SCIENCE POLICY RESEARCH UNIT

RECENT DEVELOPMENTS IN SCIENCE AND TECHNOLOGY INDICATORS: A REVIEW

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CHAPTER 1

Introduction

In considering new developments in science and technology indicators it is necessary to take into account the social process which generates such indicators and leads ultimately, in some cases, to their incorporation in official national and international statistical series. Four different levels of activity are involved and all of them are important for this review.

The first level is the collection (and sometimes publication) of a variety of partial indicators for purely local purposes of internal monitoring, budgeting and planning by many different organisations. Examples are the membership records and publications of scientific societies, laboratory records of university chemistry departments, personnel records of industrial R and D departments, and (at the national and local level) the archives of patent offices and various government departments. At this level most of these indicators are originally a by-product of administration, although they may become a very important input into policy-making and analysis at other levels, undreamt of when the original data were assembled.

The second level is that of the use of indicators from the first level, and of others specifically collected for research purposes, to understand and interpret more general processes of the development of science and technology. This work, typically undertaken by academic researchers, but also by others in industry, government or Foundations, involves attempts to resolve problems of reliability, coverage and interpretation of the various indicators and their use for comparative and analytical purposes. Initially, it may be experimental and exploratory but it may soon point to important conclusions for policy-making by firms, governments or other institutions.

The third level is that of the official incorporation of a particular set of indicators in some regular statistical survey activity of central government. At this level there is typically a rather systematic effort to standardise definitions and concepts, to improve response rates, to adopt more regular and systematic procedures and to improve the quality of the data. Typically, at this level too, there is a more regular link between the collection of indicators and their use in national policy-making. However, it is important to recognise that indicators produced at the third level are not necessarily any better than those produced and published at the first or second level and may indeed be less reliable, even though (usually) more comprehensive.

Finally, the fourth level is that of international standardisation and comparison, in which some international organisation accepts the responsibility for attempting to reconcile and harmonize the various national definitions and procedures, or when this proves to be impossible, to establish statistical techniques enabling more valid international comparisons to be made. Activity at this level may be quite innovative and catalytic, disseminating 'best practice' across national frontiers and stimulating new developments, as has been the case with OECD work on R and D indicators; or it may be rather passive, simply assembling and publishing indicators even with non-standard definitions.

All four levels should be seen,not as self-contained, sequential stages, but as parts of an interactive system with a great deal of feed-back between the various levels. Thus, for example, the initiative for a new or improved set of indicators could come from any level in the system, although most commonly it would emerge at the first or second level, in the first instance.

The way in which science and technology indicators have emerged and evolved over the past century resembles that of the research-innovation system itself. Most of the indicators reflect the increasing professional specialisation of that system. The demand for more satisfactory indicators of inputs and outputs of the system reflects the greatly increased scale and importance of these activities in most countries throughout the world.

The complexity of the research-innovation system is also mirrored in the nature and limitations of the science-technology indicators which we have so far been able to develop. Conceptually it is useful to distinguish between basic research, applied research, inventive work, experimental development, innovation and diffusion of innovations. But, as everyone involved in the system knows very well, these are far from being watertight categories and still less are they linked in a regular, linear, sequential manner. The interactive nature of the system is illustrated in Table 1.1. This was originally prepared by Machlup (1962) for his book on The Production and Distribution of Knowledge, but it has been modified by the author to take account of new developments and the particular purposes of this review.

The Table is an important one, not only because of its demonstration of the importance of feed-back loops at every level of the system, but also because of the distinction it makes between "intangible" and "measurable" inputs and outputs of the system. For example, there is no doubt that unsolved scientific problems and "bugs" in technical development, and even innovations which fail commercially, are an extremely important "intangible" input into many scientific and technical activities; but no-one has yet devised a way to measure them and perhaps nobody ever will. From this it is apparent, that even a greatly extended and improved system of measuring inputs and outputs of research and development (R and D), or scientific and technological le 1.1 Inputs and Outputs in Research, Invention, Development and Innovation

ge	Input			Outout	
	(i) Intangible	(ii) Tangible	(iii) Measurable	(iv) Intangible	(v) Measurable
'basic and applied re-search' (in-tended output: 'formulas')	scientific knowledge (old stock and out-put from 1a and STS) scientific problems and hunches (old stock and output from 1b,2b and 3b and STS)	scientists technical aides clerical aides laboratories materials, fuel, power	personnel payrolls, current and deflated instruments outlays, current and deflated outlay per person	a. new scientific know-ledge, hypotheses and theories b. new scientific prob-lems and hunches c. new practical prob-lems and ideas	research papers and memoranda;
'inventive vork' :including ninor im-›rovements ›ut excluding further de-velopment of nventions) intended ›utput: sketches')	scientific knowledge (old stock and out-put from 1a and technology) (old stock and out-put from 2a and 3a and STS) practical problems and ideas (old stock and output from 1c, 2c,3c and 4a and STS)	scientists inventors engineers technical aides clerical aides laboratories materials fuel, power	personnel payrolls, current and deflated instruments outlays, current and deflated outlay per person	a. raw inventions' tech-nological recipes patented inventions patentable inventions not patented but published patentable inventions, neither patented nor published non-patentable inven-tions, published non-patentable inven-tions, not published minor improvements b. new scientific problems and hunches c. new practical problems and ideas, 'bugs'	patent applications and patents technological papers and memo-randa research papers and memoranda
development ork' intended utput: blueprints nd specifi-ations')	scientific knowledge (old stock and out-put from 1a and technology (old stock and out-put from 2a and from STS) practical problems and ideas (old stock and out-put from 2a and STS)	scientists engineers technical aides clerical aides laboratories materials fuel, power pilot plants prototypes	personnel payrolls, current and deflated instruments outlays, current and deflated outlay per person	2a (above) and a. developed inventions blueprints, specifi-cations, samples b. new scientific prob-lems and hunches c. new practical prob-lems and ideas, 'bugs'	blueprints and speci-fication for new and improved - products and - processes - licenses patent applications and patents technological papers
new-type lant onstruction' ew and im-roved produc-ion lines and roducts. ew services intended utput: new-type lant' and ew products)	developed inventions (output from 3a) scientific and tech-nical information (stock and output from 1, 2 and 3 and from a variety of STS) business acumen and market forecasts financial resources enterprise (ventur-ing) ideas from engineers, workers, managers	scientific and technical people entrepreneurs managers financiers and bankers builders and contractors workers building materials machines and tools	investment in new-type plant and products outlays for STS classified by type of service expenditures for licenses and technical know-how other outlays for innovations	a. new practical problems and ideas, 'bugs'	new-type plant or production lines producing novel products better products cheaper products, i.e products and process innova-tions

:e: Modified version from p.8 in:
Freeman, <u>The Economics of Industrial Innovation</u>, (2nd Edn) 1982; derived from Machlup, <u>The Production and Distribution of Knowledge</u>, (1962).

services (STS), would still not capture some important "intangible" inputs, outputs and flows. Although it is important to realise these limitations, it is also salutary to recognise that such well-established and useful measures as GNP also have similar limitations, for example, in relation to the "informal" economy and the measurement of "output" in many service sectors.

Only a few science and technology indicators are at the third and fourth levels of official national or international standardised collection and publication. Many actual or potential indicators have been at the first or second level for a long time. However, many of the most interesting recent developments are at these levels and there is a real prospect of constructive interaction with levels 3 and 4 over the next decade. Some of these new developments could be of particular interest to the developing countries. This review therefore does not confine itself to levels 3 and 4, but on the contrary devotes further attention to levels 1 and 2 especially in relation to output indicators.

Structure of the Review

Part One of the review deals with "input" measures (column iii of Table 1) which are at levels 3 and 4, whilst Part Two deals with "output" measures (column v of Table 1), most of which are still at levels 1 and 2.

Part One is divided into two chapters: the first (Chapter 2) deals with R and D statistics, the second (Chapter 3) with statistics of STS. Both chapters are relatively brief as R and D input indicators reached the fourth level some time ago and in both cases there is a great deal of published information easily available from the major international organisations: OECD and UNESCO. The main new developments which have taken place in R and D statistics in the last two decades relate to refinement and improvement of established definitions and concepts rather than to any fundamental innovations in the field.

Chapter 3 deals with a much broader group of scientific and technical activities, which are now usually described in the international literature as "STS" - scientific and technological services. The General Conference of UNESCO at its 20th session in Paris in November 1978 adopted a "Recommendation Concerning the International Standardisation of Statistics on Science and Technology", which defined "Scientific and Technological Activities" (STA) as comprising:

(a) Research and Development (R and D)
(b) Science and Technology Education and Training at the third (higher) level (STET)
(c) Scientific and Technological Services (STS)

Whilst education and training are of course extremely important for the widespread dissemination of science and technology, they are outside the scope of this review. Education statistics, although they are of central interest to UNESCO, are a specialised branch of statistics, which are relevant here only as they affect the most important input into R and D and STS - the supply of qualified scientists, engineers and technicians.

The most important new development in the STS field relates to Scientific and Technical Information and Documentation (STID) and this is the main concern of Chapter 3. It has long been recognised that for developing countries the wider range of STS, and especially STID, may be of greater interest than R and D itself. An important feature of these new developments is that two developing countries (Mexico and Sudan) are involved in the experimental survey work undertaken with the support of UNESCO.

The STID work is an encouraging and important new international development, but even greater long-run significance is attached to the development of output indicators, which are discussed in Part Two. Although output measurement is both conceptually and in practical terms a much more difficult problem than input measurement and was relatively neglected in the 1950s and 1960s, the measurement of the flow of scientific papers and of patents has been well established at levels 1 and 2 for a long time. The nature and significance of these measures is of course highly controversial. The problems lie not so much in the collection of raw data, as in the processing and interpretation of vast archives of information, which are continuously available in a great many countries. New technology (cheap computing and data banks) combined with new developments in levels 1 and 2 have opened up some exciting new prospects. These are discussed in Chapters 4 and 5 dealing with the measurement of research output and inventive output respectively.

In relation to the output of innovations and their diffusion, there is still a major problem of the collection of raw data. Nevertheless, new developments have now reached a point where they offer considerable promise for the 1980s and 1990s and they are therefore briefly reviewed in Chapter 6, even though they have barely begun to be noticed at levels 3 and 4. Intrinsically, the diffusion of innovations, discussed in Chapter 6, is one of the most important fields of interest to the developing countries. The measurement of diffusion of innovations relates also to statistics of international trade, (which have been well established at Levels 3 and 4 for a long time), to international investment flows and to the indicators of the "technological balance of payments". These also are very briefly considered in Chapter 6. Recommendations are included in the final chapter (7), which might accelerate the availability of measures of primary interest to the Third World.

CHAPTER 2

R and D Inputs

Origins of R and D measurement

The development of R and D measurement illustrates well the involvement of the four different levels described in Chapter 1. The earliest measures were made by universities and learned societies to monitor their own activities and make rough estimates about those disciplines or research activities of the greatest interest. As industrial firms began to establish their own R and D laboratories or departments in the latter part of the 19th century, they too became increasingly interested in measuring the scale of R and D in particular industries and making comparisons with competitors. Between the two world wars various industrial organisations in the leading industrial countries were already collecting and publishing the results of surveys of industrial R and D expenditures. However, definitions and standards were still very loose and coverage was by no means comprehensive (level 2).

It was not until the 1930s in the Soviet Union and the 1940s in the United States, that central government began to play a more active role in the establishment of definitions and procedures and in carrying out regular systematic surveys (level 3). Prior to this, individual scientists, such as Huxley (1934) and Bernal (1939) had attempted to make comprehensive estimates of the total amount of Research and Development expenditures and manpower in particular countries (level 2). Their efforts contributed to the ultimate success of the official activities, but because they were using incomplete statistics with a variety of non-standardised definitions, they seriously underestimated the D part of R and D in industry. Nevertheless their work had a significant influence on the public debate, leading to a climate of opinion during and after the second World War which was strongly favourable to a rapid increase in government sponsorship of R and D activities in universities, in industry and in government itself. For example, the Report of Vannevar Bush (1945) to the United States Federal Government, "Science, the Endless Frontier", played a big part in the decisions which led to the setting up of the National Science Foundation and other long-term commitments to the support of science and technology.

The NSF was indeed the agency which, when it did come into existence, was empowered to undertake the first regular surveys of R and D in the United States. Since the early 1950s, their surveys have been the main official indicators of the scale of R and D activities throughout the United states economy and of the trends in each discipline, branch of industry or product field. Not only have the NSF R and D surveys been an important influence on Federal Government policy-making, they have also had an important feed-back effect on the academic work devoted to the analysis of the economic and social dimensions of science and technology. This influence was already apparent, for example, in the first major

Conference on Research, Development and Innovative Activities organised by the National Bureau of Economic Research (1962) and in the work of economists such as Nelson, Peck and Kalachek (1967) or Edwin Mansfield (1968).

Finally, the initiative of the United States government, through the NSF surveys, had a powerful influence on many other member countries of the OECD (then OEEC). During the 1950s and early 1960s most of them followed the US lead in setting up R and D survey activities and incorporating them in the regular machinery of central government statistics. When the OECD set about the task of standardisation of R and D statistics on an international basis, the NSF definitions and procedures were the strongest single influence in the preparation of the "Frascati Manual" in 1962-63 (OECD, 1963). This activity had now reached level 4.

Failure to Tackle STS

In one sense this was a missed opportunity, as it meant that a major international impetus in the early post-war period flowed into the relatively narrow channel of R and D inputs measurement, neglecting or at least postponing, the development of a wider range of STS input indicators. Moreover, the fact that the major initiative towards international standardisation came from a relatively restricted group of the wealthier countries (OECD), rather than from the UN as a whole, meant that attention was focussed on a range of activities which were not necessarily the most important for the larger number of poor countries, most of whom had very little professional R and D. Many of those who have researched the problems of science and technology indicators in developing countries have drawn attention to these problems, for example Katz (1969) and Arraoz (1981).

This is not to criticise the work of the OECD in this field, which has set extremely high standards and achieved a great deal with very limited resources. Within its own field the OECD has been extremely innovative and has done a lot, both to improve definitions and methods, and to disseminate best practice more widely. It has also performed an invaluable service by publishing the results of a series of "International Statistical Years" (OECD, 1967, 1969, 1971, 1973, 1975, 1977, 1979, 1981) on R and D in the OECD area. Moreover the OECD has done its best to stimulate work on R and D output measurement by holding a series of international meetings and workshops on this topic (see Part Two).

Whilst it is a matter for regret that most OECD countries in the 1950s and 1960s confined their efforts to R and D input measurement and did not tackle STS; in the circumstances which prevailed at the time this outcome was probably inevitable. Virtually no work had been done at level 1 or level 2 to provide a framework for official STS measurement in the market economies and the only major country with experience of measuring the whole range of STS (including R and D) was the USSR. Whilst Soviet definitions and methods were largely imitated in the other East European countries, the institutional and ideological barriers to international standardisation on Soviet definitions in the UN system more generally were far too great (Freeman and Young, 1965).

The UN system has not succeeded in reconciling definitions between Eastern and West European countries for such major economic indicators as GNP measurement; thus it is hardly surprising that the tentative attempts, which were made by UNESCO in 1967 and 1968, in the field of R and D and STS indicators proved abortive (Borowy, 1967 and Freeman, 1969).

In a market economy there are very great practical difficulties, as well as conceptual problems, in measuring some parts of STS. These will become apparent in Chapter 3, which considers in some detail the case of scientific and technical information and documentation (STID). The range of private publishing activities, of private computing and information services, and of abstracting and translating services is now so great and the difficulties of separating their scientific and technical from their other activities so formidable, that progress must inevitably be slow.

It could be more rapid if a strong political will was present, but during the 1960s and 1970s resistance to the collection of statistics for government use has increased substantially in the main industrial countries, especially the USA, the German Federal Republic and the UK. This means that there is very great reluctance to embark on new and difficult surveys which would require considerable assistance from the private sector. Even with established statistical series there is strong opposition to the inclusion of new additional questions in regular questionnaires. This generally conservative mood, which has prevailed in relation to government statistics over the past decade or so, has meant that in practice the changes in the official input measures have been confined to:

(1) Relatively minor improvements in the R and D input series. These are dealt with in the remainder of this chapter. OECD has taken the lead in making and disseminating improvements in this area.

(2) The first official attempts to measure one part of STS - the STID (Scientific and Technical Information and Documentation). Significantly, after a little preliminary work by OECD, it is UNESCO which has recently become the main driving force in this area, which is dealt with in Chapter 3.

The Improvements in R and D Input Measurement

The most recent edition of the Frascati Manual (OECD, 1981) contains an Annex and extensive bibliography which describe the main changes made in the successive revisions of the Manual (2nd edn. 1970, 3rd edn. 1976, 4th edn. 1981). Only a very brief summary is included here.

Following the adoption of the first Frascati Manual in 1963 the OECD commissioned an experimental international comparison of R and D expenditures and manpower between USA, Western Europe and USSR (Freeman and Young, 1965) and an official "International Statistical Year" (OECD, 1967) in which 17 countries took part, many of them undertaking surveys for the first time.

The strong interest of the member countries in the international comparative studies,and their approval of the quality of work undertaken by the Secretariat,led to the establishment of the ISY as a regular biennial activity. The staff working on these surveys was consolidated into a "Science and Technology Indicators Unit" directed by Yvan Fabian, and since 1976 has published a "Science Resources Newsletter" giving summary results and highlights of recent work.

