process of accumulating technological *competencies*.

Our own concept of a national system of innovation builds on these earlier contributions, and can be defined as follows: *the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change-generating activities) in a country.*

But this definition remains very broad and begs two major questions:

- *Which* institutions, incentives and competencies are important for national systems of innovation?

- What are the important *differences* amongst countries in the rate and direction of technological accumulation?

We shall spend the rest of the paper trying to answer these two questions.

2.1 *Institutions*

Four sets of institutions — and of related activities — are widely recognised as central features of national systems of innovation in all countries:

- *business firms*, especially those investing in change-generating activities;

- *universities* and similar institutions, providing basic research and related training;

[1] See in particular, the critiques of Schmookler (1966) by Rosenberg (1976) and Walsh (1984), of demand-determined models by Mowery and Rosenberg (1979), and Vernon's recognition that his explanation of international differences in technological activities based on relative wage rates was inadequate (1966, 1979).

- a mixture of *public* and *private institutions*, providing general education and vocational training;

- *governments*, financing and performing a variety of activities that both promote and regulate technical change.

2.2 *Incentives*

Economic analysis has been particularly useful and influential in exploring the implications of incentive structures for the activities — and the institutions — generating technological learning.

- The economic case for *government support for basic research* (given non-appropriability and non-depletability) is accepted in all countries. Less attention has been devoted to another "market failure", namely, in *firm-based training* (including training in change-generating activities) when employees are mobile between firms.

- The difficult balance between the incentive of temporary monopoly profits for *innovation*, and the pressure of competition for *imitation* has also been widely recognised and analysed in market economies. The inadequate nature of such incentives in the previously centrally planned economies was a major reason for their lack of technological accumulation (Hanson & Pavitt, 1987).

- However, until recently, little attention has been devoted to exploring the effects of incentive structures on *international differences* in the rate and direction of technological activities amongst advanced market economies (to be illustrated later in this paper). One welcome exception is Porter (1990), who stresses the importance of the local supply of *skills*, specific local *demands*, and the pressure of *competition.*

2.3 *Competencies*

It is now widely recognised that one major reason for observed *international* differences in growth and trade performance is the existence of international technology gaps: in other words, international differences in technological competence resulting from differences in the volume and sectoral pattern of R & D and related activities. At the same time, notions of *inter-firm* differences in competence have received little analytical attention in mainstream industrial economics, even though empirical evidence shows clearly that, at any point in time, firms differ greatly:

- in the range of goods and services they are able to provide;

- within each range, in the efficiency of their provision;

- in the range of possible paths of change in the future.

The recently developed "dynamic competencies" view of the firm makes these properties of business firms central to their analysis (see, in particular, Teece *et al.*, 1990), and widens the notion of competencies to include the organisation and managerial, as well as the technological, dimensions of the management of change.[2]

3. COMPARING NATIONAL SYSTEMS OF INNOVATION

3.1 *The Promise and Problems of Measurement*

There are very real difficulties in measuring and comparing technological accumulation across firms, sectors and countries. As we have seen, the activities contributing to technological accumulation are complex and varied, encompassing basic research in universities at one end of the spectrum, and routine tinkering in production, at the other. If only for this reason, all measures are bound to be imperfect. However, as a result of the growing demands from public and private policy-makers for better data, progress has been made in both measurement and conceptualisation. The advantages and drawbacks of the various measures have been extensively reviewed elsewhere (Freeman, 1987; Grilliches, 1990; Patel & Pavitt, 1994; van Raan, 1988).

In order to answer the questions posed in this paper, it is possible to make useful international comparisons amongst OECD countries of the change-generating activities of the major institutions in national systems of innovation.

- For *business firms*, there are data on R & D activities performed by business firms, and on patents granted in the USA according to their country of origin. We have shown in our earlier work that the combined use of R & D and US patenting data gives a plausible and consistent picture of technological activities at the world's technological frontier (Patel & Pavitt, 1991b). The one drawback of both measures (and of all the others available) is that they measure only very imperfectly change-generating activities in software technology.

- For *universities* and related institutions, there are data on R & D inputs, and on outputs in the form of numbers of papers published, and of citations made to them by scientific peers.

- For *educational institutions*, there are census-based data on the qualifications of the population, and a widening range of international comparisons of educational attainment of pupils at different ages and in different subjects.

[2] Differences in "competencies" amongst firms, groups within firms, or amongst countries cannot — in our framework — be reduced to either "barriers to entry" or to "information asymmetries", given the central importance of tacit (i.e. uncodifable) knowledge. We propose that economists and other analysts adopt the same model for business firms that they apply in practice to their colleagues and students, and to their favourite sporting and artistic activities. Namely, sustained differences in performance do not result from withholding easily transmissible information, but from differences in accumulated competencies, caused in part by differences in innate ability, but mainly by differences in conscious investment in learning activities.

3.2 Business Firms

Business-funded R & D. One widely used measure of national investment in change-generating activities is the share of Gross Domestic Product spent by business on R & D activities. Table 1 compares this measure in 17 OECD countries since 1967. It shows a certain stability in the rankings throughout the period at the two ends of the spectrum: Switzerland has remained with the highest share, and Ireland, Spain and Portugal with the three lowest shares. Otherwise there are countries who started near the top but have moved down the rankings: Canada, Netherlands and — above all — the UK; there are also countries that have improved their positions: FR Germany, Sweden, Japan and — above all — Finland. Overall, there are no statistical signs of convergence in the industry-funded shares over time, since the standard deviation of the distribution has not decreased over the period: on the contrary, it has increased markedly in the 1980s, suggesting technological divergence amongst countries.[3]

In this context, it is worth noting that the US share began slipping progressively below that of FR Germany, Japan, Sweden and Switzerland in the 1970s, and that the gap grew much larger in the 1980s. These four leading countries are also those where new technologies find rapid and wide acceptance (G. Ray, 1989). This comes as no surprise in our analytical framework, where R & D is seen as part of wider processes of learning, as well as the discovery of new things.

