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Efficiency of government intervention in technical change in telecommunications: ten national economies compared

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Abstract

In all the countries examined in this paper, the government is — directly or indirectly — involved in the system of telecommunications research and development (R&D). All these governments' policies tend to create market distortions, yet there is little in common between the ten countries that are compared. Among them, different working divisions have evolved between industry, network operators and state establishments for R&D in the telecommunications field. This paper highlights the diversity of structures present in some important industrial countries. A comprehensive measurement system for R&D efficiency in telecommunications is currently not available. This paper thus presents and discusses a set of quantitative, but non-monetary, indicators such as R&D expenditure, R&D personnel, scientific publications, patents and turnover. Expert assessments are added to this indicator system so as to overcome the incomplete links between them, their poor correlation with one another, and data availability problems.

The quantitative findings are quite discouraging for both technology policy and R&D management. Most of the current preconceptions are not justified when measured carefully. Cross-wise, all possible correlations between government and network operator R&D contributions have been checked against world market shares, and the like. No significant correlations were found, and thus the future technological competitive position is likely to remain the same whether there is more or less government intervention in national R&D systems. In addition, vertical integration and the intensity of R&D cooperation between national network companies and the related manufacturers do not result in typical success patterns between R&D and commercialization. There is no optimum, and no really disadvantaged setting for regulatory or business environments. Finally, it is important to note that the introduction of the formal framework of science and technology indicators within the sensitive area of modern telecommunications R&D may be regarded as a facility to assist objective assessments derived from expert interviews, and may enlighten economic studies of the Schumpeterian type.

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1. Introduction

Over half a century, Schumpeter's writings mainly, but not exclusively, dealt with the interdependence of invention, innovation, imitation and the creative as well as destructive role of monopolistic practices [1]. Reconsidering these interdependencies at the end of the 1980s is the main aim of this contribution.

To follow a 'Schumpeterian Approach' [2], the case of the telecommunications industry was selected for empirical study. Recently, Zajac [3] examined the 'Technological Winds of Creation and Destruction' in the case of a single firm, AT&T, which had an unusual global influence. He found that Schumpeter's writings and arguments are cogent, but American economists tend to have under-emphasized them by minimizing or ignoring technology and invention. In this paper, the Schumpeterian approach is extended to other telecommunications service and manufacturing companies in ten countries. Of special interest is the respective influence which governments exert on industrial invention and innovation, and the economic efficiency of their interventions.

In many ways, the process linking knowledge, research, industrial development and innovation resemble the production of public goods. They tend to have one or both of two economic characteristics in common: non-rivalry in supply (consumption of them by one consumer does not, in general, leave less of them for someone else), and non-excludability (because of zero or low marginal costs, it is inefficient and often infeasible to exclude consumers from using them). Traditional examples are law and order, roads, public health and defence or national security [4]. Knowledge itself is a kind of public good. In particular, when proprietary knowledge is patented, the patent law forces the inventor to disclose the fruits of his or her research to the public (though the use of such knowledge for profit-making purposes is limited).

Rather than a direct, sequential link between basic knowledge inputs and innovative outputs, there is a set of cyclic functions [5]: applied research may have among its inputs basic research, but unresolved problems from industrial development projects may trigger more applied research. Grupp *et al.* [5] have portrayed the knowledge-innovation cycle, and developed a model to measure performance within this cycle by a set of quantitative — but non-monetary — indicators.

The existence of such indicators makes possible a further advance in the study of post-Schumpeterian issues — the construction of quantitative models to measure the efficiency of research and development (R&D) resource use for turnover or export advantages. Such studies are required because the public-good nature of innovation dynamics does not validate the assumption that competitive markets guarantee full or near-full efficiency [6]. This is particularly relevant if — as in the case of telecommunications — the 'tax state' provides a considerable amount of funds for R&D, and also procures large parts of the respective innovative output. As Bator [4] has already shown, the provision of public goods is subject to market failure. Government regulation implies that allocative efficiency through price mechanisms cannot be assumed. Systems other than self-regulation and market feedback must be employed to attain efficiency. The question then arises as to how successful are the telecommunications economies, in various countries, in achieving efficiency in R&D resource use? To answer this question, the following sections compare the extent of government intervention in telecommunications R&D in ten countries.