As a result of the experience accumulated by the STIU and by the member countries in successive surveys, it became possible to make many improvements in successive revisions, affecting clarification of definitions, concepts and procedures. In addition, useful illustrative examples were incorporated which have made the Manual particularly useful for countries embarking on Surveys for the first time. The Manual has been translated into many languages in addition to the two official languages of the OECD, including Spanish, Portuguese, German, Norwegian, Japanese, Serbo-Croat, Italian and Dutch.

Special attention was given to reconciliation with UN international standards of classification, and the OECD has consistently stressed this point. For example, the most recent edition includes a new first chapter, which sets the measurement of R and D in the wider context of STS, with particular reference to the UNESCO recommendations on measurement of scientific and technological activities (UNESCO, 1978, see Chapter 1).

The third edition of the Manual (OECD, 1976) incorporated more substantial changes. National survey techniques had greatly improved and member countries had by now participated in four international statistical years. Social sciences and humanities were now included for the first time, following preparatory work commissioned by the OECD. In addition classification of R & D activities by "objectives" was included for the first time.

The costs of R and D may not increase at the same rate as the general rate of inflation, so that a problem which has preoccupied policy-makers is that of appropriate "deflators" for R and D expenditures over time. Originally, the main interest of the OECD in the related problem of "research exchange rates" concerned the wide differences in R and D costs (especially salaries) between the USA, most West European countries and the USSR (Freeman and Young, 1965). Since that time the gaps between USA and Western Europe have greatly diminished so that the problem for comparisons in this region is not so acute. However some old gaps remain and new "gaps" are opening up; the general instability of exchange rates also means that the problem is still often a real one, especially for developing countries. The OECD Science and Technology Indicators Unit (STIU) has done very useful work in this field and convened a workshop on "R and D Deflators" in October 1977 (OECD, 1977), which brought together most of the useful experience and knowledge in this field. This has now been consolidated in the fourth edition of the Manual (Chapter 7).

The Director for Science, Technology and Industry at the OECD, David Beckler, could fairly claim in his "Preface" to the most recent edition of the Manual (OECD, 1981) that "with this fourth edition the Manual can be said to have reached maturity." However, this does not mean that all the problems have been solved, or that new developments in R and D input statistics have come to a halt. The OECD Science and Technology Indicators Unit has recently reviewed national questionnaires for R and D and has identified a number of interesting new developments in one or more countries.

Australia collects ratherdetailed information (1976-77 questionnaire) on R and D performed by "related enterprises," including overseas organisations, leading to Tabulations on "Foreign Control and Influence". This could be of particular interest to developing countries.

Several countries have attempted to collect information on the breakdown between <u>product</u> and <u>process</u> R and D, usually also distinguishing between "new" and "improved" products and processes (e.g. Denmark, Finland, Sweden, Norway, German Federal Republic, United States). This follows regular data collection on this basis at Level 2, for example, in the McGraw Hill surveys in the United States and in the survey by the Federation of British Industries in 1961.

Belgium and Canada are two countries which have been particularly innovative and ready to experiment with new types of data collection. Belgium attempted to collect data in 1977 on numbers of innovations and on the life of new products. Canada pioneered the collection of data on costs of innovation (Stead, 1976), which was very important in counteracting the widespread mythology, which maintained that R and D costs were relatively insignificant as a proportion of total costs of innovation. The Canadian data showed that R and D costs in several important industries amounted to half or more of total innovation costs and not 10 per cent or less, as had sometimes been suggested.*

Several countries (particularly USA, Japan, UK and Sweden) have collected data on "product field" of R and D as well as on the basis of the industrial classification of reporting companies. Academic work by Scherer (1982), Pavitt (1982) and by Kodama in Japan suggests that this type of breakdown could be of particular interest in analysing changing patterns of industrial structure and diversification. For example, it appears that firms in "declining industries" in Japan spend most of their R and D in product fields outside these industries. This analysis could also be very important in understanding the relationships between industries of very low research-intensity and their suppliers of machinery, materials, components etc, who may have much stronger R and D. Unfortunately this is often a difficult and sensitive question for respondents, so that, for example in Canada, the results could not be published, because they would have disclosed too much about individual companies.

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* This does not mean of course that the "non R and D" costs of innovation can be disregarded. On the contrary, one of the most urgently needed improvements is the measurement of these costs, particularly design-engineering costs (D-E). In the diffusion of technical innovations DE is frequently more important than RD.

Some countries are making greater efforts to relate their R and D data, which are frequently collected by a special agency (such as the NSF), to data collected by other agencies. This applies both to more general economic data, such as output, employment, investment etc and to other science and technology indicators. Most countries can now make direct comparisons of R and D data with comparable information on sales and employment of industrial firms. Belgium, Germany and Sweden can also now do this for gross investment as well. Australia, Canada and Ireland collect information on patents arising from R and D in the respondent firms. As we shall see in Chapter 5, this information could be especially important in the interpretation of patent statistics, as one of the problems in using these statistics is that many patents are taken out as a result of activities unconnected with industrial R and D. To measure the sources of patents more precisely in all countries and to be able to relate this <u>output</u> indicator directly, rather than very approximately, to industrial R and D inputs, would be a very welcome improvement.

Finally, several other countries, in addition to Australia and Canada, also collect data on the so-called "Technological Balance of Payments" with their R and D questionnaires. Again, this is a welcome development, as although most of the OECD countries now have regular data on the TBP, they are usually collected by the Central Bank or the Patent Office, so that again there is a problem of reconciling data collected by different agencies with different classification systems (see Chapter 6).

As output measurement develops and takes off, this is likely to become a more and more serious problem in the OECD countries, as many of the new output indicators are assembled at present by non-governmental agencies or different government agencies. This problem is one that could in principle be avoided by many developing countries, as they set up science and technology measurement systems.

The Centre for Policy Alternatives at MIT recently prepared a paper for NSF (Hill, Hansen and Maxwell, 1982) on the feasibility of new science and technology indicators. They concluded after discussions and tests with nine American industrial firms that it would be both possible and useful to collect information on organisational structure of R and D, on central laboratories of large R and D organisations, on venture mechanisms for launching innovations, on extra-mural expenditure in higher educational institutions (these questions are already included in some countries), and perhaps on numbers of new products or other questions relating to new products. Table 2.1 summarises the results of the CPA Survey. Unfortunately, they did not so far make recommendations on the use of STS or output indicators other than new products. Even if all these recommendations were adopted by NSF, they would add very little to our present knowledge. However, it is apparent that "respondent" resistance to the introduction of new measurements in American industry is now rather high, so that it may well be that the main advances at Level 3 will come in smaller countries, such as Canada, Australia, Belgium and Scandinavia. Some of the developing countries would now also be in a position to catch up and overtake the present leaders in R and D measurement, if they are ready to take a more systematic and long-term view of the developments which are described in Chapters 3 to 6.

Table 2.1

SUMMARY OF FEASIBLE INDICATORS
RECOMMENDED FOR FURTHER TESTING
BY MAIL SURVEY

CONCEPT	INDICATOR
The extent to which R&d activity is oriented toward market opportunities and meeting user needs.	Organization of R&D -Organizational structures for R&D -Allocation of R&D spending to central or corporate facility
The extent of scientific and technical interaction between industries and universities.	Industry/University Interactions -Grants and contracts by industry to universities -Industry expenditures for university consultants
Encouraging technical entrepreneurship in large organizations.	Technical entrepreneurship -Number of firms using each of six mechanisms to encourage technical entrepreneurship
The production and significance of new products.	New Product Development -Number of new products introduced -Fraction of sales due to new products
The extent of technology transfer among producer firms.	Royalty Receipts -Total royalty and license receipts -Foreign and domestic allocation -Fraction from affiliates and subsidiaries -Number of firms from which receipts are received

Source: Hill, Hansen and Maxwell (1982)

CHAPTER 3

STS Inputs

UNESCO and the Measurement of STS

As has already been noted in Chapter 1, the General Conference of UNESCO in November 1978 adopted a set of 'Recommendations concerning the international standardisation of statistics on Science and Technology'. This encouraged member countries to collect statistics on a broad range of STS as well as R & D. Section 2.1 (c) of this document defines STS in terms of 9 activities:

(i) S & T services provided by libraries, archives, information and documentation centres, reference departments, scientific congress centres, data banks and information processing departments.

(ii) S & T services provided by museums of science and/or technology, botanical and zoological gardens and other S & T collections (anthropological, archaeological, geological etc.) .

(iii) Systematic work on the translation and editing of S & T books and periodicals (with the exception of textbooks for school and university courses).

(iv) Topographical, geological and hydrological surveying; routine astronomical, meteorological and seismological observations; surveying of soils and of plants, fish and wildlife resources; routine soil, atmosphere and water testing; the routine checking and monitoring of radio-activity levels.

(v) Prospecting and related activities designed to locate and identify oil and mineral resources.

(vi) The gathering of information on human, social, economic and cultural phenomena usually for the purpose of compiling routine statistics e.g. population censuses; production, distribution and consumption statistics; market studies; social and cultural statistics etc.

(vii) Testing, standardisation, metrology and quality control; regular routine work on the analysis, checking and testing, by recognised methods, of materials, products, devices and processes, together with the setting up and maintenance of standards and standards of measurement.

(viii) Regular routine work on the counselling of clients, other sections of an organisation or independent users, designed to help them make use of scientific, technological and management information. This activity also includes extension and advisory services organised by the state for farmers and for industry but does not include the normal activities of project planning or engineering offices.

(ix) Activities relating to patents and licences; systematic work of a scientific, legal and administrative nature on patents and licences carried out by public bodies.

These recommendations are a major step forward in the international efforts to measure scientific and technological activities. Nevertheless there is one very serious omission from the definitions of STS - Design/Engineering. These activities are measured in the Soviet Union and other socialist countries. Indeed the separation of DE from R and D is one of the main problems in comparisons between East and West European countries. Moreover, a great deal of empirical work (Bell et al.,1980; Katz 1969) has shown that technical change in developing countries depends heavily on adaptive design and modification of production processes imported from abroad. Typically, this work is not carried out by R and D Departments, (and indeed is aften not R and D within the strict Frascati definitions; see page 2.10), but by process design organisations, consulting engineering organisations and "design", "engineering" or "production engineering" departments of manufacturing firms. The sum total of their activities is very great in purely quantitative terms and so too is their qualitative importance in the process of implementing technical change in developing countries. Katz (1969) demonstrated that a high rate of technical change in Argentinian manufacturing firms was related to adaptive R and D carried out by such organisations and groups within firms, rather than to formal R and D departments. In the United States Hollander (1968) came to very similar conclusions for the rayon industry. Hence it is extremely desirable that at Levels 1 and 2 efforts should be made to fill this extremely important gap. We return to this point in chapter 7.

With this qualification, the UNESCO 1978 recommendations were very welcome. Their adoption followed a long period of preparatory work and data collection activities going back to the 1950s. In the early days UNESCO largely confined its role to the assembly and presentation of national data on R and D and education in the Statistical Yearbook (UNESCO, Annual from 1969) and other general publications. Some 80 countries now contribute information to UNESCO on R and D and/or related activities. During the 1960s an increasing effort was made to grapple with the problems of the variety of definitions and methods in use in member countries, and to initiate work on the measurement of STS as well as on R and D and STET. Many seminars and conferences were organised which helped to clarify the main problems and to disseminate international experience. Background papers were prepared on many different aspects of the measurement of STS (Sirilli, 1980). Some of these early proposals did include reference to DE as well as R and D, but practical problems led to their elimination. UNESCO issued a series of "Guides" and "Manuals" to aid administrators in member countries to develop and improve their S & T statistics (UNESCO, 1970, 1977, 1978). The most recent general summary of the outcome of all this activity is the "Provisional Manual for Statistics on Scientific and Technological Activities" originally prepared by Dr. Giorgio Sirilli (UNESCO, 1980).

UNESCO and the Measurement of STID

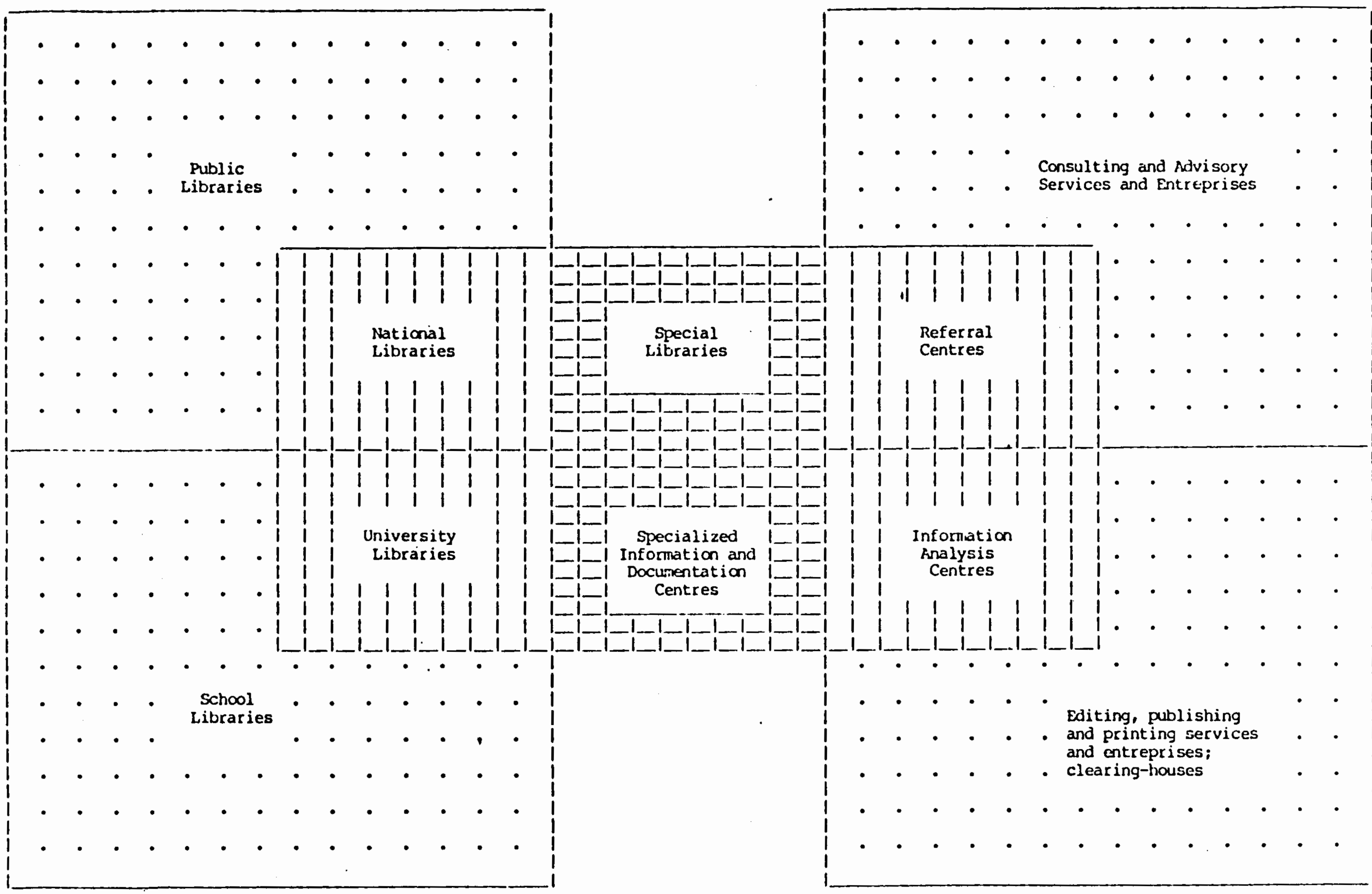
Apart from its work on STET (which is not considered here), over the last few years in pursuit of the recommendations of the General Conference, the Office of Statistics of UNESCO has concentrated in particular on the measurement of STID. Four member countries: Australia, Mexico, Poland and Sudan, have collaborated closely with the Office of Statistics in pilot projects in order to develop concepts, definitions and methods and establish feasibility. On the basis of this experience a draft "Guide to Statistics on STID" has been prepared (UNESCO, 1982) and assistance is now offered to a wider range of member countries to initiate and undertake regular survey work in this field. It will probably be a good many years before a large number of countries embark upon this activity. Nevertheless, this is the first major attempt to stimulate the collection of data relating to STS on an international basis, and is an extremely welcome and encouraging initiative on the part of UNESCO. Moreover it is a development which is of particular interest to third world countries and one in which they have been directly involved from the outset.

Whilst the "Draft Guide" which has been prepared by UNESCO recommends that the main effort in member countries should be concentrated on Section (i) of the full range of STS listed above, it clearly envisages that this may sometimes involve the simultaneous collection of data relating to Sections (ii), (iii), (vi), (viii) and (ix). In fact STID is so defined as to go beyond category (i) (pages 4 to 9 of the "Draft Guide") and countries are encouraged to embark on this set of measurement activities within the context of a broad appreciation of the full range of STS.