Table 1 Trends in industry financed R&D as a percentage of GDP in 17 OECD countries: 1967 to 1991

	1967	*1969*	*1971*	*1975*	*1977*	*1979*	*1981*	*1983*	*1985*	*1987*	*1989*	*1991*
Belgium	0.66	0.64	0.71	0.84	0.91	0.95	0.96	1.02	1.09	1.16	1.14	1.16
Canada	0.40	0.39	0.38	0.33	0.32	0.39	0.49	0.45	0.56	0.57	0.54	0.59
Denmark	0.34	0.39	0.41	0.41	0.41	0.42	0.46	0.53	0.60	0.66	0.71	0.85
Finland	0.30	0.32	0.44	0.44	0.49	0.53	0.62	0.72	0.89	0.98	1.07	1.07
France	0.60	0.64	0.67	0.68	0.69	0.75	0.79	0.88	0.92	0.92	0.98	0.99
FR Germany	0.94	1.03	1.13	1.11	1.12	1.32	1.40	1.48	1.65	1.80	1.78	1.57
Ireland	0.19	0.23	0.30	0.23	0.22	0.23	0.26	0.27	0.35	0.40	0.45	0.58
Italy	0.33	0.38	0.44	0.43	0.37	0.40	0.43	0.42	0.49	0.49	0.56	0.61
Japan	0.83	1.00	1.09	1.12	1.11	1.19	1.38	1.59	1.81	1.82	2.05	2.13
Netherlands	1.12	1.04	1.02	0.97	0.87	0.86	0.83	0.89	0.96	1.11	1.07	0.91
Norway	0.35	0.39	0.41	0.49	0.49	0.50	0.50	0.61	0.80	0.88	0.81	0.77
Portugal	0.04	0.06	0.09	0.05	0.04	0.09	0.10	0.11	0.11	0.11	0.14	0.14
Spain	0.08	0.08	0.11	0.18	0.18	0.18	0.18	0.22	0.25	0.29	0.34	0.38
Sweden	0.71	0.69	0.80	0.96	1.07	1.11	1.24	1.45	1.71	1.74	1.68	1.71
Switzerland	1.78	1.78	1.67	1.67	1.71	1.74	1.68	1.67	2.16	2.13	2.07	2.07
United Kingdom	1.00	0.92	0.81	0.80	0.80	0.82	0.91	0.86	0.95	1.02	1.04	0.94
United States	0.99	1.03	0.97	0.98	0.98	1.05	1.17	1.31	1.42	1.37	1.36	1.36
Standard Deviation												
All Countries	0.46	0.46	0.43	0.43	0.45	0.47	0.48	0.52	0.61	0.61	0.60	0.58
Excluding US	0.47	0.46	0.43	0.44	0.45	0.47	0.48	0.52	0.62	0.62	0.62	0.59

Source: OECD.

[3] Verspragen and Soete (1993) have similarly detected the end of convergence in productivity in the 1980s.

Table 2 Shares of West European Patenting in the US: 1963 to 1990

	1963-68	*1969-74*	*1975-80*	*1981-85*	*1986-90*
Germany	34.21	36.37	38.60	41.56	41.35
France	13.62	14.46	14.46	14.70	15.20
United Kingdom	25.15	21.36	17.93	15.66	14.94
Switzerland	8.78	8.58	9.00	8.05	7.08
Italy	4.34	4.85	4.98	5.50	6.36
Netherlands	4.74	4.43	4.45	4.68	4.88
Sweden	5.31	5.25	5.70	5.03	4.61
Belgium	1.65	1.94	1.78	1.62	1.65
Finland	0.25	0.47	0.72	1.04	1.37
Denmark	0.94	1.09	1.04	0.99	1.00
Spain	0.42	0.49	0.57	0.42	0.65
Norway	0.51	0.54	0.64	0.56	0.63
Ireland	0.06	0.13	0.11	0.16	0.25
Portugal	0.03	0.04	0.02	0.03	0.03
	100.00	100.00	100.00	100.00	100.00

Source: Data supplied to SPRU by the US Patent & Trademark Office.

European Shares of US Patenting. Table 2 shows that, even within the European framework, there is no sign of technological convergence patenting in the USA. Again we see relative decline of the UK, and the spectacular relative growth of Finland. We also see more clearly the absolute technological strength of Germany, which has increased its share of the total to more than 40%, and has diverged steadily from the other three countries of equivalent size: France, Italy and the UK.

Sectoral Composition of National Technological Activities. So far, we have compared countries' aggregate technological performance. Table 3 summarises the sectoral patterns of technological advantage of the USA, Western Europe and Japan. Based on the US patent classifications, it divides technologies into 11 fields. The content of most of them will be clear from their titles: technologies for extracting and processing raw materials are related mainly to food, oil and gas; defence-related technologies are defined as aerospace and munitions. For each country-region and technological field, we have calculated an index of "Revealed Technology Advantage" (RTA) in 1963–68 and 1985–90.[4]

Table 3 shows markedly different patterns and trends amongst the three main, technology-producing regions of the world in their fields of technological advantage and disadvantage. The USA has seen rapid decline in motor vehicles and consumer electronics; growing relative strength in technologies related to weapons, raw materials and telecommunications; and an improving position in chemicals. In Japan, almost the opposite has happened: growing relative strength in electronic consumer and capital goods and motor vehicles, together with rapid relative decline in chemicals, and continued weakness in raw materials and weapons. In Western Europe, the pattern is different again, and very close to that of its dominant country — FR Germany: continuing strength in chemicals,

[4] RTA is defined as a country's or region's (or firm's) share of all US patenting in a technological field, divided by the same country's share of all US patenting in all fields. An RTA of more than one therefore shows a country's or region's relative strength in a technology, and less than one its relative weakness. This measure corresponds broadly to the measure of revealed comparative advantage used in trade analysis.