Among the industrial countries, different working divisions have evolved between industry, state and network operators (called *common carriers* in this paper) for R&D in the telecommunications field. This paper highlights the diversity of such structures in some important industrial countries.

A comprehensive measurement system for R&D efficiency in telecommunications is currently not available, as far as the author is aware. Consequently, subjective expert assessments are essential for the present indicator systems to overcome incomplete links between indicators, their poor correlation with one another, and data availability problems. For a comprehensive discussion of these problems, see Grupp and Schwitalla [7]. The statistical sections contained in this paper therefore necessarily had to be supplemented by a series of personal discussions in various countries (see below).

There are only a few earlier such treatises on the research area relevant to this paper. The pioneering work done by Freeman [8] is worth mentioning as it signalled the movement towards 'science-oriented technology', taking electronics as an example, and supported patent lists and research expenditure. Our preliminary work at the Fraunhofer-Institut fuer Systemtechnik und Innovationsforschung (Fraunhofer Institute for Systems and Innovation Research) is dedicated to the establishment of patent, bibliographical and economic indicators in selected narrow fields of technology (such as enzyme technology, laser technology, robotics and solar engineering [9]), but to date never to such an all-embracing field as telecommunications which — as Freeman [10] quite rightly found — is involved in a technological revolution.

As the methods used for evolving the individual invention and innovation measures differ widely, they are usually not assembled together in one paper. Relevant publications are thus known *only* on R&D statistics, *only* on patent statistics, or *only* on publication statistics (bibliometrics) for many research areas (e.g. see the more than a dozen contributions edited by Grupp [11]). However, such research cannot usually be used for cross-referencing, as inadequate correspondence of indicator demarcation cannot be removed after the event. Therefore, this report is largely of a pioneering nature.

The present investigation essentially covers ten non-socialist countries (see Table 2), all of whom, with the exception of the Republic of Korea, belong to the OECD (Organization of Economic Co-operation and Development).

TABLE 1. Subfields of telecommunications R&D (source: Grupp [12])

Acronym	Heading	Contents
TH	information and communications theory, artificial intelligence	information theory, speech synthesis, general information and communication theory
WI	grid-based (wired) communication	grid-based transmission systems (incl. cables), telephone traffic (incl. telephone sets, private branch exchanges), switching, transmission technology, electromagnetic converters (mouth piece), multiplexing for analog systems
RA	radio engineering	antennae, aerial transmitting/receiving, radio communication systems (incl. satellites), noise reduction, control of oscillations, secret radio traffic
PI	general picture transmissions	TV systems, image processing and recognition, cable systems for picture transmission, closed circuit TV
IM	image communication	facsimile (standing picture communication), moving picture communication (picture telephone)
DI	digital transmission	pulse technique, digital transmission (incl. telegraphy) analog to digital converter, pulse code modulation, encoding, digital transmission systems, digital networks
FI	optical (fibre) communication	lasers for communications, optical cables, light control, light modulation, optological elements, optical analog to digital converters, optical semiconductor elements
HF	high frequency communication	wave guides, radionavigation, radar systems and equipment
ME	telemetering	traffic telemonitoring, telecontrol, telemetry
OE	other equipment (if not included elsewhere)	scanners, electrography, magnetography, data terminals, speech recognition apparatus, printers, plotters, electronic displays, holography, information storage
SO	services, software, policy	services, electronic mail, politics (laws, standards, norms), frequency administration, electronic media, TV systems applications, telecommunications in management, applications

2. Data sources and definitions of the telecommunications field

2.1. Demarcation

Definition of the subject in question, specifically just what 'R&D in the telecommunications field' is understood to mean, cannot be established irrefutably and unassailably. The demarcation used (see Table 1) tries to deal consistently with diverse statistics and data sources and the definitions which these contain.

So just what is telecommunications research and development? After perusal of various classification systems and the relevant literature, 'telecommunications' has been defined as a combination of 11 sub-areas (see Table 1). Other demarcations are conceivable, as no 'natural' scientific accessible definition comes to mind. Consequently, certain moments of licence cannot be eliminated.

Owing to a lack of data, R&D statistics inclusive of personnel statistics cannot differentiate between the individual fields within the telecommunications sphere. Consequently, R&D expenditure plus R&D personnel can be quoted only for the field as a whole. Armaments-related R&D data are especially difficult to distinguish from civilian data.