The "Guide" is realistic in recognising the variety of national circumstances and the extent to which national authorities may be willing to broaden the range of coverage. "Figure 3" (page 8 of the Draft Guide) indicates the broad scope of coverage and comments:

> "The shading indicates the order of priority in that that darker the area is, the more priority it has. Therefore special libraries and specialised information

Figure 3. Types of information institutions and units



and documentation centres can be seen to form the core STID institutions which must absolutely be covered in the data collection. Then come national and university libraries, as well as referral and infromation analysis centres, which should be covered if the data collected are to be useful in the planning and coordination of the national information infrastructure and network. Finally, if there is a need for a complete understanding of all institutions involved in information activities in the country, and at the same time the manpower and financial resources to carry out the data collection are sufficient, then editing, publishing, printing, consulting and advisory services and enterprises can also be included in the coverage, as well as public and even school libraries. In any case, the choice for inclusion of any of these kinds of STID institutions depends on the particular need of data to aid in decision-making and planning, and the resources available for carrying out the data collection. The anticipated ease or difficulties to collect data on each of them will also have to be taken into consideration."

Whilst the "Guide" is flexible and realistic in its approach to these and other practical difficulties involved in data collection on STID, these comments show that it will probably be quite a long time before any satisfactory degree of international comparability can be attained for indicators of this kind. This does not mean that the data cannot be extremely useful at the national level in the planning, assessment and coordination of national information and documentation services. Indeed the "Draft Guide" recommends the collection and classification of information activities in a form which could be very helpful in understanding and promoting national information and documentation services.

For example, it is suggested that the activities of STID units can be classified into 9 broad categories as follows:

(a) Information handling and processing - relating to the search, acquisition, cataloguing, abstracting, indexing, storage, and other controlled organization of collections.

(b) Information analysis - comprising activities in evaluating, analysing, synthesizing, and repackaging STID; and in selective dissemination of information (SDI).

(c) Translation - referring to the translation of documents from and into other languages.

(d) Publication - involving the preparation and publication of secondary publications such as indexes, abstracts, bibliographies, accessions lists, catalogues, directories, etc., as well as primary publications such as books and periodicals.

(e) Reference services - involving the provision of services of current awareness, bibliographical references, literature search and retrieval.

(f) Referral, advisory and consulting services - relating to activities of advising and making referrals to other sources of information and documentation.

(g) Loan of publications and documents - relating to the provision on loan of documents and publications.

(h) Distribution and circulation of publications, documents, or their reproduced copies, free or against the payment of a fee.

(i) Other information activities - including meetings, exhibitions, workshops, seminars and training sessions during which STID are transferred and exchanged; as well as research in information sciences, and information management.

Such information could provide the basis for a handbook of STID units, as well as an analysis of their activities. Recommendations are also made on the classification of services provided, on the classification of STID personnel, expenditures, and source of funds, on the availability of various types of equipment and services and the frequency of their use.

The Draft Guide is particularly useful for decision-makers and administrators because it contains a set of 11 Appendices, which include a "Model National Questionnaire" and Definitions: "Standard Instructions for Interviewers"; a Recording Sheet and a Coding Sheet; a "Model Questionnaire for Identifying STID Institutions and Units"; examples of Summary Tables and Charts; a model Directory and Catalogue and a bibliography. It is a good example of a valuable stimulus from Level 4.

All of this reflects the experience gained by UNESCO Office of Statistics over many years in trying to stimulate efforts at data collection in this field. During the 1970s, UNESCO commissioned a series of background papers and documents, which are listed in the bibliography, and which provided a framework within which it has proved possible to embark on the activities described above. Particularly important were the experiences in Ireland, as the Irish Republic was one of the first countries to initiate measurement work in this field (Cooper and Wood, 1978 and Murphy, 1979).

In considering probable future developments it is important to anticipate some of the difficulties which may arise. The main one is likely to be the fuzzy boundary between the specialised STID institutions and units on the one hand and the much wider range of organisations and enterprises which have some involvement in STID activities. Whilst experience so far has confirmed that it is quite feasible to build up directories of the main professional STID units and to collect data about their activities, it is by no means clear what proportion of the total "universe" of STID activities is captured in this way. The only way to find out is to continue on the course charted by UNESCO in full awareness of these difficulties. But as "Figure 3" of the UNESCO Draft Guide indicates, it may prove very difficult to collect data outside the heavily shaded areas, particularly in the larger market economies. The exploratory work of the OECD in this area and in particular the pioneering study commissioned at the "Studiengruppe für Systemforschung" at Heidelberg already foreshadowed these difficulties.

"Information" occupations of one kind or another were already estimated to account for over a quarter of United States total employment in 1962 (Machlup, 1962). More recently, Porat (1977) estimated that they now account for over half. Clearly many of these people are concerned with entertainment rather than information. Nevertheless, there is a major problem in such areas as publishing and consultancy in distinguishing STID from a much wider range of activities. This suggests that progress is likely to depend (as in the case of R and D) on adopting a rather restrictive definition of professionalised and specialised STID activities, even though the wider context must be kept in mind. It is likely to be the 1990s before STID measurement reaches the stage of maturity and comparability attained by R and D statistics in the 1960s.

PART II: OUTPUT INDICATORS

CHAPTER 4

Basic Science Indicators

General Problems of Output Measurement

In Chapter 1 it was pointed out that new developments in output measurement have taken place mainly at levels 1 and 2. However, this does not mean that there has been a lack of interest at government level or in the international organisations. On the contrary in several countries there has been specific encouragement for output measurement and the OECD, in particular, has done a great deal to stimulate progress at Levels 1 and 2 (OECD,1980 and 1982), as well as promoting some steps at Level 4. The successive revisions of the Frascati Manual (Chapter 2) have all included an appendix on output measurement, stressing its long-term importance.

The National Science Foundation in the United States, whilst recognising the limitations of many of the existing output indicators, has nevertheless published since 1972 a biennial publication: Science Indicators (NSF, 1972-1982),which regularly includes some output indicators, even though these are not collected by the NSF, or other Federal Government Agencies, as part of the regular national statistics. These include statistics relating to patents and innovations as well as scientific publications.

The need for output indicators has been widely recognised by policy-makers for a long time. Whether in considering the allocation of government funds to various Research Institutes and projects, or in considering budgets for industrial R and D, decision-makers are constantly searching for some means of evaluating the past and probable future performance of individuals, groups and institutions. Appointments Boards for University posts commonly make use of information relating to the publications records of applicants. At the national level, Governments would like to be able to assess the quality of their scientific and technical institutions in various fields of endeavour, to compare these with the international competition, to identify areas of weakness, and to take remedial measures, where appropriate.

Even though research activities may account for a relatively smaller proportion of total scientific and technical activities in developing countries, the acute limitations imposed by scarcity of resources mean that it is imperative for policy-makers in these countries to make the best use of these resources (Bell et al., 1980). And even though the criteria by which output is assessed may differ somewhat from those used in the industrialised countries, the development of output indicators is certainly an important issue for policy-makers in all parts of the world.

The NSF publication Science Indicators represents the recognition by many policy-makers and some parts of the scientific community that something more is needed than R and D input statistics. The NSF of course is very well aware of the difficulties associated with the use of the existing indicators and the Science Indicators Unit at the NSF has placed 17 small research awards between 1979 and 1982 designed to advance the state of the art in output measurement. These have gone partly to individuals in academic institutions, such as University of Dayton Research Institute, New York University or Georgia Institute of

Technology, and partly to consultancy groups such as Computer Horizons Inc., The Futures Group Inc., and the Rand Corporation. About a third of them have been concerned primarily with research publications and citations. Dr. Charles Falk, who has inspired many of these new developments at NSF, has commented rather favourably on the use of such indicators:

> "Since the primary objective of ... [basic] research is the development of new knowledge, and since the type of knowledge involved is generally not subject to proprietary constraints, the announcement of such new knowledge is an excellent output indicator measure. Thus, bibliometrics, involving analyses of publications and citation counts, can provide a fairly good indication of both the quality and quantity of basic research output. Furthermore, since publications and citations can be counted relatively easily, a comprehensive computerised data base has already been developed, which has been used extensively to measure basic research output. Current bibliometric studies incorporate quite sophisticated analyses to identify and overcome inherent methodological difficulties." (Falk, 1982)

The NSF probably has more experience in the use of science and technology indicators than almost any other organisation in the world. Moreover, they have been rather cautious in their approach to output indicators of all kinds. Hence, the rather positive assessment of the uses of bibliometric techniques made by Charles Falk must carry considerable weight. However, it is by no means non-controversial and there has been considerable opposition to the use of these techniques, both within the scientific community and outside it. Therefore, it is important to review briefly the main features of this controversy in order to assess the value of the indicators and the circumstances in which they may be of value to policy-makers, particularly in developing countries. But, before embarking on this review, we must first of all dispose of two arguments which would seek to discredit all attempts to develop and use output measures in relation to scientific and technical activities.

First of all, it should be recognised at the outset that published papers do not comprise the total output from research activities (Table 1, Column v). Unsolved problems, oral communications, letters, internal memoranda and records, new types of instruments, are examples of output which may be very important for future scientific activity, but are, if not immeasurable, at least very hard to identify or measure. So, at the outset it must be conceded that published papers represent a partial indicator and not a total output measure of research activity. Nevertheless, the pressures and incentives to publish results are fairly strong within the science system throughout the world and the international character of scientific publication is very well established. Consequently, even though scientific papers do not represent the entire output of research activities, they do represent an extremely important part of that output, and one moreover which offers at least the possibility of international comparability. GNP statistics do not measure the entire output of any national economy; it is well-known that they are more deficient as a measure of economic activity whenever the domestic, informal, or non-market sectors are large. Nevertheless, GNP measures have often proved useful partial indicators for many different types of economy. Similarly, because publications are partial indicators of research activity (and as we shall see in Chapter 5, patents are also only partial indicators of inventive activity), this does not mean that they are of no value.

Secondly, it is sometimes argued that the relationship between input and output in an activity such as scientific research is too variable, uncertain and arbitrary to permit any valid attempt to assess "efficiency" of such activities, or to make comparisons between institutions or countries. This argument is often buttressed by reference to the supposedly accidental factors involved in the advance of science (see, for example, Taton, 1957). The logical fallacy involved in this sceptical attitude lies in assuming that because accidental elements are present in individual cases, it is therefore inpossible to make valid, useful generalisations about a large number of cases or a class of phenomena. There are unique, peculiar features about every individual street accident but this does not prevent us from forecasting with a fairly high degree of accuracy the probable number of street accidents each month and framing policies for prevention and emergency services accordingly. Or again the relationship between inputs and outputs is very variable in agricultural systems because of "accidental" factors (the weather, pests, etc). But this does not mean that information about crop yields, and other output data are useless, only that they require great care in their use and interpretation.

The nub of the contemporary controversies about the use of publications and citations as measures of reasearch output is the interpretation of the data. The most valuable contributions from Level 2 have been those which have demonstrated both the limitations and the positive features of the increasingly abundant information available from level 1, through the use of computerised abstracting services and citation analysis.

The Development of "Scientometrics"

Among the earliest applications of "bibliometrics" were those attempted by historians of science and sociologists of science (for example, Rainoff, 1929). Probably Derek de Solla Price has done more than any other living historian to develop and use bibliometrics as a research tool in the history of science. His earlier work (Price, 1961 and Price, 1963) was concerned mainly to demonstrate the steady exponential long-term growth pattern of world science in terms of numbers of scientists, scientific papers and scientific journals and to show that this process must reach a limit. More recently (Price, 1978) he has qualified this analysis by measuring and explaining the deviations from this long-term trend. Within this overall framework he has attempted international comparisons in contributions to scientific literature (Price, 1967), analysis of the variation in publishing patterns of individual scientists (Price, 1963) and comparisons of publishing patterns, respectively in science and technology (Price, 1965).

Although he has given a strong impulse to scientometrics generally, the main thrust of Derek Price's work has been to emphasize the statistical regularities in scientific publication. He tends to emphasize the similarities in patterns of publication across disciplines (except for technology) over time and across frontiers, and to minimise the significance of differences in quality between scientific publications and of socio-cultural differences between countries. Thus, for example, he emphasises that those scientists who have been responsible for the most important advances in science have also tended to be prolific in terms of quantity of output i.e. numbers of scientific publications. Consequently, he dismisses the notion that outstanding scientists might publish only a few very high quality papers, whilst second or or third-rate scientists might publish a large number of papers. Whilst there may be some justification for this very broad sweep in relation to the issues with which he was primarily concerned, it is precisely the analysis of differences which is of primary interest to policy-makers. Price sometimes appears to assume a relatively constant relationship between input and output, and even to use input and output measures interchangeably. Our interest here, however, is in the efficiency with which resources are used in a research system and in the cultural, organisational and social factors which affect that efficiency.

From this standpoint, probably the most valuable recent work has been that of Irvine and Martin (1980, 1981 and 1982), whose work has been received with interest by policy-makers in several countries. They have used bibliometric techniques for several different purposes: for the comparative evaluation of the work of Research Institutes in various countries (but in the same sub-disciplines of science); for the evaluation of the performance of a network of scientific institutions in particular countries, especially Norway (Irvine and Martin, 1981); and to throw light on specific policy problems.

Following Moravcsik (1973), they distinguish in their work between (1) scientific activity, (2) scientific production and (3) scientific progress. The first category corresponds simply to the consumption of inputs and is covered by existing statistics (see Chapter 2). The second category, they believe, is well covered by formal publications. Although they accept that in the early stages, informal communication channels (letters, invisible colleges, memoranda etc) may be very important, they assume that most of this informal output is subsequently incorporated into scientific publications. Moravcsik (1973 and 1977) has raised some doubts about the continuing validity of this assumption, but it is widely accepted. The novelty of the Irvine-Martin approach is that it attempts to combine a number of indicators relating to the third category - the so-called "convergent indicators" approach.

"Convergent Partial Indicators"

Irvine and Martin explicitly recognise that a simple count of numbers of scientific papers may sometimes give misleading indications if used alone as a measure of output. They accept the validity of many of the criticisms of this approach (e.g. Moravcsik, 1973), which point to such factors as the variations in social, institutional and political pressures affecting publication as well as quality variations and the uneven distribution of opportunities for publication. They point out that the apparent "productivity" of some theoretical physicists quadrupled over a 20-year period whilst that of experimentalists working in the same speciality apparently stayed constant (Sullivan et al., 1977).

From their review of the earlier literature Irvine and Martin (1983) conclude: (1) that numbers of papers must be used in combination with other partial indicators, which give a better indication of qualitative factors; (2) that the problems of comparison across different disciplines would require further modifications of their approach or a different approach altogether.

The other "partial indicators" which they make use of in their comparative international studies of radio astronomy, optical astronomy and nuclear physics institutions are citation analysis and peer judgement.

Irvine and Martin do not uncritically accept the view of Porter (1977) that citations are "the best practical indicator of the worth of research". They recognise that there are technical problems (such as multiple authorship), as well as more substantive problems, such as self-citation; negative citation; differences in the "referencing" behaviour of authors; "assimilative neglect" (very important contributions may no longer be cited after a while, such as $E = mc^2$); narrow scope for citation in highly specialised fields; "technique" citations and the "halo effect". They accept that the whole publication and citation system is itself to some extent a social artefact and must be seen in a changing social context. Distinguishing between (a) "quality", (b) "importance" and (c) "impact", like Garfield (1963), they regard citations as primarily an indicator of impact rather than quality or importance":

> "The citation rate is a partial indicator of the impact of a scientific publication: that is, a variable determined partly by (A) the impact of the paper on the advance of scientific knowledge, but also influenced by (B) other factors including various social and political pressures, such as the communication practices (for example, the reading and referencing habits of different individuals in different institutions, countries and research areas), the emphasis placed on numbers of citations for obtaining promotion, tenure or grants, and the existing visibility of authors, their previous work, and their employing institution. As with the numbers of publications it cannot be assumed that the effects of (B) are relatively insignificant compared to those of (A), nor that (B) comprises a set of random influences whose effects cancel out in analyses of large aggregations of scientists or for extended time periods. The 'other factors' that make up (B) are largely social and political rather than purely 'scientific', and while some of their effects on citation rates may be random, others can be expected to vary in a systematic way between individuals or groups of scientists occupying different cognitive and social locations". (Martin and Irvine, 1980)

Martin and Irvine* approach peer judgement in the same spirit as citation anlaysis: i.e. in full recognition of the sociological aspects of the problem. Just as the University promotion or appointments board

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* As befits authors working in this field, Irvine and Martin rotate first authorship in their own publications.

will recognise that the simple unaided use of numbers of papers or citation rates should be complemented by direct knowledge of the research field under review, so Martin and Irvine recognise that some type of "peer judgement" is another extremely important partial indicator. But they insist that to counteract the biases of many contemporary processes of peer judgement, a number of safeguards should be introduced (Table 4.1.C.).

Using their technique of "convergent partial indicators" Irvine and Martin have come up with interesting (though still controversial) results concerning the performance of research institutes in various disciplines. On the whole they have found a high degree of convergence between the various partial indicators. The leading institutions not only make a greater contribution to the world scientific literature, their papers are more frequently cited and they have a high proportion of the most cited papers. Finally, extensive interviewing of a high proportion of the research staff of the relevant research institutions (including young junior scientists as well as older ones) showed a very similar ranking order in relation to perceived contributions to world science.