Table 3 Sectoral patterns of revealed technological advantage: 1963-68 to 1985-90

	United States		*Japan*		*Western Europe*	
	1963-68	*1985-90*	*1963-68*	*1985-90*	*1963-68*	*1985-90*
Fine Chemicals	0.89	0.97	2.95	0.72	1.34	1.33
Industrial Chemicals	0.93	0.98	1.62	0.92	1.29	1.19
Materials	1.04	0.95	1.02	1.42	0.86	0.83
Non-Electrical Machinery	1.01	0.99	0.77	0.85	0.99	1.13
Motor Vehicles	0.89	0.55	0.83	2.21	1.48	1.02
Electrical Machinery	1.00	1.01	1.17	1.08	1.00	0.92
Electronic Capital Goods	1.02	0.97	1.47	1.65	0.92	0.61
Telecommunications	1.03	1.04	1.06	0.97	0.91	0.94
Electronic Consumer Goods	0.94	0.65	1.99	2.50	1.26	0.59
Raw Materials Based Technologies	1.08	1.28	0.44	0.37	0.61	0.83
Defence Related Technologies	0.99	1.15	0.36	0.09	1.14	1.40

Notes: For the definition of the Revealed Technology Advantage Index see Footnote 4 in the text.
For a definition of Western Europe Table 2.
Source: Data supplied to SPRU by the US Patent & Trademark Office.

growing strength in weapons, continued though declining strength in motor vehicles, and weakness in electronics.

Table 4 examines the similarities and differences amongst countries' technological specialisations in greater and more systematic detail.[5] It uses correlation analysis to measure both the stability over time of each country's sectoral strengths and weaknesses in technology (first row), and the degree to which they are similar to those of other countries (correlation matrix). The first row shows that, with five exceptions (Australia, Ireland, Italy, Portugal and the UK), most OECD countries have a statistically significant degree of stability in their technological strengths and weaknesses between the 1960s and the 1980s: 10 at the 1% level, and a further 4 at the 5% level, thereby confirming the path-dependent nature of national patterns of accumulation of technological knowledge.

The correlation matrix also confirms the differentiated nature of technological knowledge, with the very different strengths and weaknesses in Japan, the USA and Western Europe: each is negatively correlated with the other two, and significantly so in two cases out of three (the USA with the other two regions). More generally, it confirms that countries tend to differ markedly in their patterns of technological specialisation.[6] Of the 171 correlations amongst pairs of countries in Table 4, only 32 (19%) are positively and significantly correlated at the 5% level, of which 14 at the 1% level. Amongst the latter, we find FR Germany similar to Switzerland (chemicals and machinery), and Canada similar to Australia, Finland and Norway (raw material-based technologies). Japan has a unique pattern of specialisation, with no significant positive correlations with other countries, but plenty of negative ones.

The Role of Large Firms. Large firms play a major role in national systems of innovation. This conclusion is based on data that we have compiled on more than 600 of the

[5] For the purpose of this analysis, each country's RTA was calculated for 34 technical fields. These can be aggregated into the 11 fields shown in Table 3.

[6] Archibugi and Pianta (1992) also find that the degree of national technological specialisation is increasing over time.

Table 4 Stability and similarities amongst countries in their sectoral specialisations: correlations of revealed technology advantage indices across 34 sectors

Stability: Correlations Over Time: 1963-68 to 1985-90

Australia	*Austria*	*Belgium*	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Neth'land*	*Norway*	*Portugal*	*Spain*	*Sweden*	*Swl'land*	*UK*	*USA*
0.28	0.76*	0.54*	0.67*	0.47*	0.59*	0.82*	0.35*	0.05	0.32	0.45*	0.66*	0.35*	0.25	0.53*	0.73*	0.83*	0.23	0.55*

Similarities: Correlations Amongst Countries: 1985-90

	Australia	*Austria*	*Belgium*	*Canada*	*Denmark*	*Finland*	*France*	*Germany*	*Ireland*	*Italy*	*Japan*	*Neth'land*	*Norway*	*Portugal*	*Spain*	*Sweden*	*Swl'land*	*UK*	*USA*
Austria	0.36*																		
Belgium	–0.09	–0.14																	
Canada	0.52*	0.47*	0.05																
Denmark	0.18	–0.03	0.33*	0.32															
Finland	0.47*	0.45*	0.20	0.54*	0.45*														
France	–0.27	–0.16	0.10	–0.14	0.10	–0.15													
Germany	0.27	0.05	0.22	–0.18	0.21	0.32	0.29												
Ireland	0.07	–0.10	0.09	0.21	0.14	0.03	–0.09	–0.31											
Italy	0.28	0.28	0.06	0.34*	0.30	0.53*	–0.23	0.22	0.28										
Japan	–0.43*	–0.07	0.06	–0.44*	–0.22	–0.26	–0.44*	–0.20	–0.13	–0.13									
Netherlands	–0.24	–0.18	–0.03	0.06	–0.04	0.07	–0.33*	–0.38*	0.27	0.08	0.24								
Norway	0.36*	0.36*	–0.20	0.62*	0.22	0.28	0.02	–0.12	0.02	–0.03	–0.50*	–0.23							
Portugal	0.32	0.48*	0.17	0.31	0.11	0.43*	–0.09	0.15	0.11	0.35*	–0.20	–0.04	0.06						
Spain	0.32	0.13	–0.11	0.34*	0.68*	0.38*	0.00	0.28	–0.07	0.38*	–0.23	–0.28	0.41*	0.20					
Sweden	0.25	0.46*	–0.05	0.38*	0.40*	0.53*	0.36*	0.26	–0.07	0.19	–0.38*	–0.35*	0.30	0.30	0.45*				
Switzerland	0.35*	–0.12	0.11	–0.21	0.01	0.07	0.06	0.72*	–0.12	0.17	–0.19	–0.26	–0.14	0.04	0.13	–0.04			
UK	0.08	–0.15	–0.04	–0.10	0.40*	0.03	0.23	0.30	–0.02	–0.03	–0.34*	–0.20	0.17	0.00	0.32	0.10	0.20		
USA	0.22	–0.03	–0.20	0.42*	–0.02	–0.01	0.23	–0.37*	0.25	–0.09	–0.81*	–0.03	0.50*	0.06	–0.02	0.13	–0.26	0.11	
W Europe	0.26	0.04	0.21	–0.08	0.33*	0.34*	0.49*	0.93*	–0.19	0.27	–0.41*	–0.37*	–0.02	0.17	0.35*	0.39*	0.73*	0.45*	–0.19