Delimitation of the individual sub-areas in telecommunications with the aid of international patent symbols or classification symbols from bibliographical databanks is a more accurate way of proceeding than using the verbal description in Table 1. Wherever possible, an entire sub-area defined by a classification symbol is allocated to one field only. In those cases where this appears to be impermissible from the professional standpoint, apportionment is done by logical links with key words.

2.2. R&D expenditure and personnel

Technically detailed analysis of R&D finance continues to be outstandingly problematical. At the heart of the matter is the so-called 'Frascati Definition' of R&D which states the following: 'Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications' (a summary of the Frascati Manual is reprinted in the appendix by Freeman [8]). Activities to be excluded from R&D are teaching and training, scientific and technical information services and data collection, testing, standardization and normalization, plus economic activities directed towards marketing (innovation) and production. The construction of prototype and pilot plants is to be included, along with design and building work (with the proviso that they are required for the R&D phase and not the production process).

There is some argument as to whether software origination ('programming') equates to an R&D activity; it is of extreme importance to economic progress in telecommunications. On the one hand, the 'state of the art' in 'software technology' is often improved, thereby elevating software generation to the status of a genuine R&D service. On the other hand, frequently only well-established programming procedures are employed for writing and improving programmes, which cannot be rated as an R&D characteristic. In the United States, these have not qualified for any R&D tax relief, and this has been challenged (see Office of Technology Assessment [13]).

The most important supranational data bank on R&D expenditure and personnel is managed by the OECD. From this data bank, at the highest disaggregation stage, the R&D expenditures of economic sector ISIC 3832 can be obtained, which includes the manufacture of communications equipment including radio and television sets; this is therefore too broad a concept for the basic definition here. Thus, national sources of the most disparate kind need to be involved.

Owing to gaps and inconsistencies in heterogeneous and, to some extent, contradictory data, and as a result of nationally differing demarcations, examination and assessment of the material was unavoidable. Overall, consistency trials show that the statistical data compiled are indeed reliable, but display many gaps and inconsistencies.

Information about R&D personnel usually covers 'research staff' and 'technicians'. However, even in regard to the information available from fully reporting companies, it should be remembered that these categories are not comparable in every case, and will vary with the type of training and other national requirements.

2.3. Patents

The enormous importance of foreign patent applications is undisputed, as the correspondingly higher expense (fees, translations, foreign patent agents) usually leads to the elimination of minor inventions. Research and technology being international in scope, the foreign patent propensity primarily of multi-nationally operating concerns is especially high. In somewhat regulated markets such as those in telecommunications, for the time being it could be assumed that certain foreign applications are unimportant. Therefore, each invention with at least one foreign duplication was included in the survey. For this purpose, a data bank representing collective patent output from the internationally most important patent offices needs to be used. WPI/L, PATSEARCH and PATDPA were employed for this survey. If foreign applications from various application years are available, the year of the first application ('year of invention') ought to be construed as being the 'priority year'.

The spread of patent activity over various telecommunication sub-areas provides an R&D profile of individual firms and institutions. Certainly, patent propensity fluctuates between the technical areas. If an organization aspires to only a few patents in a certain area, the reason may be that this area does not fall within the strategic R&D field of the company (in which one is interested here), or that the area concerned is definitely not very suitable for patenting, and therfore is characterized worldwide by little patenting activity (in which one is *not* interested here). Patent propensity may vary with time, and it also depends on the organization — different companies operate different patent policies. However, the interviews performed for this study clarified that today all telecommunications companies consider foreign patent policy equally important. This particular industry tends to be more homogeneous than others.

Furthermore, investigation of the annual application numbers does not take account of the fact that patent protection applies for different lengths of time over the year of the initial application or grant. Therefore, presentation and interpretation of the totalled patent numbers can be undertaken, and at this point provide a better idea of the patent volume that can already be relied upon. The totalled patent numbers constitute an indicator for *patent potential* (PP indicator [9, 14]).

2.4. Publications

Apart from patent data banks which, save for a few exceptions, rely on official documents, bibliographical data banks are being set up in the private sector (this issue is discussed more completely by Grupp [15]). The manufacturer concerned has to prepare his own data files containing information on authors, subjects, addresses and key words using his own personnel working on hard copies of publications. In terms of consistency and completeness, therefore, the data held on bibliographical data banks are frequently not of the same high level as comparable patent data banks. The choice of data bank is thus critical to the present investigation. Consequently, the first step was to check four internationally recognized bibliographical data banks for their technical completeness [15]. It was evident that the British data bank INSPEC is clearly superior to other data banks. It is preferred on the strength of a current preconception about publications from Great Britain, because a large number of users live there and consequently are interested in finding full details on British work.