The work of Irvine and Martin is of particular interest to policy-makers because it offers the possibility of an evaluation procedure, at least for parts of the science system, which overcome some of the main defects of other approaches. If all the partial indicators <u>do</u> converge, the results can be used with much greater confidence. If they do <u>not</u> converge, then the analysis of the factors underlying the

Table 4.1

Main problems with the various partial indicators of scientific progress and details of how their effects may be minimized

Partial indicator based on	Problem	How effects may be minimized
A. Publication counts	1. Each publication does not make an equal contribution to scientific knowledge	Use citations to indicate average impact of a group's publications, and to identify very highly cited papers
	2. Variation of publication rates with specialty and institutional context	Choose matched groups producing similar types of papers within a single specialty
B. Citation analysis	1. Technical limitations with <u>Science Citation Index</u>:	
	(a) first author only listed;	Not a problem for research <u>groups</u>
	(b) variations in names; (c) authors with identical names; (d) clerical errors;	Check manually
	(e) incomplete coverage of journals;	Not a serious problem for Big Science
	2. Variation of citation rate during lifetime of a paper - unrecognised advances on the one hand, and integration of basic ideas on the other 3. Critical citations 4. 'Halo effect' citations	Not a problem if citations regarded as an indicator of impact, rather than quality or importance
	5. Variation of citation rate with type of paper and specialty	Choose matched groups producing similar types of papers within a single specialty
	6. Self-citation and 'in-house' citation (SC and IHC)	Check empirically and adjust results if the incidence of SC or IHC varies between groups
C. Peer evaluation	1. Perceived implication of results for own centre and competitors may affect evaluation 2. Individuals evaluate scientific contributions in relation to their own (very different) cognitive and social locations 3. 'Conformist' assessments (e.g. 'halo effect') accentuated by lack of knowledge on contributions of different centres	1. Use a complete sample, or a large representative sample (25% or more) 2. Use verbal rather than written survey so can press evaluater if a divergence between expressed opinions and actual views is suspected 3. Assure evaluaters of confidentiality 4. Check for systematic variations between different groups of evaluaters

Use only indicators that yield convergent results lack of convergence may shed a great deal of light on the issues involved, as well as on the nature of the indicators. In any case, the results of such analysis can only be one of the inputs into national decision-making.

International Comparisons of Scientific Publications

An important conclusion for policy-makers in developing countries is that although a simple count of publications and the use of citation analysis may give a useful first approximation of the contribution of scientists from country X to a particular descipline, y, and the way in which this is changing over time, this must be complemented by a deep understanding of the sociological aspects of the measurement techniques being used. It may be an important stage in the development of country X to establish and build up publications in the language of country X. Initially and for some time, such publications may not be included in the "Citation Index" or other internationally used sources. The citation patterns may primarily reflect peculiar national circumstances, including the learning, monitoring and adaptive processes characteristic of countries which are in a "catching up" phase in relation to the leaders in world science and technology. However, at some point it will become important to assess how far scientists in country X have succeeded in gaining some degree of recognition in the world science community. "National" publication may become an alibi for low standards in scientific work. At this stage the various partial indicators which have been described may be very useful. An example of the use of "domestic" publication indicators combined with a "world" publication indicator is that of Tsukahara and Yamada (1982) who used this technique to demonstrate the level attained by Japanese technology in synthetic materials already in the 1930s.

Examples of the use of simple counts of publications are Frame (1980) and Macioti (1980). In a comparison of publication numbers with other science and education indicators for 13 Middle Eastern countries, Frame argues that the publication indicator correlates well with the other indicators, but is probably more reliable. Macioti uses the crude publication indicators to compare with the crude indicators of patent numbers (which are discussed in Chapter 5). His statistics of the numbers of scientific publications by authors from each country are derived from statistics of the Philadelphia Institute for Scientific Information, covering over 2200 scientific publications from 40 countries (Table 4.2). He points on the one hand to the relatively strong performance of Japan and Switzerland in the measures of inventive activity as compared with scientific publication. On the other hand he stresses the relatively strong performance of the UK and USA in scientific publication as compared with patenting.

This is a point which would not emerge from a comparison of R and D <u>input</u> statistics. Japan shows a rather high proportion of GERD (Gross Expenditure on Research and Development) going into basic research whilst both USA and UK show rather a low proportion by international standards. Part of the explanation probably lies in the way in which the various statistics are collected, for example in relation to university research. Japanese propensity to patent is probably higher than American or British. The Swiss need to patent more abroad because of their position as a small advanced industrial country in a large European market.

TABLE 4.2

A comparison of patents and scientific authors (Year 1976)

Country	Patents granted at home and abroad to residents	Publishing scientific authors (Quoted)	Patents / Authors
Switzerland	15.745	4,760	3.30
Japan	50.993	15,847	3.21
F.R. Germany	49.895	21.762	2.29
U.S.S.R.	44,271	24.050	1.84
Italy	11.000	6,992	1.57
France	23.759	18,087	1.31
U.K.	23.413	32.238	0.72
U.S.A.	105.614	155,929	0.67

There is also probably some language bias in the journal coverage of the Institute for Scientific Information. In 1976 the 2200 journals included 900 from USA and 400 from UK, but only 140 from France, 130 from Germany, 80 from Japan and 60 from the Soviet Union. Whilst there is some genuine lead of academic publications based in USA and UK (for historical reasons and because of the role of the English language in world science and technology), this distribution almost certainly underestimates the contribution of scientific publications in other languages. For a thorough discussion of these and other sources of bias, see the overview of the US Bibliometric Indicators series in Narin and Carpenter (1980). All of these sources of bias must be taken into account by researchers and policy makers in assessing the results of such comparisons as those made by Macioti (1980), as he himself clearly recognises. Nevertheless he is probably right that the contrast between Japan and Britain does indicate some real and important differences in the performance of their science-technology systems. He points out too that the rather high contribution of India to world science literature and the relatively lower contribution to world patents reflects some of the true strengths and weaknesses of the Indian science-technology system.

In an early application of the use of foreign publications in bibliometric analysis for policy purposes Oldham (1967) in a study for UNESCO, demonstrated that it could provide a useful guide for decision-making in relation to the comparative quality of research performance of university chemistry departments in a particular developing country. However, all such applications of output measurement techniques, require great caution and awareness of the complexities affecting both the measurement themselves and the social system which gives rise to these measurements. This implies that just as developing countries need to develop an indigenous capacity to screen, assess and modify the various foreign technologies which they may wish to import, so too, they need to develop an indigenous capacity to asses the performance of their new scientific institutions, both in relation to their own social needs and in comparison with world standards. We shall return to this point in the conclusions presented in Chapter 7.

CHAPTER 5

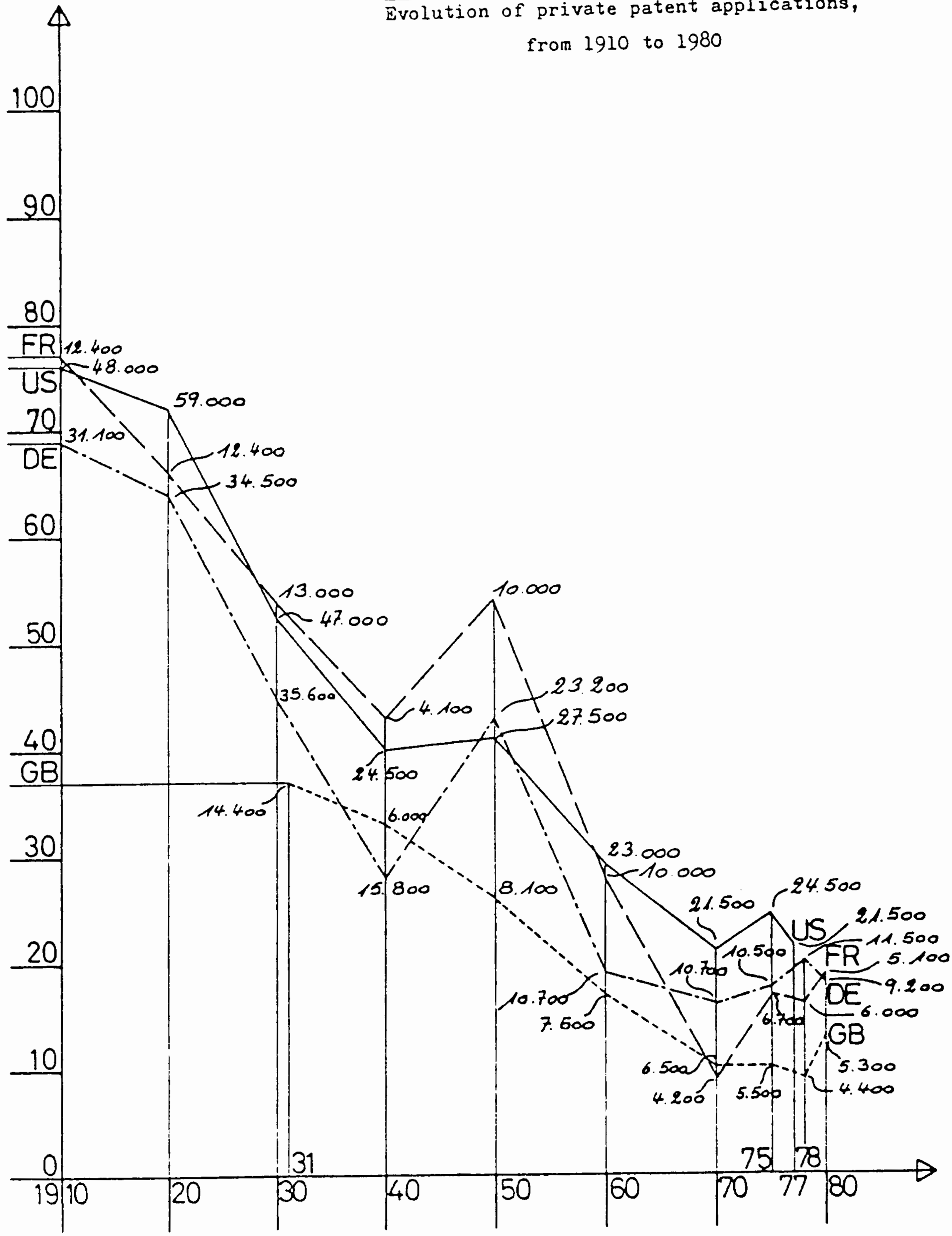
Indicators of Inventive Activities

Patent Statistics and R and D Statistics

A simple comparison between R and D "input" and a measure of inventive output, such as patents, can be dangerously misleading unless some account is taken of the great differences between the two types of measurement. In the first place, patents (and other measures of invention) do not arise uniquely from industrial R & D activities. In the United States between 1967 and 1978, a quarter of all patents of US inventors were still granted to individuals, and 3 per cent to government. Of the 72 per cent which were granted to corporations, many arose from the efforts of engineers, technicians and other workers outside the formal R and D structure. In France, Germany, and Britain, as in the United States, the proportion of patents granted to individuals has been falling during the 20th Century from about three quarters of the total to less than a quarter (Diagram 1). However, in Italy, in 1976 the proportion of applications from individual inventors as a ratio of total applications from Italian nationals was still over half of the total (Sirilli, 1982). In the second place, not all R and D activity is inventive activity. Between 10 and 25 per cent of GERD in most countries is devoted to fundamental research, from which the main output is publications, not inventions. Admittedly, the proportion of industrial R and D devoted to fundamental research is much lower, but even for applied research activity in industry, an important part of the output is also in the form of publications.

Private Patents as
% of all Patents

Diagram 1
Evolution of private patent applications,
from 1910 to 1980



Source: Kronz and Grevink (1982)

Derek Price (1965) has maintained that technology and science are largely independent fields of endeavour and that the characteristic modes of registering output are quite different between the two activities. However, he recognised that in some of the newer technologies, notably electronics and chemicals, publication of scientific papers by technologists or industrial scientists was increasingly important. If it is conceded that these two technologies are increasingly dominant throughout the industrial system, then it must be accepted that publications are now an important part of "output" for both basic and applied research. Indeed, as we shall see, the patent citation literature now increasingly refers to scientific publications as well. The more science-related nature of modern technology may indeed be one reason why patent numbers have increased at a slower rate since the second World War than either scientific publications, or industrial R and D activities.

In any case, the lack of correspondence between the input source and the output measures must give rise to great caution in the interpretation of input-output relationships. Finally, it must be continually kept in mind that patents are a measure of intermediate output. Both patented knowledge and unpatented knowledge contribute to the ultimate objective of industrial R and D activities - innovation output (Column (v) in Table 1.1). Both also contribute a feedback input to basic research (Column (i) in Table 1.1).

Several studies (for example Fabian, 1963; Pavitt, 1982) have compared the R and D input data by branch of industry with relevant patent statistics. It is by no means easy to re-classify patent information in this way, since they are collected and classified in most Patent Offices on an entirely different basis.(See,for example, the paper by Scherer (1981) on the OTAF classification system and the reply from Lawson (1982).) Nevertheless, such comparisons can be extremely instructive, as they offer clues both as to the nature and the limitations of the two types of data, and to possible weaknesses in the conduct of R and D in various firms, industries or countries. For example the aircraft industry in the USA and UK absorbs a very high proportion of total industrial R and D expenditures (as much as a third) but accounts for only a few per cent of the patents. This may be explained in terms of the government funding of most of the R and D and its effects on patents, the related issue of the high proportion of military work, the high costs of prototype testing, the nature of the technology and so forth. Soete (1978) argues that as the propensity to patent is lower in large firms than in small firms, the use of patent data may be more useful in dealing with small firms.

Already in 1961 at the Conference organised by the National Bureau of Economic Research on "The Rate and Direction of Inventive Activity", Schmookler (1962a and 1962b) came in for some heavy criticism for his attempts to use patent statistics. He expressed both surprise and delight that an NSF study showed a rather high correlation between patents pending and R and D expenditures. He described the correlation as higher than he would have expected, especially because a good deal of corporate R and D activity was not devoted to inventive work:

> "The production of patentable inventions begins towards the close of what the NSF calls applied research and terminates some time after the beginning of what it defines as development. The wide variation between industries and between firms of different sizes in the relative proportions of what the NSF defines as basic research, applied research and development and the existing uncertainty as to the precise location of pure inventive activity alone provide grounds for anticipating a less than perfect association between the output of patentable inventions and aggregate R and D expenditures. In view of these considerations, a correlation coefficient of 0.83 between the number of patents pending in 1953 and the 1953 R and D outlays of eighteen groups of firms suggests that it is quite reasonable to use the total number of patent applications as an indicator of fluctuations in inventive activity".(Schmookler, 1962b).

In view of these considerations, too, it is perhaps reassuring that some studies do not find such a close association between R and D expenditures and patents by industry. Sirilli (1982) in his study of Italian industry found far less relationship than Pavitt and found that patents per researcher were 5 or 10 times as high in some industries as in others. Such differences must reflect many other factors in addition to variations in the relative efficiency of R and D performance in various sectors of Italian industry.

Some Problems of Patent Statistics

As in the case of scientific publications and citations, it must be recognised that patents can only be a partial indicator of inventive activity, or of that part of R and D which leads to inventions (mainly experimental development and applied research). This is so for several reasons. In the first place, there are some types of invention which cannot be patented, for example computer software, either because of the way in which patent laws are framed, or because of difficulties in specification of the invention. Secondly, some types of incremental improvement are too insignificant to warrant all the effort (and often heavy expenditure) involved in applying for patent protection. Yet, in total these incremental improvements may amount to an important source of technical change. Thirdly, some inventors may believe that secrecy is a better form of protection than that offered by the patent law. This will apply especially to process inventions and according to some observers it is an attitude which has become increasingly widespread since the war. Fourthly, inventors may believe that the process of technical change in some areas is so rapid that patents may be overtaken by events, and are not worth obtaining. Finally, some firms may assign a very low value to patents or have policies which make it difficult to obtain patents for reasons peculiar to the management of that firm.

All of these could be reasons for believing that patent numbers may understate the 'true' output of inventive results, either in general, or for particular firms, industries, technologies, or countries. However, there are also reasons for believing that in some circumstances patent numbers may overstate this output or provide an inflated measure of its true significance. Sometimes firms may take out "blocking" patents i.e. try to protect their position by preventing competitors, at least temporarily, from following alternative technical solutions. Sometimes they may put up a "smokescreen" of relatively trivial patents to disguise the really important ones. Sometimes they may take out patents mainly to use as bargaining counters in negotiations with other firms in oligopolistic markets. Sometimes trivial patents may result from reward schemes for inventors within companies. This apparently occurred at one time in the US telephone industry (Sanders, 1962). The extent to which such "inflation" may occur will obviously vary with the national examination system and the fees which have to be paid. It is most serious where there is no examination and procedures are cheap and easy. It is less serious (and may even be of very little importance) in countries with rather rigorous examination, such as Germany or the Netherlands. The ratio of patent applications to patents granted varies from 4 in the Netherlands to 1 in Belgium.

This does not exhaust the reasons for approaching patent statistics with caution. Other difficulties relate to the variations in quality and significance between different patents and (in the case of international comparisons) other big variations between patent laws, enforcement practices, and anti-trust policies in different countries. For a full discussion of these problems see Harris et al. (1979).

Advantages and applications of Patent Statistics

Nevertheless, even those who are most wary of these and other dangers associated with the use of patents as indicators, seldom dismiss them entirely. It is almost universally recognised that, notwithstanding the qualifications made above, a vast amount of technical inventive activity does lead to patents and that patent records do constitute one of the most complete archives of technical information in the world. An American study (US Department of Commerce, 1977) suggested that about 80 per cent of US patents contain information that is not disclosed in the non-patent literature. If correct, this would imply that one of the main claims traditionally made for the patent system is still valid: it leads to a very widespread disclosure of new technical information. The world-wide nature of patenting activities and the fact that many patent records go back for more than a century (sometimes more than three centuries) are additional reasons for regarding patents as one of the most important indicators which are available. Schmookler (1966) put the matter very well when he said:

> "...we have a choice of using patent statistics continuously and learning what we can from them, or not using them and learning nothing about what they alone can teach us."