Notes: For the definition of the Revealed Technology Advantage Index see Footnote 4 in tthe text.
For a definition of Western Europe Table 2.
* Denotes Correlation Coefficient significantly different from zero at the 5% level.

Table 5 Nationalities of the Top 20 Firms in US Patenting: 1986-90

	Japan	*United States*	*West Europe*
Defence Related Technologies	0	15	5
Raw Materials Based Technologies	1	17	3
Fine Chemicals	1	12	7
Industrial Chemicals	1	11	8
Materials	6	11	3
Telecommunications	6	9	4
Electrical Machinery	7	10	3
Electronic Capital Goods	7	10	3
Non-Electrical Machinery	9	8	3
Motor Vehicles	12	4	5
Electronic Consumer Goods	14	4	2

Note: For a definition of Western Europe Table 2.
Source: Data supplied to SPRU by the US Patent & Trademark Office.

world's largest, technologically active firms, as measured by their patent activity in the USA (Patel & Pavitt, 1991a and b). We have shown the following:

- The share of these large firms in the world's technological activities varies greatly amongst fields. For all fields combined, it is about 49%, but the share increases to nearly 70% in electronic capital and consumer goods, and to more than 60% in motor vehicles, and more than 50% in fine and industrial chemicals, materials and telecommunications. Mechanical engineering (including instruments) is the field with the smallest share.

- The technological strengths and weaknesses of each region, shown in Table 3, are in general reflected in the number of nationally based large firms appearing in the ranking of the world's top 20 firms in terms of US patenting in Table 5. Thus, Japanese firms make up 12 of the top 20 firms in motor vehicles and 14 in consumer electronics and photography, US firms make up 17 of the top 20 in raw materials and 15 in defence, whilst European firms have their largest numbers in chemicals.

- In addition to the fields of technological specialisation, both the level and the rate of growth of national technological activities are reflected in those of large firms (Patel & Pavitt, 1991a). This is because an overwhelming proportion of the technological activities of the world's largest firms continues to be performed in their home country (Patel, 1994). Table 6 shows that, in the second half of the 1980s, 89% of the technological activities of the world's largest firms continued to be performed in their home country — a 1% decrease over the previous five-year period. Table 6 also shows that the foreign technological activities of large firms are not globalised, but concentrated almost exclusively in the "triad" countries — especially the USA and Europe (and, more specifically, Germany).

All this suggests that — trends towards globalisation notwithstanding — national systems of innovation still matter. We shall now present briefly some comparative data on important dimensions such national systems, where public institutions — rather than business firms — play a major role: basic research, and education and skills.

Table 6 Geographic location of large firms' US patenting activities, according to nationality: 1985-90

Percentage Shares

Firms' Nationality	*Home*	*Abroad*	*Of which USA*	*Europe*	*Japan*	*Other*
Japan (143)	98.9	1.1	0.8	0.3	–	0.0
USA (249)	92.2	7.8	–	6.0	0.5	1.3
Italy (7)	88.1	11.9	5.4	6.2	0.0	0.3
France (26)	86.6	13.4	5.1	7.5	0.3	0.5
Germany (43)	84.7	15.3	10.3	3.8	0.4	0.7
Finland (7)	81.7	18.3	1.9	11.4	0.0	4.9
Norway (3)	68.1	31.9	12.6	19.3	0.0	0.0
Canada (17)	66.8	33.2	25.2	7.3	0.3	0.5
Sweden (13)	60.7	39.3	12.5	25.8	0.2	0.8
UK (56)	54.9	45.1	35.4	6.7	0.2	2.7
Switzerland (10)	53.0	47.0	19.7	26.1	0.6	0.5
Netherlands (9)	42.1	57.9	26.2	30.5	0.5	0.6
Belgium (4)	36.4	63.6	23.8	39.3	0.0	0.6
All Firms (587)	89.0	11.0	4.1	5.6	0.3	0.9

Note: The parenthesis contains the number of firms based in each country.
Source: Data supplied to SPRU by the US Patent & Trademark Office.

3.3 Basic Research

Governments in all countries provide the greatest proportion of funds for the performance of basic research in universities and related institutions, as a support for the change — generating activities performed by industrial firms themselves. The nature of this support is richer and more complex than the simple provision of codified "information" that is stressed in mainstream economic analysis.[7] It also includes training for researchers who go on to work in business firms (involving the formulation of researchable problems, and the ability to develop and use the latest research techniques and instrumentation), and membership of national and international professional networks. Since many of these contributions are "person-embodied" (i.e. they can be realised only through personal contacts and personal mobility), their benefits tend to be localised within a country, even if a local "market failure" element remains, thereby justifying public expenditure (Jaffe, 1989).

International comparisons of inputs into basic research in universities and related institutions are particularly difficult, given the often arbitrary nature of the distinction made in statistical practice between research and teaching (Irvine *et al.*, 1990). Similarly, measured outputs in the form of numbers of papers published are subject to the English language bias of the journal data base, such as that compiled by the Institute for Scientific Information (ISI), from which international comparisons are made.