Publications statistics in the realms of theory, software and telecommunications services are especially interesting as patent protection here is out of the question, and the patent indicator fails accordingly.

2.5. Discussions with experts

However carefully indicators are investigated and compiled, much information important for understanding the international work breakdown in telecommunications R&D is wasted, as it does not lend itself to numerical depiction. A substantial part of the investigation was therefore an international comparative field investigation in which prominent R&D participants in the telecommunications field were questioned personally. The R&D indicators were included in these discussions with a view to obtaining an interpretation or assessment of its expressiveness in cases of doubt. The survey conducted in the second half of 1988 and early 1989 covered all ten countries. The conversations centred around how R&D in the telecommunications field was organized, primarily the form of cooperation and work apportionment between R&D carriers; however, in addition an attempt was also made to assess the R&D indicators adopted hitherto. Table 2 shows the number of personal discussions, and hence provides some idea of the intensity of interviewing.

TABLE 2. Overview of the range of personal inquiries made to specialists and country codes used (per the three digit ISO code)

Country (ISO code)	No. of conversations	No. of persons who participated
USA (USA)	17	32
Japan (JPN)	15	19
Germany (DEU)	46	51
France (FRA)	11	13
Great Britain (GBR)	13	15
Italy (ITA)	13	25
Spain (ESP)	14	21
Republic of Korea (KOR)	11	17
Netherlands (NLD)	9	10
Sweden (SWE)	7	9
Total	156	212

3. Country reports

Each of the ten countries studied was comprehensively analysed. The full results are published in a separate chapter of a two volume book (in German) edited by Grupp and Schnöring [16].

3.1. United States of America

Insofar as one is able to talk at all about industrial policy in the United States, this is essentially directed towards armaments engineering and, latterly, space technology [17]. At the moment, around three-quarters of R&D funds made available by the Federal Government are used for military purposes. This is especially true of communications technology.

Broadly simplifying (for more details see [18]), from the way that R&D in all fields is structured nationally in the USA, it has been established that around 75% of the money available overall for R&D is being spent in the private sector. Around 10% of R&D expenditure in industry is on telecommunications (see Fig. 1). The total funds available for R&D are half government funded and half funded by industry. The overall expenditure on R&D in the telecommunications sphere in 1987 can be estimated at a scant US$13 000 million [18].

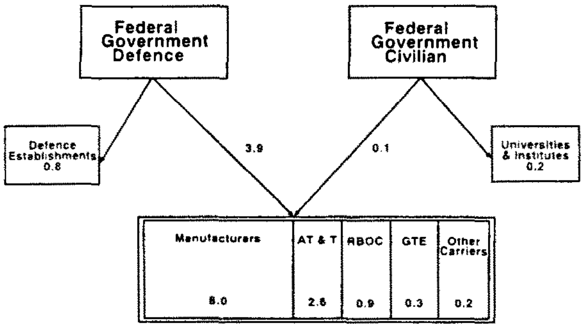

Fig. 1. Most important R&D actors in telecommunications in the USA, including estimated R&D expenditure as of 1987 (US$1000 million). Arrows denote flows of R&D funds, figures in boxes expenditure for R&D irrespective of the source of funds. The numerical differences between the figures in boxes and those on incoming arrows represent the R&D funds of the respective performer.

Within telecommunications R&D, the USA, internationally speaking, specializes particularly in quasi-military high frequency telemetry, theory, radio research and digital communications technology. Image-related technology is highly, wired telecom technology slightly, in deficit.

The disintegration of what had been until then the world's largest telecommunications concern, AT&T, in which regional companies (RBOC) became independent and a joint R&D company Bell Communications Research (Bellcore) was founded, has not subdued but intensified research activity at the surviving world famous Bell Laboratories at AT&T in the medium term. But AT&T is still special insofar as both the network service and the equipment manufacturing businesses are both very important to the company. AT&T's R&D is performed in 29 facilities located in six states [19].