Progress depends on using these indicators, whilst taking full account of the genuine difficulties and taking appropriate steps in each specific case to minimise these difficulties.

For a long time, firms and individual inventors have recognised that they can learn a great deal about the progress of technique and about their competitors' activities by monitoring patent applications. This "level 1" use of patent indicators relies less on counting numbers of patents than on assessment of technical significance and direction of effort. Specialised firms, such as Derwent Publications, have developed to meet this need and now employ hundreds of engineers and scientists in this work. Patent records are and will remain an extremely important part of any scientific and technical information system. The more systematic use of numbers of patents as indicators has developed mainly as a result of Level 2 studies by academic researchers. These efforts have been greatly facilitated as a result of computerisation of many Patent Offices and related data bank developments.

In view of the long period covered by patent statistics, it is perhaps not surprising that historians, and others concerned with the analysis of long-term trends in the economy and in technology, were the leading figures in early applications. Already at the beginning of this century, Tisell (1907) used patent statistics to discuss the relationship between economic fluctuations and the level of inventive activity in Sweden. Since that time the analysis of this relationship has been a continuing although rather spasmodic concern of economists and technologists.

Jonason (1982) showed in her study of patent statistics in Sweden that although the numbers of patent applications fell during the Great Depression of the 1930s, they fell much more steeply in the leading industrial countries: USA, Germany and UK. Sweden recovered from the Depression more quickly than any of these three countries and the fall in Swedish industrial production was in any case far less. Jonason concluded that the fall in patenting activity in each of the four countries was broadly related to the severity of the Depression and speed of recovery, with the patent indicator lagging a little behind the indicators for production. Freeman, Clark and Soete (1982) also showed that the index of patent applications for the United States reflected the influence of the deep depression of the 1830s and 1930s, but that an index of "key patents" showed fluctuations which were apparently independent of these major cycles. We shall return later to this distinction between ordinary patents and key patents.

Just as Derek Price was largely responsible for stimulating more widespread public interest in the use of publications and citations as indicators of scientific output in the 1960s, the same role was played by Schmookler in relation to patent statistics as indicators of inventive output. Already in the late 1940s he began his patient work with the United States patent archives assisted by a number of post-graduate students. In several early publications (Schmookler 1950, 1953, 1954) he defended the use of patent statistics as indicators of inventive activity although always carefully qualifying his conclusions and recognising such problems as variations in propensity to patent between firms and industries, legislative changes, the scale of government-funded R and D, and Patent Office procedures. His major contribution to economic history (Schmookler, 1966) was published just before his untimely death.

Despite his scholarly approach to these problems, as already noted, Schmookler came in for some heavy criticism (Sanders, 1962) at the Conference organised by the National Bureau of Economic Research in 1961 on "The Rate and Direction of Inventive Activity". This conference was a land-mark in the use of scientific and technical indicators. The main controversy surrounded the issue of the post-war trend in the numbers of patents in the United States. Several participants pointed to the contrast between the very high rate of increase in R and D expenditures since the Second World War and the absolute decline (or stagnation) in numbers of patents compared with the 1920s. Schmookler (1962a) himself offered a number of possible explanations for this contrast. These mainly concerned the shift away from ingenious individual mechanical inventions associated with the shift of inventive activity to large corporations, who had less incentive or need to patent than private individuals or small firms, and who in any case were under various pressures (especially anti-trust activities), likely to induce them to patent less.

Schmookler (1962b) vigorously defended his use of patent statistics, maintaining that if used in full awareness of their limitations, they were the best available indicators of trends in inventive activities. In his (1966) analysis of economic fluctuations in the United States economy between 1850 and 1950 he maintained that in the capital goods industries inventive activity responded to changes in demand for the various types of capital goods. He drew this conclusion from the observation that the indicator of inventive activity (numbers of patents) tended to turn down some time <u>after</u> a down-turn in capital investment in the relevant industry, whilst it turned upwards, again with a short time lag, following a revival of investment. From these statistical observations Schmookler derived a general theory of demand-led invention.

Patent Statistics and the Demand-Pull Controversy

Recently these rather general conclusions have been questioned, notably by Mowery and Rosenberg (1979). Other studies (particularly Walsh et al., 1978) have shown that in some industries, such as drugs and synthetic materials, there is statistical evidence suggesting that at least for some periods there are "counter-Schmookler" patterns, when indicators of inventive activity (and of scientific activity as measured by publication counts) appear to lead the economic indicators of investment and production. Freeman, Clark and Soete (1982) have suggested a theoretical framework which could reconcile these divergent findings: in the very early phase of introducing a new technology (which may last only a decade or two and may often be associated with a scientific breakthrough), a surge of scientific and inventive activity shows the possibility of a range of new products and markets. The subsequent exploitation of these possibilities leads to many new inventions, including a vast number of improvement inventions and process inventions associated with economies of scale. By now the characteristic "Schmookler pattern" has set in and may easily last for a century or more, as he maintained. Invention is now highly sensitive to the stimulus of market demand (or lack of it). Product and process improvements reflect the changing nature of the market and the competitive pressures at work; not surprisingly, large fluctuations in aggregate demand may depress or stimulate the total number of inventions, as shown by Jonason (1982).

Whilst this controversy about the relative significance of "demand-pull" and "discovery (or technology) - push" is mainly an academic one, i.e. at Level 2, it clearly has major implications for Level 3 (government). Insofar as policy-makers may wish to stimulate scientific and technical activities in any particular country, with regard to their potential economic benefits, then the techniques which are appropriate at an early stage of growth of a new technology (e.g. some of the newer bio-technologies today) may not be the most appropriate at later stages. At the embryonic stage support for scientific research and for R and D generally may be the most important form of public involvement. But at later stages, such subsidies might actually do more harm than good; then the most effective public policies may involve procurement contracts (encouraging exploitation of economies of scale, as well as product and process improvements), investment subsidies consultancy and information dissemination activities.

Schmookler (1966) himself maintained that (at least for his purposes) it was not desirable to attempt any qualitative evaluation of the significance of patents. He pointed to the strong subjective element involved in any attempt to rank patents in terms of importance, to the difficulties of establishing any satisfactory criteria for such ranking, and to the extremely time-consuming nature of the work. He also maintained that by using large numbers of patents over fairly long periods, the differences in quality could be disregarded, because of the law of large numbers.

Freeman, Clark and Soete (1982) criticised Schmookler's failure to pursue the distinction between "key patents" (or "master patents") and improvement patents, maintaining that this distinction, although admittedly difficult to measure, was sometimes essential to a proper understanding of growth cycles of products, industries and technologies, as well as their relationship with wider economic fluctuations. They themselves (Clark, Freeman and Soete, 1981) made use of Baker's (1976) work, which systematically listed "key patents" and "master patents" in the British patent archives. Other criticism of Schmookler's neglect of this distinction comes from the detailed study of specific innovations, as for example in Wiseman's (1983) study of synthetic fibre intermediates.

Other "partial indicators" of inventive output

Like Irvine and Martin, Schmookler had shown himself well aware of the sociological factors involved in the development of various measures of the output of scientific and technical activities. But whereas this awareness led them to the combined use of several partial indicators, in Schmookler's case it led him to a rather restricted use of counts of patent numbers in applications where (in his view) the various limitations were not of great significance.

Most other researchers since Schmookler, whilst accepting part of his argument, have not felt able to go along with his complete neglect of the qualitative differences between patents. For some purposes these differences clearly are very important, as in the analogous case of scientific publications. The OECD (1980) Science and Technology Indicators Conference pointed to qualitative differences as one of the major limitations of patent statistics, along with variations in propensity to patent; non-patented types of inventive activity; and varying rates of disclosure and commercialisation.

As in the analogous case of scientific publications, it might be possible to cope with the problem of quality variation at least in part by the use of citations. Any attempt to do so should take account of Martin and Irvine's (1980) point that citations are, strictly speaking, a measure of impact rather than intrinsic quality. The impact may partly reflect quality factors, but it has other aspects too (e.g. the "halo effect"). It seems likely that this is even more true of patent citations. Whereas a great deal of work has already gone into the use of literature citations, very little work has been done on patent citations. The Battelle Institute (Campbell and Nieves, 1979), together with Computer Horizons (Narin 1982 and Carpenter, 1981).

Narin and Carpenter compared US examiners' citations for 100 patents known to be associated with important technological advances with a random sample of 102 patents. The "important patents" were identified through the awards of the journal Industrial Research and Development for the "most significant new technical products" in 1969 and 1970. The results showed that the "key" patents were cited twice as often by examiners as the control group of "normal" patents (Carpenter, Narin and Woolf, 1981).

Whilst this is an important result, much remains to be done in the study of referencing behaviour patterns in various countries before patent citations can be used with as much confidence as literature citations. It is probably the case that legal aspects of prior inventive activity, as well as competition between firms, have some influence on citation patterns and chains. However, patent citations may also prove very useful in the exploration of linkages between basic science literature and industrial research and development. Several studies have already shown the importance of these links by study of literature citations (for example, Lieberman, 1978). The use of the patent citation literature will add an extra dimension to this research and could prove extremely fruitful. The nature and strength of the interaction between the university science community and the industrial R and D community must be a matter of concern to policy-makers in any country and may be especially valuable for developing countries in the "overtaking" phase.

The Battelle Institute have also demonstrated the commercial potential of patent citation, as well as of patent statistics themselves, for providing a "technological profile" of a company. From 1982 Computer Horizons has also been able to offer a commercial service covering several thousand US companies, which includes a ten-year "combined profile" (1971-1980) or a year-by-year profile of each company. Similar computerised information services have been provided by Derwent Publications (UK) for some time, and are increasingly available from national patent offices, as well as from INPADOC (the

International Patent Documentation Centre set up in 1972 by the World Intellectual Property Organisation and the Austrian Government). From time to time these services may well be of value to policy-makers in developing countries, for example in considering investment or licensing proposals from various multi-national companies, or in assessing the principal sources of technical know-how in rapidly growing new technical fields.

It is still a little early to assess the value of patent citation in the measurement of "impact" or"quality". However, some other techniques have been used to provide additional "partial indicators". Mention has already been made of Baker's (1976) work which demonstrated the feasibility of distinguishing "key patents" and "master patents" over a wide range of technologies. It is also possible in some cases to combine indicators of inventive and of innovative output (see Chapter 6).

<u>International Comparative Applications of Patent Statistics</u>

Not all appliaations of patent statistics depend upon the introduction of "weighting" systems or other partial indicators. Schmookler's argument about the law of large numbers may often be valid. The great importance of patent statistics for understanding the role of technological competition in international trade performance has been demonstrated in several publications by Pavitt and Soete (1980); Soete (1978, 1981 and 1982) and by Pavitt (1982).

They tend to treat patent statistics and R and D statistics as alternative or complementary measures of inputs into innovation, rather than using the one as a measure of the output of the other. Pavitt (1982) in a thorough exploration of some of the issues involved, claims that with the exception of a few industries, such as aircraft, there is a broad correspondence between the percentage distributions by branch of industry of patents and R and D expenditures respectively, for the leading industrial countries (Table 5.1).

This work has made an extremely important contribution to the understanding of scientific and technical inputs and outputs for several reasons. On the methodological level, Pavitt and Soete have demonstrated the great value of using patenting in the US as a common denominator, which eliminates many of the problems raised by the incomparability of national patent systems and statistics. This procedure can be justified on several grounds, including the size and importance of the US market and its world technological leadership. It also acts as a filtering or screening device since companies will tend to make applications in the United States only for their more important patents. On a more fundamental level this work has made a major contribution to the theory of international trade (Soete, 1978 and 1981). Ultimately it may be possible to use the new European Patent Data collected since 1978 as an alternative to US patents, but as several papers at the OECD workshops (1980 and 1982) showed, this will only be possible after adjustment to the new European system.

Table 5.1
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	11.8	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	43.5	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	16.0	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: Pavitt (1982)
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.

The international comparative applications of patent statistics are likely to be of particular interest and importance for policy-makers in developing countries. Initially, such countries are likely to be heavy importers of industrial know-how and patent information may be of value primarily in the identification and monitoring of potential sources of imported technology and of their various strengths and weaknesses. Where industrialisation policies are successfully pursued, the measurement of local patenting activities may become of growing importance. Macioti (1980) showed that only 37 countries granted more than 1000 patents per annum in 1976 but these included Argentina, India, Mexico, Korea and Venezuela. Only 16 countries originated more than 1000 patents abroad, per annum (Table 5.2).

Macioti (1980) fully recognises that such data can give only a very crude first approximation to world-wide trends of inventive activity. Differences in patent laws, in trading blocs, in industrial specialisation and in national policies all affect the interpretation of these simple statistics. Whereas the technique used by Pavitt and Soete "normalises" for some of these variations (Table 5.3), these comparisons do not. Nevertheless, as we have seen he is able to point to some interesting contrasts with world scientific publication patterns as measured by the equally crude first approximation of the statistics of the Philadelphia Institute for Scientific Information.

TABLE 5.2

Patents granted in 1976[a)]

Country	Grants of patents to: Residents	Non-residents	Total	Grants obtained abroad[b)]
Argentina	1,264	2,843	4,107	117
Australia	910	10,164	11,074	948
Austria	1,177	5,235	6,412	2,015
Belgium[b)]	1,034	12,110	13,144	2,115
Bulgaria[b)]	752	675	1,437	169
Canada	1,301	20,449	21,750	2,950
Czechoslovakia	4,880	2,120	7,000	1,042
Denmark	208	2,068	2,276	1,241
Finland	291	921	1,212	761
France	8,420	21,334	29,754	15,339
German D.R.	3,755	2,375	6,130	2,433
F.R. Germany	10,395	10,570	20,956	39,500
Greece	1,343	1,285	2,628	71
Hungary	594	1,155	1,749	1,260
India	433	2,062	2,495	64
Iran	64	1,969	2,033	
Ireland	27	1,046	1,073	119
Israel[b)]	210	1,932	2,142	293
Italy[c)]	5,000(?)	18,000(?)	23,000	6,008
Japan	32,465	7,852	40,317	18,528
Luxembourg	95	1,954	2,049	316
Mexico	500(?)	1,990(?)	2,490	197
Netherlands	370	3,219	3,589	5,900
New Zealand	193	1,147	1,340	214
Norway	210	1,883	2,093	664
Poland	5,619	2,380	7,999	382
Portugal	46	1,319	1,365	
ROK (Korea)	3,593	1,727	5,320	
Romania	1,123	572	1,695	150
South Africa	2,442	5,287	7,729	458
Soviet Union	41,259	1,883	43,142	3,012
Spain[b)]	1,972	7,286	9,258	841
Sweden	1,888	6,967	8,855	5,067
Switzerland	3,482	8,818	12,300	12,263
United Kingdom	8,855	30,942	39,797	14,558
United States	44,162	26,074	70,236	61,452
Venezuela[b)]	223	1,215	1,438	

a) In the Socialist countries (and in particular in Bulgaria, Czechoslovakia and the Soviet Union) residents usually only obtain an author's certificate (with no monopoly right), while non-residents are usually granted patents. The data listed in the above table for these countries include both types of grants: It should however be noted that the technological value of the authors' certificates is very doubtful and that accordingly the position of the Socialist countries in the tables of this article should be considered definitely overstated.

b) Statistics for 1975.

c) Statistics for 1974.