In an earlier analysis, we estimated that per capita inputs and outputs of basic research in four Western European countries (France, FR Germany, Netherlands and UK) are at about the same level as the USA, with Japan at about half this level (Patel & Pavitt, 1991b). Recent data published by ISI (Science Watch, 1991) allows a more refined set of international comparisons of the output measure. Table 7 shows — for the same 17

[7] For two recent reviews of the contributions of basic research to technological practice, see Pavitt (1991) and Rosenberg and Nelson (1992).

Table 7 A comparison of rankings in basic research and industrial R&D amongst 17 OECD countries

Country	*Mean Citations per Scientific Paper, 1981-90*	*Business Financed R&D as a % of GDP, 1985*
Switzerland	7.33	2.16
Sweden	6.72	1.71
USA	6.65	1.44
Denmark	6.22	0.61
Netherlands	6.01	0.99
United Kingdom	5.62	0.96
FR Germany	5.47	1.65
Belgium	5.39	1.20
Canada	5.31	0.56
France	5.05	0.92
Finland	4.97	0.85
Norway	4.85	0.80
Japan	4.42	1.84
Italy	4.26	0.49
Ireland	3.94	0.35
Spain	3.17	0.26
Portugal	<2.19	0.11

Source: Science Watch, 1991 and OECD.

OECD countries as in Table 1 — the frequency with which their scientific papers were cited by scientific peers in the period 1981–90. It therefore compares scientific impact and may correct — at least to some extent — for language bias. On the other hand, the citation rates in certain small countries may be inflated by one or more reputed international laboratories (e.g. CERN in Switzerland).

Nonetheless, the comparison between the rankings of national performance in technology in Table 1, and in basic research in Table 7, remains intriguing. In overall terms, the country rankings are similar: the Spearman rank correlation coefficient between those in Table 7 and those in Table 1 (for the year 1985) is more than 0.7. And the country rankings in Table 7 are correlated with country rankings of GDP per head with a correlation coefficient greater than 0.5. This suggests that high quality basic research — like a high level of business-funded R & D — is increasingly necessary as countries approach the world best-practice technological frontier, because it is the most efficient way to combine excellent research training, state-of-the-art development and use of research techniques and instrumentation, and ready access to high-quality international networks of professional peers (Pavitt, 1991).

But there are also some interesting differences in the country rankings in science and in technology. Both the USA and the UK rank higher in basic research than industrial R & D, together with Canada, Denmark, Netherlands and Sweden. But FR Germany and — above all — Japan, have a higher rank in industrial R & D than basic research. We interpret this as evidence that:

- numbers of citations is a lagging indicator of quality of basic research;
- trends in the quality of basic research lag behind trends in the volume of business R & D, which can be seen as a proxy measure of business demand for basic research activities.

Thus, Britain's relative performance in basic research — papers and citations — has been declining throughout the 1980s, following the strong relative decline in business funded R & D in the 1970s. At the other extreme, basic research quality has been improving in FR Germany and Japan in the 1980s, following rapid expansion of business funded R & D in the 1970s. FR Germany surpassed the UK in citation performance in the late 1980s (Science Watch, 1991). Japan's rate of growth of scientific papers and citations has been amongst the highest in the 1980s (Observatoire des Sciences et des Techniques, 1991). Japanese scientists have already established commanding positions in fields closely related to sectors of their technological excellence (e.g. optical electronics, superconductivity, materials; see Science Watch, 1990), and have surpassed the UK in highly cited papers in physics (Martin, 1992).

We shall now argue that a more lasting difference between FR Germany and Japan, on the one hand, and the UK and the USA, on the other, resides not in the quality of basic research, but in the educational and professional quality of the labour force.

3.4 Work-Force Education and Training

International comparisons of education and training over the past ten years have moved well beyond the average numbers of years of schooling that used to be common usage. Greater attention is now paid to the distribution of education levels amongst different groups in the working population, and to quality as measured through educational attainment. One of the main pioneers has been S. Prais and his colleagues in the National Institute of Economic and Social Research in London.[8] Some of the major results of their work are summarised in Table 8, which uses census data to compare the vocational qualifications of the workforce in five European countries.

It shows striking *similarities* between countries in the proportion with university degrees (7–11%), but even more striking *differences* in the proportions with intermediate qualifications (66% in Switzerland – 27% in the UK), and with no vocational qualifications (63% in the UK — 23% in Switzerland). Although there had been some improvement in the UK position in the 1980s, the qualifications gap between Germany and France, on the one hand, and the UK, on the other, actually widened (Patel & Pavitt, 1991b). These skill levels in the workforce are reflected in productivity differences resulting from differences in machine maintenance, consistency in product quality, workforce flexibility, and learning times on new jobs.

These studies have been supplemented by comparisons of educational attainment across countries, and which tend to confirm their findings: thus, Dutch adolescents are 2–3 years ahead of their English counterparts in mathematical attainment (Mason *et al.*, 1992). Over a broader geographical area, similar differences are found, adolescents from Japan, the four East Asian "tiger" countries, and continental Europe (including Hungary) clearly out-performing their counterparts from the USA in mathematics (Newton *et al.*, 1992).

[8] See, most recently, S. Prais, 1993.

Table 8 Vocational qualifications of the workforce in Britain, the Netherlands, Germany, France and Switzerland

Level of qualification	*Britain 1988*	*Netherland 1989*	*Germany 1987*	*France 1988*	*Switzerland 1991*
University Degrees	10	8	11	7	11
Higher Technician Diplomas	7	19	7	7	9
Craft/Lower Techn. Dips	20	38	56	33	57
No Vocational Qualifications	63	35	26	53	23
Total	100	100	100	100	100

Source: Prais 1993.

4. NATIONAL SYSTEMS OF INNOVATION: "DESIRABLE DIVERSITY" OR "SYSTEM FAILURE"?

The above comparisons have revealed some striking differences — even divergences — amongst the national systems of innovation, in the OECD countries. Some reflect inevitable "diversity", in stages of economic and technological development, or a desirable "diversity" in fields of national scientific and technological specialisation. Others can be interpreted as an "institutional failure", because — if allowed to persist — they are likely to reinforce uneven and divergent rates of national technological and economic development in future. We shall begin with the second type of difference, and then briefly discuss the first.