Centralization of R&D activities at AT&T Bell Laboratories has, in principle, been retained as the AT&T management operates on the principle that the marginal advantages from an internal company decentralization are more than offset by the lower efficiency to be expected. However, there is certainly no denying the fact that a shift towards short-term, application-oriented R&D has begun, which is bound to have a negative effect on American fundamental research. AT&T's research (as opposed to development) contribution, standing at almost one fifth in the international comparison, is still very high. For the present, AT&T concentrations on R&D in wired, digital and fibre cabling predominates. Over 80% of AT&T's R&D funds originate from its producing companies and are used for near-market, specific and also imaginative development work. The remaining R&D funds are raised centrally by the organization and used for fundamental research, strategic technology maintenance and quality assurance. Despite splinterization and the associated loss of qualified R&D personnel in Regional Bell Laboratories, it is an established fact that network operators' research activities overall are continuing unabated. However, there could be repercussions if the original strategy, whereby every new network operator was to build up his own independent R&D capacity, is unable to stay the course.

In the context of this investigation, owing to the size of the USA, it was not possible to investigate primary data for all the major companies conducting telecommunications-relevant R&D in the same detail. Furthermore, two prominent companies were not prepared to make the appropriate information available. This must be attributed primarily to the swingeing changes in company structure that are also affecting the R&D side.

From the number of patents, for the mid-1980s the organizations conducting R&D in the telecommunications field could be ranked as follows: AT&T — US Government — RCA Corp. — Motorola Inc. — ITT — GTE — General Electric Co. — IBM — Westinghouse Electric Corp. — Zenith Radio Corp. — Xerox Corp. Of these leading innovators, AT&T, GTE and RBOC are analysed further in this contribution on the side of the network operators, and IBM and Motorola again together with AT&T on the side of the telecommunications manufacturers.

An analysis of the organizations conducting R&D in the USA by reference to patent grants over the last ten years shows that there is a marked intensification in technological competitiveness in the wired communications sub-area and in other appliances. Over the decade under consideration, the diversification of competing participants has remained more or less constant in radio technology, image communications and high frequency communications. Concentration processes are observable for the, at any rate, generally deficitary picture transmission, digital telecommunications technology, optical communication and signal transmission technology.

Extreme competitiveness (with the exception of armaments), self-sufficiency in R&D and the large home market have for some time made it appear as though there was not much of a common denominator for company behaviour in the USA. Slowly, this situation appears to be changing. To what extent new, concentrated R&D activities like SEMATECH are successful is hard to assess for the moment.

From the European standpoint, American universities are particularly willing to cooperate, and also at the same time constitute an important resource for company research. From the US internal survey, complaints are, however, received in the telecommunications sector to the effect that the knowledge available in the colleges is underutilized to provide effective support for industrial competitiveness. Certainly, for a few years there have been improvements in this direction. Accordingly, other meassures, particularly the setting up of a new major, national, target-oriented, technical information research centre, will involve liaison with a major university. It is also expected (ideally with government financial backing) that the breakaway groups from Bell Laboratories, owing to inadequate capacities of their own in fundamental research, will increasingly endeavour to cooperate with universities.

3.2. Japan

The R&D organization of the Japanese telecommunications centres was and is characterized in the country comparison by very marked cooperation between carriers and manufacturing industry, which essentially consists of four large companies in the electronics sector. Universities tend to be bystanders, and the other research institutes fulfil only one specific role (see Fig. 2).

This centrally regulated structure has hardly been altered by re-regulation in the telecommunications industry [20]. The privatized carrier NTT behaves increasingly like a vertically integrated telematics concern, but the supplier monopoly of the so-called Denden Family, consisting of NEC, Fujitsu, Hitachi and Oki, has hardly been altered (of the four companies, the former two are analysed further below). Even though NTT is endeavouring, in an increasingly competitive home market, to better safeguard its own interests in the R&D field, personnel and know-how exchange plus the three-stage procurement facilities, which develop R&D assignments for manufacturing industry via procurement contracts, all carry on in the same way. It may still be too early to expect changes, for the public authorities have not yet sold two-thirds of the shares elsewhere as planned.