Source: WIPO Statistics for 1976

Table 5.3 Patents Granted (1/63-12/81) by Country of Origin in the USA

	NUMBER OF PATENTS															
	63-67	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	TOTAL
TOTAL	289968	59103	67559	64429	78362	74763	74142	76278	72002	70227	65269	66100	48852	61819	65770	1234643
U.S. ORIGIN	231825	45783	50395	47077	56011	51496	51503	50649	46713	44277	41484	41252	30079	37356	39224	865124
FOREIGN ORIGIN	58143	13320	17164	17352	22351	23267	22639	25629	25289	25950	23785	24848	18773	24463	26546	369519
WEST GERMANY	15841	3442	4523	4435	5525	5726	5587	6153	6036	6180	5537	5850	4527	5747	6250	91359
JAPAN	4416	1464	2152	2625	4030	5149	4939	5888	6352	6543	6217	6911	5251	7125	8388	77450
UNITED KINGDOM	11696	2481	3178	2954	3470	3161	2855	3145	3043	2991	2651	2722	1910	2406	2475	51138
FRANCE	6231	1446	1809	1731	2215	2228	2143	2566	2367	2408	2108	2119	1604	2088	2181	35244
SWITZERLAND	4127	822	1058	1112	1281	1305	1328	1454	1456	1475	1347	1330	1025	1265	1239	21622
CANADA	4036	897	993	1066	1330	1237	1346	1326	1296	1192	1219	1226	862	1080	1135	20241
SWEDEN	2427	569	675	628	843	774	762	925	914	1002	862	826	573	822	766	13368
ITALY	1967	477	556	571	727	837	759	807	738	753	756	725	596	806	883	11958
NETHERLANDS	2192	476	559	543	696	672	686	731	617	744	708	659	525	654	641	11103
U.S.S.R.	236	95	159	218	333	356	382	492	421	426	394	412	354	460	373	5111
BELGIUM	760	169	220	233	305	319	283	348	277	334	255	264	185	244	263	4459
AUSTRIA	599	160	191	189	250	271	236	294	310	296	243	274	222	286	279	4080
AUSTRALIA	521	119	155	144	200	182	202	234	248	261	243	281	211	265	319	3585
DENMARK	445	82	144	138	169	173	154	178	146	178	155	168	105	157	130	2520
CZECHOSLOVAKIA	264	96	132	118	153	110	94	112	117	111	93	91	50	55	41	1637
NORWAY	236	49	69	68	77	88	83	91	103	103	106	89	80	79	93	1414
FINLAND	110	31	43	46	59	69	88	109	98	109	105	125	77	121	140	1330
ISRAEL	177	38	61	46	54	55	84	88	95	105	94	99	84	113	123	1316
S. AFRICA	236	35	65	50	71	54	86	86	74	83	68	81	64	74	111	1238
SPAIN	190	48	59	57	74	60	87	89	93	102	96	92	49	65	58	1219
MEXICO	394	40	67	43	64	43	42	51	67	78	42	24	36	41	43	1075
HUNGARY	107	21	22	37	38	48	46	62	51	75	80	66	83	87	98	901
NEW ZEALAND	66	13	16	14	17	26	25	20	28	33	32	41	23	51	47	452
POLAND	35	25	31	33	31	21	25	27	36	26	24	33	29	36	38	450
ARGENTINA	100	18	17	23	22	29	28	24	24	24	20	21	24	10	25	417
BRAZIL	67	13	18	16	14	16	18	21	17	18	21	24	19	24	23	329
ROMANIA	16	21	21	37	35	33	25	35	17	15	18	11	10	14	10	318
CHINA(TAWIAN)							1		23	28	52	29	38	65	80	316
LIECHTENSTEIN	54	15	14	23	28	10	14	15	13	21	11	11	8	18	20	275
IRELAND	23	10	13	12	29	18	28	17	15	20	17	21	10	17	17	267
BULGARIA	7	1	7	9	11	10	16	13	24	19	33	32	14	23	27	246
HONG KONG	37	7	7	8	20	7	15	9	10	20	9	21	13	27	33	243
INDIA	34	15	18	16	10	19	21	17	13	17	13	14	14	4	6	231
EAST GERMANY									21	31	25	24	19	35	52	207
LUXEMBOURG	25	7	2	1	5	8	6	19	16	15	16	16	21	13	27	197
OTHER CNTRIES (77)	471	118	110	108	165	153	147	185	113	114	115	116	78	97	111	2201
U.S. ORIGIN	231825	45783	50395	47077	56011	51496	51503	50649	46713	44277	41484	41252	30079	37356	39224	865124
U.S. CORP. OWNED	164864	33351	37073	34948	40850	37855	36812	36073	33395	32136	29546	29380	21125	25910	27592	620910
U.S. GOVT. OWNED	6951	1458	1806	1761	2136	1764	2078	1727	1882	1807	1480	1228	951	1226	1112	29367
U.S. INDIV. OWNED	59410	10768	11299	10096	12597	11555	12346	12549	11181	10081	10248	10400	7809	9940	10243	210522
FOREIGN OWNED	600	206	217	272	428	322	267	300	255	253	210	244	194	280	277	4325
FOREIGN ORIGIN	58143	13320	17164	17352	22351	23267	22639	25629	25289	25950	23785	24848	18773	24463	26546	369519
U.S. OWNED	7035	1596	1885	2028	2321	2119	2048	2207	2254	2322	2018	2045	1443	1774	1887	34982
FOREIGN OWNED	51108	11724	15279	15324	20030	21148	20591	23422	23035	23628	21767	22803	17330	22689	24659	334537
FOREIGN CORP.	36994	8837	11779	11855	15780	16732	16412	18612	18566	19469	17827	18768	14339	18495	20387	284852
FOREIGN GOVT.	1008	134	258	216	84	71	70	53	175	230	220	273	214	344	362	3712
FOREIGN INDIV.	13106	2753	3242	3253	4166	4345	4109	4757	4294	3929	3720	3762	2777	3850	3910	65973

Source: OTAF Special Report - All Technologies.

From all that has been said, it is clear that there are many actual and potential applications of patent statistics which could be of great interest to policy-makers in some developing countries. But it is also clear that such applications are frought with methodological difficulties and require great care in analysis and interpretation. These aspects of the problem are dealt with in the conclusions and recommendations in Chapter 7.

CHAPTER 6

Indicators of Innovative Activities

New Developments of Innovation Indicators

Indicators of innovation and diffusion of innovation are probably the most important area of output measurement from the policy standpoint, but at the same time they are the most difficult, conceptually and in practical terms. In the area of scientific publications and patents, there is an abundance of statistics and the problems are those of interpretation, critical analysis, qualitative assessment and selection of techniques appropriate to the problem under review. In the area of innovation measurement there is a real dearth of elementary raw data, as well as all the other problems. For innovations there is no equivalent of the Institute for Scientific Information, the Citation Index, the Patent Offices or INPADOC.

However, even in this area there are some encouraging developments to report. It will be a long time before anything equivalent to the data banks on scientific publications or patents is available, but in three major European countries (German Federal Republic, France and UK) much more deliberate efforts are now being made to assemble comprehensive information about innovations on a regular and systematic basis. These efforts mean that ultimately it may be possible to go beyond the "do-it-yourself" innovation statistics of individual scholars working at level 2 on particular industries or product groups.

The work of Hufbauer (1966) on synthetic materials, of Flueckiger (1972) on steel, of Townsend (1976) on coal-mining machinery, of Priest (1977) on railroads, of Mansfield (1977) on chemicals, of Abernathy (1978) on automobiles, or of Dosi (1981) on microelectronics on all examples of the value of innovation indicators for economic analysis, historical interpretation and policy advice. But each of these studies required a great deal of individual painstaking and time-consuming effort at data collection. Often, it has been through the dedicated efforts of post-graduate students that such studies have been completed.

There is now a serious possibility that during the 1980s these individual efforts will be supplemented by much more comprehensive data collection. In the German Federal Republic, one of the leading applied economic research institutes, IFO in Munich, has been collecting innovation statistics on a regular quarterly basis since 1980 (Scholz, 1982). IFO has close contacts with German industry and its quarterly survey of investment and other trends in the German economy is well established as a source of 'Konjunktur' data. The innovation data can thus be related to other information on investment, employment, output, and research and development collected on a similar basis. The first statistical results are beginning to emerge, although still on a confidential basis. Other German research institutions are now also becoming involved in the measurement of innovation, notably the Institute for Systems Innovation in Karlsruhe, affiliated to the Fraunhofer Gesellschaft, a major Government research network.

In France, André Piatier and his co-workers at CETEM (Ecole des Hautes Études en Sciences Sociales) have completed a major survey of French innovations, with the support of French Government Agencies. The interest of the French Government has also been shown in the establishment of a major new policy research unit in 1982, with a strong interest in the development of science and technology indicators.

In the UK the British Technology Group (the Government organisation concerned with the finance and promotion of innovative enterprises) has supported an experimental quarterly survey of innovation in collaboration with the Financial Times This was initiated by Paul Joachim at the British Technology Group and represents the most original and promising initiative in the field of innovation measurement. Whereas most other innovation surveys depend on circulating questionnaires to industrial respondents, the BTG Data Bank is based on "bibliometric" techniques. It thus offers the potentiality of a truly international archive of innovation, which would not be dependent upon the official machinery of industrial surveys in each country, with their attendant problems of inertia and resistance from government statistical offices and reluctance of hard-pressed respondents to provide the information. The difficulties of collecting additional information on "outputs" through the official R and D surveys have already been noted in Chapter 2.

The assumption of the BTG Data Bank is that at the point of commercial introduction firms will almost always wish to gain publicity for their product innovations (although not always for their process innovations). Consequently systematic abstracting from the *Financial Times* itself, together with similar trade and technical journals in all the leading industrial countries, should lead to the identification of by far the major part of the flow of product innovations, including the minor, incremental innovations which are frequently overlooked or neglected in other types of survey. There are, of course, teething problems involved, as with the experimental development of any other major innovation in data collection and analysis. Among the main problems are that of national bias, which as we have seen, also affects the data for scientific publications and (to a lesser extent) the patent archives. At the moment the survey covers only a few countries (US, Japan, UK, France, German Federal Republic), which however together account for a high proportion of contemporary industrial innovation. Lesser problems, such as the screening out of repetitious announcements, are being overcome.

At present the future of this extraordinarily promising innovation is still uncertain as it depends on commercial subscriptions to the data bank. But, whether it develops on a private commercial basis, or with governmental support, or on a mixed basis, its future is of the greatest importance, as it offers the ultimate promise of a global archive of innovations, comparable to patent or publication data. It is especially important that the interests of developing countries (so far unrepresented) should find expression at some stage in the development of such services (see Chapter 7).

Although the development of large-scale international computerised data banks, on the lines of the BTG/FT Innovation data bank, is the most hopeful long-term prospect, it would not in itself resolve all the problems. Process innovations are likely to be seriously under-represented and, as we have seen, this bias is probably a feature of patent statistics as well. It is also probable that organisational, system and social innovations would be under-represented in this type of enumeration. There may well be other sorts of bias, as yet unrecognised, in a bibliometric approach to innovation measurement. Finally, there are problems of classification and ranking of innovations which could not be tackled directly through this type of data collection.

For these and other reasons, innovation measurement based on bibliometrics must be complemented and checked by other types of data collection and analysis, such as the industrial survey techniques employed by IFO. In addition, because these types of measurement have only just begun, it is desirable to build up retrospective innovation data banks. The most ambitious of such efforts is being undertaken at the Science Policy Research Unit at the University of Sussex. For some time efforts have been made at SPRU to measure British innovations in a large number of industrial sectors. The first efforts covered about half of manufacturing industry for the period 1945-1970 (Freeman, 1971). This was later extended, to cover the period 1971-1980 and some additional sectors (Townsend, 1982). Most recently the coverage is now being extended to cover all industries, including service sectors. In addition a survey is being undertaken of the most important world innovations over the past half century.

One of the main problems encountered in the SPRU work has been the ranking and classification of innovations. This is clearly a problem for any innovation data bank, as with the definition of "novelty" in any patent system based on examination. It is also an even more difficult problem in those data banks and applications which attempt to identify "basic" innovations, "radical" innovations, or "important" innovations. These problems came to the forefront in the controversy surrounding Mensch's work on "technological stalemate" (Mensch, 1975; Clark, Freeman and Soete, 1981a, 1981b; Kleinknecht, 1981; Mensch, 1981), where the identification and classification of 'basic' innovations was one of the main issues. The limitations and subjective bias of 'experts' or 'panels of experts' has been one of the difficulties in some of the United States work on measurement of innovations (Buzzelli, 1982). Work at SPRU and at IFO is attempting to overcome this problem by developing more objective criteria or guidelines for the ranking and classification of innovations.

Innovation Measurement Systems

All of these surveys are based on discrete innovations as units of measurement. Priest and Hill (1980) have argued cogently that this is potentially the most fruitful approach to innovation measurement. In their view it is likely to give more useful results than the alternatives of the production function residual approach, sometimes used in econometric analysis, or the attempts to measure specific attributes of particular products, such as aero-engines or tractors (Alexander et al, 1973; Coombs et al, 1980). The "product attribute" approach, although certainly relevant to product innovation, and having the advantage of measuring gradual improvements, which are difficult to specify in terms of discrete innovations, nevertheless is difficult or impossible to generalise and is relevant primarily to improvement innovations within a small group of eatab-lished products. The production function approach does not identify innovations; it cannot solve the problem of complementarity between the various inputs into technical change, and is in any case relevant only to process innovation.

Priest and Hill conclude that the discrete measurement of innovations has "the potential to be accurate and universally applicable to identifying any type of technological innovation". While this claim may be a little strong it does seem, from the experience of the last 20 years, that discrete innovation measurement does offer the greatest probability of building up a comprehensive source of information and of usable statistics.

Priest and Hill (1980) stress the importance of developing an appropriate taxonomy of innovations, so that the measurement system is comprehensive and does not overlook particular classes or sub-sets of innovation. The method of interrogating firms or of inviting expert panels to list innovations may lead to the neglect of certain types of innovation, as well as carrying the risks of subjective bias. For example, they stress the importance of "level of resolution"; at one level, only major product innovations would be identified, whereas at another level numerous component and sub-system innovations would be included. In their view, Flueckiger (1972) provided a thorough and logical solution to this problem in his work on research, invention and innovation in the steel industry from 1700 to 1899. He identified 93 innovations, all of which could be considered as modifications of a single entity - the "iron and steel" industry. But of these 93 innovations nine were "entirely new", while the remaining 84 were "improvements", either to the original production equipment or to the nine entirely new types of equipment introduced over the period.

However, this approach does not cover all types of innovation in the steel industry and nor is it appropriate for other types of industry, especially those characterised by numerous product innovations and product improvement innovations. Priest and Hill give other examples, particularly from the drug industry

(Schwartzmann, 1976 and Hattis et al, 1980) and the railroad industry (Priest and O'Neil, 1977), where other methods were used to deal with the problem of "level of resolution". In the drug industry, as a result of administrative requirements, various regulatory agencies have introduced procedures which greatly facilitate the classification of new drugs, for example into "new chemical entities", "new salts", "new formulations", "new combinations" etc. In railway terminal operations Priest and O'Neil identified 350 innovations and classified them into three groups: physical (mostly mechanical innovations); operational innovations in procedures and processes; and institutional innovations in organisational configurations. They found that innovations occurred with almost equal frequency in all three areas and were frequently inter-active. They sub-divided the three main categories into 13 sub-categories, thus ending up with 3 "levels" of analysis.

These various examples suggest that the problem of "level of resolution" cannot be divorced from the issue of assessment of "importance" even if this judgement is made mainly in relation to a taxonomy for each industry. This means that the use of several partial indicators will be as important in some applications as in the field of scientific publications and patent statistics. The simultaneous use of several partial indicators for invention and innovation may demonstrate "convergence" but may also throw up differences which shed light on relative performance of firms, industries or countries. In a limited field Freeman et al. (1963) demonstrated the potential value of using several partial indicators of inventive and innovative output in a comparative study of industrial firms in the plastics industry. They showed that the German chemical trust (IG Farben) and its various constituent firms contributed 20 per cent of all plastics patents taken out by firms from 1791 to 1945, but 26 per cent of the major technical advances identified by a scientific consultant in the patent literature; 32 per cent of the innovations and 45 per cent of the major innovations (Freeman, 1982). The innovations were identified on the basis of their impact in world trade.

This particular study therefore, whilst confirming the extremely strong contribution of the leading German chemical firms, as measured by all the indicators, also suggested that a simple count of patent numbers understated their "true" contribution to inventive and innovative output. The reverse may be true in other cases, so that the combined use of indicators of inventive and innovative output may well be particularly important in assessing strength and weakness in different parts of the innovation system. Bassberg (1982) gave a further illustration of the value of combining measures of innovation (and diffusion of innovation) with patent statistics in his study of the Norwegian whaling industry.

As these examples suggest, simple "counts" of innovation numbers may be supplemented by "weighted" contributions to innovation, as determined by peer judgement techniques, by attribute measurement and by some measures of "impact", where time and resources permit such detailed assessment. The importance of taking into account component innovations and sub-system innovations and not just considering major single, discrete, product innovations is shown by the work of Stoneman (1976 and 1983) on the computer. He distinguishes four generations of computers (the "5th" generation is now the subject of intense R and D activity in the leading industrial countries). The distinguishing feature of each successive generation was the change in active components: from valves to transitors, then to integrated circuits and large-scale integration. The performance characteristics and the price of computers were so drastically changed with each successive generation that the diffusion process could only be realistically interpreted and modelled in the light of these price-quality changes during diffusion. This obviously means that the "level of resolution" adopted in classifying innovation in the electronic industry could be for some purposes well below the level of "the computer". The collection of data in a large number of industries simultaneously will in itself contribute to the solution of such problems, providing the inter-industry relationships are adequately considered. Thus, for example, if the electronic component industry is studied in relation to end-products (such as the computer) a more satisfactory taxonomy of innovation can be developed. This example already shows the close connection between "innovation" studies and the analysis of "diffusion" to which we now turn.

Diffusion of Innovations

All of the evidence which is now available indicates an overwhelming concentration of R and D inputs and other STS inputs in the highly industrialised countries (Bell et al., 1980). Even though there are reasons for thinking that the available output indicators may understate the true contribution of some countries to research, invention and innovation, nevertheless there can be little doubt that at present the vast majority of technical innovations originate in a very few countries. This means that a large part of world economic growth depends upon the efficient diffusion of new technology, and every country has a great deal to gain from this diffusion. This applies even to the superpowers. Several studies have recently demonstrated the heavy contribution of foreign technology to Soviet economic development (Amann, 1982) and others indicate increasing US concern over the relative decline of the US lead in technical innovation. Even if the ambitious targets suggested by Bell et al. for increasing the scale of R and D and STS in the developing countries could be realised in the 1980s, very large disparities will still remain for a long time to come.