4.1 System Failure

The most striking areas of major differences and divergences in national systems of innovation are at their core, namely, in the volume of change-generating (including R & D) activities supported by business firms, and in the skills of the work force that they employ and that they (unequally) train. National differences in basic research also exist, but appear — in the long term — to adjust to the level of demand for skills and knowledge from the business sector. Japan and FR Germany are the major countries with high company R & D and workforce skills, with the UK (and probably the USA) amongst the major countries at the other end of the spectrum. We shall discuss the two types of system failures that may occur in institutions: those related to the *incentives* that they face, and those related to their *competencies.*

Incentive Failures. Countries may differ in the degree to which companies in them can appropriate the benefits of change-generating activities.

- The most important cases are likely to be those related to investment in *person-embodied knowledge* (from training to R & D and other specialised technological activities), where there are international differences in the degree of inter-firm mobility of the workforce. High mobility is likely to result in less than optimal investment, unless it is compensated by a levy, tax or other system. Thus the UK has high workforce mobility but (unlike France) no compensatory levy system for training, which may help explain differing trends in the two countries in worker training in the past 15 years.

- There may also be international differences in the degree of appropriability of investments in *codified knowledge*, resulting from international differences in regimes for the protection of intellectual property rights. However, we know from a variety of studies (in particular, Mansfield *et al.*, 1981; Levin *et al.*, 1987; Bertin & Wyatt, 1988) that — in most industries — innovative leads are maintained by accumulated investments in tacit knowledge rather than codified knowledge, so that intellectual property regimes are not therefore of central importance.

Competency Failures. The observed international differences in the volume of technological activities also reflect institutional failures in the competence to *evaluate* and *benefit from* intangible investments that are increasingly specialised and professionalised in nature (e.g. industrial R & D laboratories employing highly qualified specialists in a variety of fields of science and engineering), and are long-term and complex in their economic impact (e.g. from research on photons, through the laser, to the compact disc, over a period of 25 years). For purposes of exposition, we have found it useful to distinguish between national systems of innovation that we define as *myopic*, and those that we define as *dynamic* (Pavitt & Patel, 1988).

Briefly stated, *myopic* systems treat investments in technological activities just like any conventional investment: they are undertaken in response to a well-defined market demand, and include a strong discount for risk and time. As a consequence, technological activities often do not compare favourably with conventional investments. *Dynamic* national systems of innovation, on the other hand, recognise that technological activities are not the same as any other investment. In addition to tangible outcomes in the form of products, processes and profits, they also entail the accumulation of important but intangible assets, in the form of irreversible processes of technological, organisational and market learning, that enable them to undertake subsequent investments, that they otherwise could not have done because of lack of the required competencies.[9]

The archetypal dynamic national systems of innovation are those of FR Germany and Japan, whilst the myopic systems are the UK and the USA. The essential differences can be found in three sets of institutions:

- First, in the *financial system* underlying business activity: in Germany and Japan, these give greater weight to longer-term performance, when the benefits of investments in learning begin to accrue. And they generate both the information and the competence to enable firm-specific intangible assets to be evaluated by the providers of finance (Hu, 1975; Corbett & Mayer, 1991).
- Second, there are the methods of *management*, especially those employed in large firms in R&D-intensive sectors: in the UK and USA, the relatively greater power and prestige given to financial (as opposed to technical) competence is more likely to lead to incentive and control mechanisms based on short-term financial performance, and to decentralised divisional structures insensitive to new and longer term technological opportunities that top management is not competent to evaluate (Abernathy & Hayes, 1980; Lawrence, 1980).

[9] For further discussions of the implications of the path-dependency of technological learning, and the consequent "option value" of investments in technological learning, see Myers (1984) and Mitchell and Hamilton (1988).

- Third, there is the system of *education* for the workforce: the German and Japanese systems of widespread yet rigorous general and vocational education provide a strong basis for cumulative learning. The British and US systems of higher education have performed relatively well, but the other two-thirds of the labour force are less well trained and educated than their counterparts in continental Europe and East Asia (Prais, 1993; Newton *et al.*, 1992).

4.2 Desirable System Diversity

Whilst the differences in national systems of innovation identified above should be worrisome to policy-makers in so-called myopic countries, other differences are an inevitable and welcome manifestation of economic development, structural change and international specialisation. Thus, in export markets we can identify two economic extremes. At one extreme, in sectors like textiles, the Heckscher-Ohlin assumptions about comparative advantage hold reasonably well: technology — in the form of tradable capital goods and other production inputs — is universally available, and technical choices made largely on the basis of factor endowments. At the other extreme, comparative advantage in the high-wage countries is dominated by technological leads and lags in science-based, scale-intensive and specialised supplier sectors (Soete, 1981; Guerreri, 1991). In between are the industrialising countries, who are progressively shifting (with varying degrees of success) from one basis of competitive advantage to the other. Associated with these shifts are changes in the sectoral composition of output and exports, generally involving relative movements out of sectors associated with abundant endowments of the conventional factors of production (e.g. textiles, mining, food processing), towards machinery, transportation and chemicals (Maizels, 1963).

At the same time, historical experience shows that paths of national technological development are cumulative and strongly influenced by prior experience (see David, 1975; Porter, 1990). In general terms, technological accumulation involved the progressive acquisition of (largely country-specific and internationally immobile) "intangible capital", in the form of personal, organisational and institutional skills that enabled countries to adopt and develop process and product technologies of increasing complexity. Changing bases of international competitiveness evolved along with, and increasingly as a result of, these technological trajectories, which have not been pre-ordained, in either their rate or their direction.