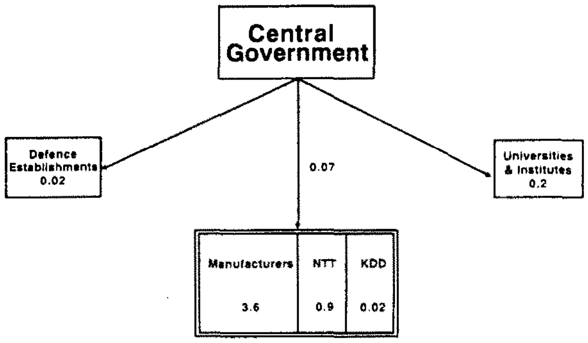

Fig. 2. Most important R&D actors in telecommunications in Japan, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

Against the background of comparatively moderate changes in regulative policies, changes in the R&D sector appear to be very fast, very far reaching, and very self-confident. On the central carrier side, NTT has completed a massive restructuring whereby whole sections of development work are passed directly over to the operating business areas. The central laboratories (originally four, now 11) are working increasingly in applied research, but the personnel have been cut back. Furthermore, NTT has changed its R&D work by giving greater prominence to software research. The same also applies to practically all manufacturers, whose R&D activities are very difficult to uncover, for only in the case of smaller company sections are the firms concerned purely telecommunications companies. Very little information is available about the internal structure of R&D, and about demarcating telecommunications research related to other work in the electronics field. However, this is no statistical problem, but depends on the fact that the respective large concerns consider their activities in an integrated form, and each one of them, from component to participant in new carriers, either is or would like to become vertically fully integrated.

Despite the concentration of central NTT laboratories on more research (instead of development), overall the R&D volume of NTT has been biased towards market-related requirements. As an offset, the Ministry of Posts and Telecommunications (MPT), apparently in a 50:50 arrangement with the Ministry of International Trade and Industry (MITI), has set up a large new laboratory for advancing long-term research projects in the public interest. This ATR research institute most recently became the centre of a new scientific town in the Kansai Region close to Osaka. The structure of the ATR laboratory is interesting in that four legally independent profit-oriented companies conduct research, whilst a fifth company undertakes all management planning and administration functions. NTT has a majority shareholding in this umbrella company. A further compensatory measure, designed at securing long-term research, is the conversion of the Post Ministry's own laboratory (CRL) from a pure radio institute into a telecommunications institute. The second large carrier, KDD, has also restructured by concentrating particularly on software-related R&D work, and quickly rearranged itself into a new institute. The new carriers have hardly any R&D activities, thus only KDD and NTT will be studied among the world's network companies.

With the exceedingly fast changing R&D structure, and with the obvious desire to obtain long-term work despite fierce competition between carrier and manufacturer, the Japanese Post Ministry has demonstrated exceptional vision and also the capacity to put ideas into effect. Alongside MITI, it has risen to become the second most important ministry in applied research. By skillfully combining regional policy aspects with research policy it has also set up a power base within the Japanese government system. Overall, it can be said to be a long-term and carefully planned but quickly executed full re-regulation of the R&D sector in telecommunications. The term 'deregulation' would be an entirely incorrect label to apply to research and development in this context.

Japan appears to be one of the few countries which has reacted to the challenge in telecommunications with a comprehensive reorganization so that continued retention of a directing function at an international level appears to be unaffected, and over a period of time ought to increase, even if some of the very ambitious projects cannot be retained as originally planned. The one true major deficit appears to be the software sector, but now this is being tackled purposively by all sides. Whether this will definitely bring the appropriate successes is still unsure, because even in the R&D field the conformity well entrenched in Japanese society can be an inhibiting factor for the discovery of creative solutions. Very little is being done on military technologies, and even the wired telecom technology sector is not very prominent in international terms.

Public funding has for some time hardly been a factor in Japanese research and development systems; even the military sector is virtually completely self-contained. Interaction between the state and the private company has always taken another form, and things will certainly not change. Although substantial state interference in technology policy is undeniable, Japanese electronics concerns have accordingly produced auto-financed services which cannot be explained by reference to state control. Purposive, pragmatic R&D performance in the telecommunications field characterizes both the public authorities, large carriers and manufacturing entities.

3.3. Germany

In Germany, the defence ministry is not an important financier of R&D in telecoms. R&D policy is overseen by the Federal Ministry for Research and Technology (BMFT) [21]. In telecommunications, the BMFT has funded R&D for satellites as part of programmes for space technology, mainly in collaboration with France, and the BMFT also has programmes for R&D in telecommunications. One main objective of the programmes was to ensure an international competitiveness of the industry. The BMFT mainly funded R&D for optical communications technology, switched broadband communications, the introduction of a very sophisticated data communication network for the science community, and R&D for high definition television (HDTV). The funds for these programmes were of minor importance compared to the national telecommunications R&D budget (see Fig. 3). Half of it went to public research institutes and universities, the other half to industry. The BMFT funds have supported medium- and long-term R&D activities in industry to some extent, and they have had a positive impact on the innovation activity of the Deutsche Bundespost, especially at the end of the 1970s [21].