However, an encouraging feature of world economic development in the 1970s was that a number of developing countries succeeded in achieving higher rates of economic growth than the established industrial powers, thus beginning to close the productivity gap, and the gap in per capita incomes. It remains to be seen how the world economy will develop in the 1980s and how vulnerable these countries may be to the heavy burden of international indebtedness in a recession more serious than anything since the 1930s. However, in principle it is clearly possible for "overtaking countries" to achieve much higher growth rates over long periods than those close to the frontier of world science and technology. This is because very great progress can be made by the efficient assimilation of technology which has already been created somewhere in the world.

It would be wrong to suggest that this process is cost-less or that it can be achieved without any R and D. Even the simple copying of foreign technology cannot be achieved without some understanding of that technology and the science to which it relates. Efficient assimilation, whether in agriculture, industry or social services depends not just on copying, but on a process of adaptation to local circumstances, and increasingly associated with that adaptation, a process of improvement.

This means that the process of international diffusion of discrete technical innovations (and the technological systems of which they are a part) is of fundamental importance for policy-makers in countries which are striving to industrialise rapidly. It has often been pointed out that for a long time Japan had a very heavy deficit in her "technological balance of payments", reflecting her intense efforts to use this mechanism in the 1950s and 1960s. Her success in this catching up phase was mirrored in the shift of the Japanese TBP deficit to surplus on new transactions during the 1970s. This already indicates the uses of one of the few ST indicators which is a partial measure of international diffusion, and which is already available for most OECD countries. There are many difficulties associated with the use of these statistics, including the role of management payments within multi-national transactions, definitions and classification problems. These are well reviewed by Vickery (1981) in a paper for the OECD meeting on the measurement of technological balance of payments in 1981 and by Bernadette Madeuf in her 1982 paper on problems of theory, measurement and evaluation of TBP. Measures of inter-country technology payments are no substitute for the analysis of diffusion rates of specific innovations, nationally and internationally. The diffusion of important innovations, such as oxygen steel-making, was more rapid in Japan than the older industrial countries (Gold et al., 1970). This indicates one of the potential advantages of "overtaking" countries. Because they have little or no commitment to earlier vintages of physical equipment, or to institutions and ideas associated with older technologies, they may be able to embody the newest technologies in more up-to-date equipment, more rapidly than some of the older countries (Soete, 1982).

The extent to which they are able to do this will depend heavily on their scientific and technical infra-structure, and their success in changing the balance of this structure gradually towards an increasing input from indigenous R and D and other STS. The entry-barriers facing new entrants to the high technologies are formidable and the decisions they take with respect to R and D and STS are among the most crucial. As we have seen (page 3.2a), the adaptation and improvement of process technology is very imperfectly measured by R and D statistics, and on the UNESCO definitions of STS, little change would be made. This is an area where improvements could probably best be initiated by developing country researchers.

Policy-makers in this area have rather few sign-posts to guide them, but logic and experience suggest that as a system of world indicators is built up, among the most useful additional indicators would be diffusion and DE indicators. As in the case of studies of "first" innovations, the research on diffusion has been mainly tackled by enthusiasts at Level 2, especially post-graduate students. When Rogers (1962) reviewed the state of diffusion studies, he could find only one which related to innovation in industry - tunnel ovens by Williams. Since that time many more have been added, for example in steel (Gold et al.,1970), textiles (Metcalfe, 1970), tufted carpets (Scott, 1976), NC tools (Romeo, 1975), computers (Stoneman, 1976). The collaboration between research institutes in several countries (IFO in Germany, Institute for Economic Research in Sweden, and National Institute for Economic and Social Research in UK) led to the first major international comparative studies of diffusion (Ray, 1969, Nabseth and Ray, 1974).

As a result of these and many other studies of diffusion in the 1970s, the early models of diffusion based on a simplified 'epidemic' type of approach have been modified to take account of such factors as changes in the technical and economic characteristics of the product (or process) which is being diffused (Stoneman,1976 and 1983). The early models were criticised by Gold (1981), Rosenberg (1976) and others for their tendency to assume not only an unchanging product, but also an unchanging adopter population. Finally, these early models often ignored the supply side of the diffusion process. More recent models have attempted to take account of some of these weaknesses (Metcalfe, 1981; Davies, 1979; Stoneman 1976 and 1983). The measurement of DE could be a very useful adjunct to these efforts, since it would open up the area of product and process modification.

In the course of the debates on the diffusion process, analogies have been made between the adoption of consumer innovations by households and of capital goods innovations by industries. The former have been more extensively studied in market research and it has been established for a long time that income elasticities are extremely important in relation to the diffusion of such products as consumer durables. A similar approach to industrial diffusion processes might suggest that size of firm could be an important variable (Davies,1979) affecting adoption, because of greater resources and more rapid access to information. Soete (1982) has suggested that Probit analysis could be highly relevant to the understanding of international diffusion processes, since per capita income differences and firm size differences are so great on the international plane. Certainly there is a need to extend diffusion studies beyond a small circle of industrialised countries, to take far more account of the special factors affecting countries in process of industrialisation.

There are no prospects of diffusion or DE measurement shifting from Levels 1 and 2 to Level 3 or 4 in the foreseeable future. Nor is there any realistic prospect of a large number of studies being undertaken simultaneously on the lines of the IFO/NIESR study. But at the same time the field has such great interest and relevance to the other ST indicators and to the development problems of the Third World, that it is desirable that they should be directly involved in advancing the state of the art in this field. An example of the type of work that could prove extremely useful, if oriented more directly towards diffusion theory, is the study of the Brazilian computer industry by Tigre (1982). A possible way in which developing country researchers might participate more actively in advancing the state of the art is suggested in Chapter 7.

A more indirect measure of technology diffusion is based on the 'embodiment' of technology in international trade and investment flows. International trade statistics are for quite some time now available at level 4, with an international Standard International Trade Classification system which is followed by both the OECD and UNCTAD. Various organisations, including the OECD and the specialised UN institutions, have been trying to develop comparable international investment statistics, yet differences in definition coverage and detail are major obstacles, so that one might expect that these statistics will remain at level 2 and 3 for some time, with specialised university institutes providing experimental data sets (Harvard's Multinationals Project and Reading's Multinational Data Bank).

The identification of the technology component in these trade and investment flows is in the first instance a practical matter. The OECD has organised various meetings (in 1978 and 1980, probably in 1983) reviewing the literature (see in particular Aho and Rosen, 1980, Hatzichronoglou, 1980 and Soete, 1980) in order to try to arrive at some common definition in terms of specific SITC-numbers, i.e. product groups, of technology-intensive trade. So far most definitions used differ slightly from each other (e.g. the EEC ones from the US ones), yet it should be relatively easy to arrive at a common definition. This would almost immediately make available trade/technology diffusion data at level 4. (The overall issue about technical change and international competitiveness is reviewed in Freeman, 1982).

International investment data raise more questions. The most detailed ones, containing specific technological information (R and D, licence and royalty payments of the subsidiaries), were published last year by the US Department of Commerce, the so-called Benchmark Survey. One can only hope that other developed countries, in particular Japan, West Germany, France, Britain, Switzerland, Holland and Sweden will initiate similar surveys.

CHAPTER 7

Conclusions and Recommendations

Taken together the new developments reported in Chapters 2 to 6, with respect to input measurement and, even more, with respect to output measurements, constitute an exciting new prospect for the development and application of indicators for science and technology. Whilst there is no likelihood that government authorities at Level 3 will directly promote the introduction of a new series of indicators, as occurred with R and D input indicators in the 1950s and 1960s, it is probable that in several countries they will directly or indirectly encourage a variety of institutions at Levels 1 and 2 to collect such statistics and to publish them. This attitude of benevolent encouragement has already been shown during the 1970s, by the National Science Foundation, notably in its own biennial publication, Science Indicators (1972, 1974, 1976, 1978 and 1980). The German, French, Canadian, Swedish and British governments are among those which have shown a sympathetic attitude to parallel efforts in these countries. Some of the agencies involved at Levels 1 and 2 have sufficient resources to make considerable progress on their own account and in any case a number of services are commercially viable in their own right, because of the great interest in these new sources of information in industry.

Consequently, it is likely that there will be a major surge forward of science and technology indicators in the 1980s and 1990s. Their value will increase as longer time series become available, as greater experience permits improvement and revision of the established series and as greater international participation permits wider cross-country comparisons.

It is highly desirable that the developing countries should not just be on the fringe of these exciting prospects, but should be active participants. Otherwise it is virtually certain that their interests will be ignored. This would be unfortunate for many reasons. It would strengthen the general bias towards a few leading countries; it would tend to neglect indicators of global diffusion processes,of DE, and of those STS of greater interest to the Third World. It would also reinforce the existing bias affecting publication and citation indices, as well as indicators of invention and innovation.

The most natural way to offset such tendencies and to involve developing countries in the new developments would be through the machinery of the United Nations at Level 4. UNESCO has made valiant efforts over the last 30 years to take account of these problems and as we have seen in Chapters 2 and 3, is now initiating an important new programme of activity in relation to STID, as well as continuing to offer consultancy advice and direct assistance to developing countries which are embarking on R and D measurement or other types of STS measurement. The positive response of the Chinese People's Republic to the new UNESCO activities is also extremely encouraging. It must be hoped that the resources available to UNESCO for this work will be greater and that their programme will be increasingly successful.

However, there are certain aspects of UNESCO's constitution and mode of operation that make it inherently improbable or even impossible for UNESCO to tackle some of the new activities which are ripe for experimental development. First, UNESCO is heavily committed to work on educational and manpower statistics as its main priority (UNESCO, 1978; OECD, 1981). This is valuable work and an essential contribution to the other activities which have been reviewed here. Secondly, UNESCO's main thrust in the R and D/STS area over the next few years will be in the area of STID. This is a huge and difficult area in its own right. Thirdly, output measurement is far more controversial and involves more experimental work, which would inevitably raise great difficulties within the framework of any large, bureaucratic organisation. Fourthly, DE activities have been excluded from the UNESCO definitions of STS.

The OECD has shown consistent interest in output indicators. The Head of the OECD ST Indicators Unit contributed a paper on output measurement at the very first Frascati Conference in 1963 (Fabian, 1963). Since then the OECD has sponsored a series of international seminars and workshops, culminating in two recent major conferences (OECD, 1980 and 1982), which have been an invaluable forum for the exchange of international experience and the exploration of solutions for outstanding problems. However, the OECD too is limited by its constitution and mode of operation. It is not designed to take account of the interests of the developing countries, nor are they represented in its structure. It is constrained by contracting financial resources in real terms and the existing indicators work constitutes a heavy burden for the limited resources available.

There is strong pressure from the member countries to sustain and enhance these activities, but little indication that additional resources will be forthcoming to support new initiatives. Some of the bureaucratic difficulties which afflict UNESCO and other UN agencies also affect the OECD, though to a lesser extent.

In these circumstances there is scope for an international initiative by a Foundation-type of institution, capable of fairly rapid and flexible response to a complex and changing set of problems and with a strong interest in the long-term development problems of the Third World. Is this a possible rôle for the IDRC in the 1980s?

What is required is the setting up of a small Third World Science and Technology Indicators Unit with three objectives: (1) to monitor new world-wide developments in STI and to provide advice and assistance to policy-makers in the Third World interested in such developments; (2) to sponsor a series of projects designed to develop and use such indicators in developing country circumstances. The STIU would also be involved in their implementation; (3) to organise occasional workshops and training courses to promote mutual exchange of experience. A relatively small programme of this kind would enable Third World countries, both to benefit from the many new developments now in progress in the industrialised countries, and to affect these developments in a direction more consistent with their interests and a balanced overall picture of world scientific and technological activities.

References

Abernathy, W.J. (1978) The Productivity dilemma: Roadblock to Innovation in the Automobile Industry, Baltimore: John Hopkins Press.

Alexander, A.J. and Nelson, J.R. (1973) 'Measuring technological Change: Aircraft Turbine Engines', Technological Forecasting and Social Change, Vol 5, pp 189-203.

Amann, R. et al. (1982) Industrial Innovation in the Soviet Union, Yale University Press.

Annerstedt, J. (1979) A Survey of World Research and Development Efforts: The Distribution of Human and Financial Resources Devoted to Research and Experimental Development in 1973, OECD Development Centre and Roskilde University Centre, Denmark.

Arraoz, A. (1981) (Ed) Consulting and Engineering Design in Developing Countries, IDRC, Ottawa.

Atherton, P. (1975) Handbook for information systems and services, UNESCO.

Baker, R. (1976) New and Improved: Inventors and Inventions that have changed the Modern World, British Museum Publications.

Bassberg, B.L. (1982) 'Technological change in the Norwegian Whaling Industry: A Case-study in the use of patent statistics as a technology indicator', Research Policy, Vol II, No. 2. pp. 163-173.

Bell, R.M., Scott-Kemmis, D. and Oldham, C.H.G. (1980) 'Towards the Assessment of Requirements for Additional Funding for Scientific and Technological activities for development: a background paper prepared for the UN Centre for Science, Technology and Development', (two parts) Sussex: Science Policy Research Unit.

Bernal, J.D. (1939) The Social Function of Science, Routledge and Kegan Paul.

Borowy, M. (1967) 'Expenditures on Research and Development in Poland 1961 to 1965', Minerva, Vol 5, No. 1, pp. 357-371.

Bush, V. (1945) Science - the endless frontier: A Report to the President, Washington, USGPO.

Buzzelli, D.E. (1982) 'Problems of innovation measurement in the USA', OECD Workshop on Patent and Innovation Statistics, Paris.

Campbell, R.S. (1982) 'Patent Trends as a Technological Forecasting Tool', OECD Workshop on Patent and Innovation Statistics, Paris.

Campbell, R.S., and Nieves, A.L. (1979) Technology Indicators based on Patent Data: The Case of Catalytic Converters, Prepared for the NSF, September 1979, Battelle Pacific NW Laboratories.

Carpenter, M.P. (1979) International Science Indicators - Development of Indicators of International Scientific Activity using the Science Citation Index, New Jersey: Computer Horizons Inc.

Carpenter, M.P. (1981) Development of Refined Indicators of Technical Innovation using Examiners' Citations in the Patent File, New Jersey: Computer Horizons.

Carpenter, M.P., Cooper, M. and Narin, C.F. (1980) 'Linkage between Basic Research and Patents', Research Management, 23(2).

Carpenter, M.P. and Narin, F. (1980) Evolution and Status of Bibliometric Data used in US Science Indicators Reports, New Jersey: Computer Horizons.

Carpenter, M.P., Narin, F. and Woolf, P. (1981) 'Citation rates to technologically important patents', World Patent Information, Vol. 3.

Clark, J., Freeman, C. and Soete, L.L.G. (1981a) 'Long Waves and Technological Developments in the 20th Century' in Petzina, D. and van Roon, G. (eds) Konjunktur, Krise, Gesellschaft, Klett-Cotta, Stuttgart.

Clark, J., Freeman, C. and Soete, L.L.G. (1981b) 'Long Waves, Inventions and Innovations', Futures, Vol 13, No. 4, pp.308-322.

Coombs, R. et al. (1980) 'An Index of Realised Technical Change : the Case of Agricultural Tractors', STIC/80.2, OECD Workshop on Science and Technology Indicators, Paris, 1980.

Cooper, R. and Wood, N. (1978) Scientific and Technical Information in Ireland: Financial Resources devoted to STID in Ireland, 1975, Dublin: National Science Council.

Davies, S. (1979) The Diffusion of Process Innovations, Cambridge University Press.

Dosi, G. (1981) 'Institutions and markets in high technology industries: an assessment of government intervention in Europen micro-electronics' in Carter, C.F. (ed) Industrial Policies and Innovation, London: Heinemann.

European Economic Community (1980) Annual Reports on Public Expenditure on R and D in the Community Countries: Analysis by Objectives: Government Financing of R and D, Brussels.

Fabian, Y. (1963) 'Measurement of Output of R and D', mimeo, OECD, DAS/PD/63.48, Paris.

Falk, C.E. (1982) 'The Measurement of the Productivity of Science and Technology', chapter 2 in Understanding R and D Productivity,

Flueckiger, G.E. (1972) 'Observations and measurement of technological change', Explorations in Economic History, Vol 9, No. 2, pp. 145-177.

Frame, J. D. (1980) 'Measuring Scientific Activity in Less Developed Countries', Scientometrics, Vol 2, March, pp. 133-145.

Freeman, C. (1967) 'A Comment on Expenditures on Research and Development in Poland', Minerva, Vol 5, No. 1. pp. 371-75.

Freeman, C. (1969) Measurement of Output of Research and Experimental Development, Statistical Reports and Studies No. 16 Paris: UNESCO.

Freeman, C. (1971) 'The Role of Small Firms in Innovation in the United Kingdom since 1945': Report of the Bolton Committee of Inquiry into Small Firms, Research Report No. 6. London: HMSO.

Freeman, C. (1982) Economics of Industrial Innovation, 2nd edn. (revised), London: Frances Pinter.

Freeman, C., Clark, J. and Soete, L.L.G. (1982) Unemployment and Technical Innovation: A Study of Long Waves and Economic Development, London: Frances Pinter.

Freeman, C. Fuller, J.K. and Young, A. (1963) 'The Plastics Industry; A Comparative Study of Research and Innovation', National Institute Economic Review, No. 26, pp. 22-60.

Freeman, C. and Young, A. (1965) The Research and Development Effort in Western Europe, North America and the Soviet Union, Paris: OECD.