Nonetheless, in most cases three mechanisms seem to have been particularly influential:

- conventional factor endowments;
- directions of persistent investment, especially those with strong inter-sectoral linkages;
- the cumulative mastery of core technologies and their underlying knowledge bases.

The relative significance of these mechanisms has changed during the process of industrialisation. In the early stages, the directions of technical change in a country or region were strongly influenced by local market inducement mechanisms related to scarce (or abundant) factors of production and local investment opportunities. At higher levels of development, the local accumulation of specific technological skills itself became a focusing device for technical change.[10]

Contemporary patterns of technological advantage in the industrially advanced countries therefore tend to reflect relative endowments in technological (human) capital, in addition to other factors of production. Thus the relative advantage of the UK in fine chemicals, and the USA in software technology, reflect their strong endowments in technologies dependent on good university research and graduates, whilst their weakness in automobiles and other engineering industries reflects their weakness in activities requiring a work force with a high level of skills.

5. CONCLUSIONS

We began our paper by attempting to demonstrate the economic importance of the concept of national systems of innovation. We hope that by now the reader will be ready to consider three brief conclusions.

First, comparative and quantitative analysis can help us better understand the essential properties and determinants of national systems of innovation. In particular, we have identified some elements of diversity that are desirable, and others that are not, and we have discussed their causes.

Second, plenty remains to be done to improve the empirical basis for understanding and evaluating national systems of innovation. In particular, we need:

- data of the type we have used in this paper, in more detail and for a wider number of countries;
- better comparative analysis of competencies and behaviour in national financial and management systems;
- more disaggregated analysis of the links between basic research and technological practice;
- better understanding of the dynamics of technological learning and related structural change in national systems of innovation.

Third, theories and models of endogenous technical change should face up to the challenge of explaining the uneven rate of development amongst countries and associated firms that we observe in practice. In doing so, they should incorporate not just the incentives and externalities associated with localised learning, but also — and above all — the differing *institutional competencies* across countries to evaluate realistically and implement effectively the economic benefits of learning activities that are increasingly complex, long-term and roundabout. "Learning to learn" should be a central subject in both the theory and the practice of technical change (Stiglitz, 1987; Romer, 1990).

References

Abernathy, W. and Hayes, R. (1980) Managing our Way to Economic Decline, *Harvard Business Review*, July/August.

Archibugi, D. and Pianta, M. (1992) *The Technological Specialisation of Advanced Countries*, Dordrecht: Kluwer Academic Publishers.

[10] For more detailed discussions, see Bell and Pavitt, 1993.

Arrow, K. (1962a) The Economic Implications of Learning by Doing. *Review of Economic Studies* **29**, 155–173.
Arrow, K. (1962b) Economic Welfare and the Allocation of Resources for Invention, in Nelson, R. (ed.), *The Rate and Direction of Inventive Activity*, Princeton UP, New Jersey.
Bell, M. and Pavitt, K. (1993) Technological Accumulation and Industrial Growth: Contrasts between Developed and Developing Countries, *Industrial and Corporate Change*, **2**, 157–210.
Bertin, G. and Wyatt, S. (1988) *Multinationals and Industrial Property*, Hemel Hempstead: Harvester-Wheatsheaf.
Cantwell, J. (1989) *Technological Innovation and Multinational Corporations*, Oxford: Blackwell.
Corbett, J. and Mayer, C. (1991) *Financial Reform in Eastern Europe*. Discussion paper No. 603. Centre for Economic Policy Research (CEPR), London.
David, P. (1975) *Technical Choice, Innovation and Economic Growth*. Cambridge: Cambridge University Press.
Dosi, G., Pavitt, K. and Soete, L. (1990) *The Economics of Technical Change and International Trade*, Wheatsheaf.
Ergas, H. (1984) *Why do some countries innovate more than others*, Centre for European Policy Studies, Paper no. 5, Brussels.
Fagerberg, J. (1987) A Technology Gap Approach to Why Growth Rates Differ, in C. Freeman (ed.), *Output Measurement in Science and Technology: Essays in Honour of Y. Fabian*, North-Holland, Amsterdam.
Fagerberg, J. (1988) International Competitiveness, *Economic Journal*, **98**, 355–374.
Franko, L. (1989) Global Corporate Competition: who's winning, who's losing, and the R & D factor as one reason why, *Strategic Management Journal*, **10**, 449–474.
Freeman, C. (ed.) (1987) *Output Measurement in Science and Technology: Essays in Honour of Y. Fabian*, North-Holland, Amsterdam.
Freeman, C. (1988) Japan: a New National System of Innovation, in Dosi, G., Freeman, C., Nelson, R., Silverberg, G., and Soete, L. (eds), *Technical Change and Economic Theory*, Pinter, London.
Geroski, P., Machin, S. and van Reenen, J. (1993) The Profitability of Innovating Firms, *RAND Journal of Economics*, **24**, 198–211.
Grilliches, Z. (1990) Patent Statistics as Economic Indicators: a Survey, *Journal of Economic Literature*, **28**, 1661–1707.
Guerrieri, P. (1991) Technology and International Trade Performance of the Most Advanced Countries, BRIE Working papers, University of California, Berkeley.
Hanson, P. and Pavitt, K. (1987) *The Comparative Economics of Research, Development and Innovation in East and West: A Survey*. Chur: Harwood Academic Publishers.
Hu, Y-S. (1975) *National Attitudes and the Financing of Industry*, Political and Economic Planning, Vol. XLI, Broadsheet No. 559, London.
Irvine, J., Martin, B. and Isard, P. (1990) *Investing in the Future*, Elgar, Aldershot.
Jaffe, A. (1989) Real Effects of Academic Research, *American Economic Review*, **79**, 957–970.
Kline, S. (1990) A Numerical Measure for the Complexity of Systems: the Concept and Some Implications, Report INN-5, Dept. of Mechanical Engineering, Stanford University.
Lawrence, P. (1980) *Managers and Management in W. Germany*, London, Croom Helm.
Levin, R., Klevorick, A., Nelson, R. and Winter, S. (1987) Appropriating the Returns from Industrial Research and Development. *Brookings Papers on Economic Activity*, **3**, 783–820.
Lundvall, B-A (1988) Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation. In Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds.). *Technical Change and Economic Theory*. London: Pinter.
Maizels, A. (1963) *Industrial Growth and World Trade*, Cambridge: Cambridge University Press.
Mansfield, E., Schwartz, M. and Wagner, S. (1981) Imitation Costs and Patents: an Empirical Study. *Economic Journal*, **91**, 907–918.
Martin, B. (1992) The Position of British Science, *Nature*, **355**, 760.
Mason, G., Prais, S. and van Ark, B. (1992) Vocational Education and Productivity in the Netherlands and Britain, *National Institute Economic Review*, May: 46–63.
Mitchell, G. and Hamilton, W. (1988) Managing R & D as a Strategic Option. *Research-Technology Management*, **31**, 15–22.
Mowery, D. and Rosenberg, N. (1979) The Influence of Market Demand upon Innovation: a Critical Review of Some Recent Empirical Studies, *Research Policy*, **8**, 102–153.
Myers, S. (1984) Finance Theory and Finance Strategy. *Interfaces*, **14**, 126–137.
Nelson, R. (1990a) US Technological Leadership: where did it come from, and where did it go? *Research Policy*, **19**, 117–132.

Nelson, R. (1990b) Capitalism as an Engine of Progress, *Research Policy*, **19**, 193.

Nelson, R. (ed.) (1993) *National Innovation Systems: a Comparative Analysis*, Oxford: Oxford University Press.

Nelson, R. and Winter, S. (1982) *An Evolutionary Theory of Economic Change*. Cambridge, Mass: Belknap Press.

Newton, K., de Broucker, P., McDougal, G., McMullen, K., Schweitzer, T., Siedule, T. (1992) *Education and Training in Canada*, Canada Communication Group, Ottawa.

Observatoire des Sciences et des Techniques (1991) *Science et Technologie: Indicateurs*, Economica, Paris.

Patel, P. (1994) Localised Production of Technology for Global Markets, *Cambridge Journal of Economics* (forthcoming).

Patel, P. and Pavitt, K. (1991a) Large Firms in the Production of the World's Technology: an Important Case of Non-Globalisation, *Journal of International Business Studies*, **22**, 1–21.

Patel, P. and Pavitt, K. (1991b) Europe's Technological Performance, in Freeman, C., Sharp, M. and Walker, W. *Technology in Europe's Future*, Pinter, London.

Patel, P. and Pavitt, K. (1994) Patterns of Technological Activity: their Measurement and Interpretation, in P. Stoneman (ed.), *The Economics of Innovation and Technical Change*, Oxford: Basil Blackwell (forthcoming).

Pavitt, K. (1991) What makes Basic Research Economically Useful, *Research Policy*, **20**, 109–119.

Pavitt, K. and Patel, P. (1988) The International Distribution and Determinants of Technological Activities, *Oxford Review of Economic Policy*, **4**, 35–55.

Porter, M. (1990) *The Competitive Advantage of Nations*, London: Macmillan.

Posner, M. (1961) International Trade and Technical Change, *Oxford Economic Papers*, **13**, 323–341.

Prais, S. (1993) *Economic Performance and Education: the Nature of Britain's Deficiencies*, Discussion Paper no. 52. National Institute for Economic and Social Research, London.

van Raan, A. (1988, ed.) *Handbook of Quantitative Studies of Science and Technology*, Amsterdam, North-Holland.

Ray, G. (1989) Full Circle: The Diffusion of Technology, *Research Policy*, **18**, 1–18.

Romer, P. (1990) Endogenous Technical Change, *Journal of Political Economy*, **98**, 71–102.

Rosenberg, N. (1976) Science, Invention and Economic Growth, in *Perspectives on Technology*, Cambridge UK, Cambridge University Press. Originally published in *Economic Journal*, **84**.

Rosenberg, N. and Nelson, R. (1992) American Universities and Technical Advance in Industry, Centre for Economic Policy Research, Stanford University.

Salter, W. (1966) *Productivity and Technical Change*, Cambridge: Cambridge University Press.

Schmookler, J. (1966) *Invention and Economic Growth*, Boston, Mass: Harvard UP.

Science Watch (1990) Four Fields where Japan leads and US lags, **1**, February.

Science Watch (1991) World Standings in Science, 1981–90, **2**, January - February.

Sharp, M. Europe: a Renaissance?, *Science and Public Policy*, **18**, 393–400.

Soete, L. (1981) A General Test of Technological Gap Trade Theory, *Weltwirtschaftliches Archiv.*, **117**, 638–666.

Soete, L. and Verspagen, B. (1993) Technology and Growth: the Complex Dynamics of Catching Up, Falling Behind, and Taking Over, in Szirmai, A., van Ark, B. and Pilat, D. *Explaining Economic Growth*, Elsevier, Amsterdam.

Stiglitz, J. (1987) Learning to learn, localised learning and technological progress, in Dasgupta, P. and Stoneman, P. (eds.), *Economic Policy and Technological Performance*, Cambridge: Cambridge University Press.

Teece, D., Pisano, G. and Shuen, A. (1990) Firm Capabilities, Resources, and the Concept of Strategy, *CCC Working Paper No. 90–8*, Centre for Research in Management, Berkeley, CA.

Vernon, R. (1966) International Investment and International Trade in the Product Cycle, *Quarterly Journal of Economics*, **80**, 190–207.

Vernon, R. (1979) The Product Cycle Hypothesis in a New International Environment, *Oxford Bulletin of Economics and Statistics*, **41**, 255–267.

Walsh, V. (1984) Invention and Innovation in the Chemical Industry: Demand-Pull or Discovery-Push? *Research Policy*, **13**, 211–234.