Friedmann, R.M. (1980) Nobel Physics Prize in Perspective, Institute for Studies in Research and Higher Education, Oslo, mimeo.

Garfield, E. (1963) 'Citation Indexes in Sociological and Historical research', American Documentation, Vol 14, No. 4, pp. 29-31.

Gold, B. (1981) 'Technological Diffusion in Industry: Research Needs and Shortcomings , Journal of Industrial Economics Vol 28, No. 1, pp. 247-69.

Gold, B. et al (1971) Explorations in Managerial Economics, Basic Books, New York.

Harris, L.J., Holman, M.A., Kitch, E.W., and Pavitt, K. (1979) The Meaning of Patent Statistics, National Science Foundation, Washington DC, U.S.A.

Hattis, D., Andrews, R., Estes, J.W. and Owen, S.T. (1980) 'Relationships between aspects of Pharmaceutical Regulation, Innovation and Therapeutic Benefits', report to the NSF by the Centre for Policy Alternatives, MIT.

Hill, C.T., Hansen, J.A. and Maxwell, J.H. (1982) 'Assessing the Feasibility of New Science and Technology Indicators', CPA 82-4, Center for Policy Alternatives, MIT, Boston (Mimeo).

Hill, C.T. and Utterback, J.M. (1979) Technological Innovation for a Dynamic Economy, New York: Pergamon Press.

Hollander, S. (1965) The Sources of Increased Efficiency: a Study of Dupont Rayon Plants, MIT Press.

Hufbauer, G. (1966) Synthetic Materials in the Theory of International Trade, London: Duckworth.

Huxley, J.S. (1934) Scientific Research and Social Needs, London: Watts.

Irvine, J.H. and Martin, B.R. (1980) 'A Methodology for Assessing the Scientific Performance of Research Groups', OECD Science and Technology Indicators Conference, September, 1980.

Irvine, J.H. and Martin, B.R. (1981) 'Government Support for industrial Research in Norway: A SPRU Report', Appendix 4 of the Report of the Norwegian Royal Commission on Government Support for Industrial Research and Technology, Norwegian Government Printing Office, 30B, pp. 195-336.

Irvine, J.H. and Martin, B. (1982) 'CERN: Past Performance and Future Prospects', SPRU (Mimeo), August.

Jonason, M. (1982) 'Patent Statistics as Related to the Industrial Development Trend in Sweden in the Period 1925-1936', World Patent Information, Vol. 4, No. 1, pp.3-11.

Katz, J. (1969) Production Functions, Foreign Investment and Growth: a study based in the Argentinian manufacturing sector 1946-1961, North Holland, Amsterdam.

Kleinknecht, A. (1981) 'Observations on the Schumpeterian Swarming of Innovations', Futures, Vol. 13, No. 4, pp 293-307.

Kronz, H. and Grevink, H. (1980) 'Patent Statistics as Indicators of Technological and Commercial Trends in the Member States of the European Communities (EEC)', World Patent Information, Vol 2, pp. 4-12.

Kronz, H. and Grevink, H. (1982) 'Trends in the Inventive Activity of 'private' applicants for patents in Germany, France and UK', OECD Workshop on Patent and Innovation Statistics, Paris.

Lawson, W.S. (1982) Letter to the Editor, World Patent Information, p.87.

Liebermann, M.B. (1978) 'A Literature citation study of Science-technology Coupling in Electronics', Proceedings of the IEEE, Vol 66, No. 1, pp.5-13.

Machlup, F. (1962) The Production and Distribution of Knowledge, Princeton University Press.

Macioti, M. (1980) 'The Power and the Glory: a Note on Patents and Scientific Authors', Research Policy, Vol. 9, No. 2, (April) pp.104-116.

Madeuf, B. (1982) 'The Technological Balance of Payments: Problems of Theory, Measurement and Evaluation', OECD, DSTI/SPR/82.62; Paris.

Mansfield, E. (1968) The Economics of Technological Change, New York: Norton.

Mansfield, E. (1977) The Production and Application of New Industrial Technology, New York: W.W.Norton.

Martin, B.R. and Irvine, J.H. (1983) 'Assessing Basic Research: some Partial Indicators of Scientific Progress in Radio Astronomy', Research Policy, (forthcoming)

See also Irvine, J.H. and Martin, B.R. 'A Methodology for Assessing the scientific Performance of Research Groups', Scientia Yugoslavica, Vol 6, Nos. 1-4, pp. 83-95, 1980.

Mensch, G. (1975) Das Technologische Patt: Innovationen Überwinden die Depression, Frankfurt: Umschau.

English Edition: Stalemate in Technology: Innovations Overcome the Depression, Cambridge: Ballinger Publishing Co. 1979.

Mensch, G. (1981) 'Comment on paper by Clark, Freeman and Soete' in Petzina, D. and van Roon, G. (eds) Konjunktur, Krise, Gesellschaft, Klett-Cotta, Stuttgart.

Metcalfe, J.S. (1970) 'The diffusion of innovation in the Lancashire textile industry', Manchester School of Economics and Social Studies, no. 2, pp. 145-62.

Metcalfe, J.S. (1981) 'Impulse and Diffusion in Technical Change', Futures, Vol 13, No. 5, pp. 347-359.

Meyer-Krahmer, F. (1982) 'Recent Results in Measuring Innovation Output', OECD Workshop on Patent and Innovation Statistics, Paris.

Moravcsik, M.J. (1973) 'Measures of Scientific Growth', Research Policy, Vol 2, pp. 266-75.

Moravcsik, M.J. (1977) 'A Progress Report on the Quantification of Science', Journal of Scientific and Industrial Research (India), Vol 36, p.195.

Mowery, D. and Rosenberg, N. (1979) 'The Influence of Market Demand Upon Innovation: a Critical Review of some Recent Empirical Studies', Research Policy, Vol 8, No. 2, pp.102-153.

Murphy, D. (1979) Statistics on Scientific and Technical Information and Documentation - a Methodological Approach, UNESCO, Paris. (PGI - 79/WS/5).

Nabseth, L. (1973) 'The Diffusion of Innovations in Swedish Industry', in Williams, B.R. (ed) Science and Technology in Economic Growth, Macmillan.

Nabseth, L. and Ray, G.F. (1974) The Diffusion of New Industrial Processes, Cambridge University Press.

Narin, F. (1982) "Assessment of the Linkages between Patents and Fundamental Research", OECD, Workshop on Patent and Innovation Statistics, Paris.

Narin, F. and Carpenter, M.P. (1979) 'Evolution and Status of Bibliometric Data used in US Science Indicators Reports', Second OECD Workshop on the Measurement of R and D Output, December, 1974, Paris.

National Bureau of Economic Research (Ed) (1962) The Rate and Direction of Inventive Activity, Princeton University Press.

National Science Foundation, Science Indicators, Biennial (1972, 1974, 1976, 1978, 1980), National Science Board, Washington D.C.: NSF.

Nelson, R.R., Peck, J. and Kalachek, E. (1967) Technology, Economic Growth and Public Policy, Brookings Institution.

Nelson, R.R. and Winter, S.G. (1982) An evolutionary Theory of Economic Change, Cambridge Mass. and London: Harvard University Press.

OECD (1963, 1970, 1976, 1981) The Measurement of Scientific and Technical Activities: proposed standard practice for surveys of research and experimental development, Paris: OECD First edition 1963, Second Edition 1970, Third Edition 1976, Fourth Edition 1981.

OECD (1967, 1969, 1971, 1973, 1975, 1977, 1979 and 1981) International Statistical Year for Research and Development: a Study of the Resources devoted to R and D in OECD Member Countries, Paris: OECD (biennial since 1967).

OECD (1977) OECD Workshop on R and D Deflators: Summary Report and Contributions, Science and Technology Indicators Unit, Paris: OECD.

OECD (1980) Papers contributed to Science and Technology Indicators Conference, Paris, mimeo.

OECD (1982) Papers contributed to Workshop on Innovation and Patent Statistics, Paris, mimeo.

Oldham, C.H.G. (1967) 'Science, Technology and the Portuguese Universities', a report to the Portuguese Government, OECD, Technical Assistance Programme, Mimeo, SPRU.

Palmer, D.C. (1970) Planning for a Nation-wide System of Library Statistics, National Center for Educational Statistics, Washington.

Pavitt, K.L.R. (1979) 'Using patent statistics in Science Indicators' in NSF, The Meaning of Patent Statistics, National Science Foundation.

Pavitt, K.L.R. (1982) 'R and D, Patenting and Innovative Activities: a Statistical Exploration', Research Policy, Vol 11, No. 1, pp. 33-51.

Pavitt, K.L.R. and Soete, L.L.G. (1980) 'Innovative activities and export shares' in Pavitt (ed) Technical Innovation and British Economic Performance, London: Macmillan.

Peck, M.J. and Goto, A. (1981) 'Technology and Economic Growth' Research Policy, Vol. 10, No. 3, pp.222-243.

Piatier, A. (1981) Enquête sur l'innovation, Paris: CEPEM.

Porat, M. U. (1977) The Information Economy: Definition and Measurement, vols. 1-9, USGPO, Washington.

Porter, A.L. (1977) 'Citation analysis: queries and caveats', Social Studies of Science, Vol 7, pp. 257-267.

Price, D. de Solla (1961) Science Since Babylon, Yale University Press.

Price, D. de Solla (1963) Little Science, Big Science, Columbia University Press.

Price, D. de Solla (1965) 'Is Technology Historically Independent of Science? A Study in Statistical Historiography', Technology and Culture, Vol 6, pp. 553-568.

Price, D. J. de Solla (1967) 'Research on research' in D. L. Arm (Ed.) Journeys in Science:Small Steps, Great Strides, University of New Mexico Press.

Price, D. de Solla, (1978) 'Ups and Downs in the Pulse of Science and Technology', in Gaston, J., (ed) The Sociology of Science, London.

Priest, W.C. and Hill, C.T. (1980) 'Identifying and Assessing Discrete Technological Innovations: an Approach to output indicators', NSF (mimeo) prepared for NSF Division of Science Resources Studies, Washington; Research Policy (forthcoming).

Priest, W.C. and O'Neil, P.E. (1977) An Identification of major US railroad terminal areas and potential improvements to terminal operations, Report prepared for US Department of Transport, TOCS Inc., Cambridge Mass.

Rainoff, T.J. (1929) 'Wave-like Fluctuations of creative Productivity in the Development of West-European Physics in the Eighteenth and Nineteenth Centuries', Isis, Vol. 12, pp. 287-319.

Ray, G.F. (1969) 'The Diffusion of New Technology in Nine Industries', National Institute Economic Review, pp. 40-81, May.

Rogers, E.M. (1962) The Diffusion of Innovations, New York: Free Press.

Romeo, A. A. (1975) 'Inter-industry and Inter-firm differences in the rate of diffusion of an innovation', Review of Economics and Statistics, Vol. 57, No. 3, pp. 311-19.

Rosenberg, N. (1976) Perspectives on Technology, Cambridge University Press.

Sanders, B.S. (1962) 'Some difficulties in measuring inventive activity', in Natioanl Bureau of Economic Research (ed) The Rate and Direction of Inventive Activity, Princeton University Press.

Saviotti, P. and Metcalfe, S. (1982) 'Technological Output Indicators, Product Characteristics and Industrial Performance', OECD Workshop on Patent and Innovation Statistics, Paris.

Scherer, F. M. (1981) 'The OTAF - Industry Concordance as a Means of Identifying Industry Technology Origins', World Patent Information, Vol. 4, No. 1. pp.12-17.

Scherer, F.M. (1982) 'Inter-industry Technology Flows in the United States', Research Policy, Vol. 11, No. 4. pp.227-47.

Schmookler, J. (1950) 'The Interpretation of Patent Statistics', Journal of the Patent Office Society, Vol. 32, pp. 123-146.

Schmookler, J. (1953) 'The Utility of Patent Statistics', Journal of the Patent Office Society, Vol. 35, pp. 407-412.

Schmookler, J. (1954) 'The Level of Inventive Activity', Review of Economics and Statistcs, Vol. 36, pp. 183-190.

Schmookler, J. (1962a) 'Changes in Industry and in the State of Knowledge as determinants of Industrial Invention' in National Bureau of Economic Research (ed) The Rate and Direction of Inventive Activity, Princeton University Press.

Schmookler, J. (1962b) "Comment" on Sanders, B.S. "Some difficulties in measuring inventive activity", NBER The Rate and Direction of Innovative Activity, Princeton University Press, pp.78-83

Schmookler, J. (1966) Invention and Economic Growth, Harvard.

Scholz, L. (1982) 'IFO Innovation Survey: Efforts to Inform Decision-makers of innovative activities in the Federal Republic of Germany,' OECD Workshop on Patent and Innovation Statistics, Paris.

Schwartzman, D. (1976) Innovation in the Pharmaceutical Industry, John Hopkins University Press, Baltimore.

Scott, T.W.K., (1976) Diffusion of New Technology in the British and West German Carpet Manufacturing Industries: the Case of the Tufting Process, D.Phil. Thesis, University of Sussex, 1976.

Sirilli, G. (1980) Manual for Statistics on Scientific and Technological Activities, UNESCO, Paris, ST-80/WS/8.

Sirilli, G. (1982) 'The Correlation Between Patent Statistics and R and D Expenditure: Fact or artefact? OECD Workshop on Patent and Innovation Statistics', Paris.

Soete, L.L.G. (1978) 'Inventive Activity, Industrial Organisation and International Trade', University of Sussex, D.Phil. Dissertation.

Soete, L.L.G. (1980) 'The Impact of Technological Innovation on International trade Patterns: the Evidence Reconsidered', OECD Science and Technology Indicators Conference, Paris.

Soete, L.L.G. (1981) 'A General Test of Technological Gap Trade Theory', Weltwirtschaftliches Archiv, Vol.117, No. 4, pp.638-66.

Soete, L.L.G. (1982) 'International Diffusion of Technology and Economic Growth: an Historical Perspective', second Conference on Technology and Industrial Policy in China and Europe (TIPCE). Science Policy Research Unit, Paper 4, University of Sussex.

Soete, L.L.G. and Wyatt, S.M.E. (1982) 'The Use of Foreign Patenting as an Internationally Comparable Science and Technology Output Indicator', mimeo OECD, 1982 Workshop on Patent and Innovation Statistics; Scientometrics, (forthcoming).

Statistics Canada, (1975) Selected Statistics on Technologigal Innovation in Industry, Ottawa, Canada.

Stead, H. (1976) 'The Costs of Technological Innovation', Research Policy, Vol 5, No. 1.

Stoneman, P. (1976) Technological Diffusion and the Computer Revolution: the UK Experience, Cambridge University Press.

Stoneman, P. (1983) The Economic Analysis of Technological Change University of Warwick (mimeo) (forthcoming).

Sullivan, D., White, D.H. and Barboni, E.J. (1977) 'The State of a Science: Indicators in the Speciality of weak interactions', Social Studies of Science, Vol 7, pp.167-200

Taton, R. (1957) Reason and Chance in Scientific discovery Hutchinson.

Tigre, P. (1982) 'Technology and Competition in the Brazilian Computer Industry', D.Phil. Thesis, University of Sussex.

Tisell, H.G. (1907) Internationell Patenstatistik för aren 1885-1904, Lund, Sweden.

Townsend, J. (1976) Innovation in Coal Mining Machinery: The Anderton Shearer-Loader, SPRU Occasional Paper No. 3, Sussex.

Townsend, J. et al. (1982) Innovations in Britain since 1945, SPRU Occasional Paper No. 16, Sussex.

Tsukamara, S. and Yamada, K. (1982) 'A Note on the Time Lag Between the Life Cycle of a Discipline and Resource Allocation in Japan', Research Policy, Vol 11, No. 2. pp. 133-141.

UNESCO (1970) Manual for Surveying National Scientific and Technological Potential, Paris.

UNESCO (1977) Guide to the collection of Statistics on Science and Technology, Paris, (ST/77/WS/4).

UNESCO (1978) Guidelines for the Evaluation of Information Systems and Services, Paris, (PGI/78/WS/18).

UNESCO (1982) Guide to Statistics on Scientific and Technological Information and Documentation (STID), ST-82/WS/11, Paris, (Draft version 9 April, 1982).

United States Department of Commerce, (1977) Technology Assessment and Forecast 8th Report, Patent and Trademark Office, US Department of Commerce, Washington DC.

Vickery, G. (1981) 'Technology payments in international transactions: a measure of the output of R and D and of technological competitivity', STIC/80/44, OECD Conference on Science and Technology Indicators, Paris.

Vilentchuk, L. (1975) Guidelines on the Conduct of a National Inventory of Scientific and Technological Information and Documentation Facilities, UNESCO, Paris, (SC/75/WS/28).

Walsh, V. et al. (1978) 'Trends in Invention and Innovation in the Chemical Industry', Science Policy Research Unit (mimeo).

Weiss, C. (1982) 'Science, Technology and the World Bank of the 1980s' , Washington: World Bank, (mimeo).

Wiseman, P. (1983) (forthcoming) 'Patenting and Inventive Activity on Synthetic Fibre Intermediates', Department of Chemistry, University of Manchester Institute of Science and Technology, (mimeo); Research Policy in press.

Young, M.L. and Young, H.C. (1979) Directory of Special Libraries and Information Centers in the United States and Canada, Detroit: Gale Research Company.