The most striking feature of the German R&D system is the insignificant role of the national carrier Deutsche Bundespost (DBP). The DBP runs a research institute employing roughly 340 people. Its main objective is to provide the carrier with an independent judgement of technological developments, and it is involved in international standardization activities. The DBP employs approximately 1500 people engaged in development activities. These people are not involved in the development of equipment, but rather in development activities for new networks and services. Overall, the DBP performs only 4% of the national R&D (Fig. 3). It finances some external research mainly at universities, and procures equipment for pilot applications. Therefore, the DBP finances a higher share of the national R&D budget (7%) than it performs (4%), but it is still quite low compared to that of other countries.

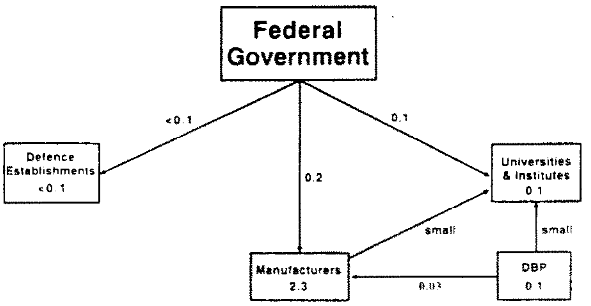

Fig. 3. Most important R&D actors in telecommunications in the Federal Republic of Germany, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

Until the end of the 1970s, the DBP had relatively close and stable relations with a small group of national manufacturers. It followed a strict policy of standardization which meant that no more than one system or one type of equipment for any given application was procured. This limited the amount of technological competition, and gave the largest manufacturer, Siemens, a leading position in the R&D process. In those days, the DBP was relatively closely involved in the definition of new equipment. During the 1970s, this system failed in the development of a new generation of public switching equipment (EWS) which, beside other factors, provided an incentive to change the old cooperative system. The DBP introduced R&D rivalry among the manufacturers, and restrained from further direct involvement in detailed technical specification of new equipment. The new procurement modes give an incentive to do specific R&D for the needs of the DBP by restricting the market for a number of years to those manufacturers which survive the first two stages of a procurement process. In the first stage, the vendors present pilot equipment which is tested by the DBP, and the second stage is a price competition among the successful vendors for a certain amount of equipment.

The DBP pays for R&D costs in the course of the actual procurement of the equipment. R&D costs are part of the price calculation of the vendors. Therefore, the amount of money the DBP expends for R&D depends on the competitive situation during the initial years when new installations are introduced, and the threat of potential competition thereafter.

In 1979, when the DBP introduced this new procurement procedure for digital public switching equipment, the participation was limited to vendors who would develop and produce the switches predominantly in Germany. This has since changed. The procurement process for digital access cross-connector systems, which started in 1988, was thrown open to any vendor, and foreign manufacturers are taking part.

In such a set-up it is not surprising that the manufacturers perform and finance (89%) almost all the R&D activities (Fig. 3). Siemens is the leading German telecommunications manufacturer with large R&D resources, but there are a number of other manufacturers with substantial R&D capacities. Standard Electric Lorenz (SEL) and Philips Kommunikations-Industrie (PKI) are parts of large multinational telecommunication and electronic companies, Alcatel and Philips respectively, with large international R&D resources. The Bosch group is establishing itself in telecommunications, and AEG has a long tradition in the market. The number of technologically independent manufacturers seems to be relatively large compared to other European countries [21]. Included in the set of companies to be further analysed are Siemens and Bosch, and Alcatel as well as Philips in total, not with their German subsidiaries alone.

Many universities and a number of public research institutes do research in telecommunications (34% of the national publications in 1986). The BMFT finances a specialized research institute, the Heinrich Hertz Institut, employing more than 250 people.

3.4. France

In a concise assessment of the R&D structure in France [22], it becomes apparent that the state network operator, France Telecom, is of considerable importance in the telecommunications R&D field, with the CNET research centre having a key function. Public research at universities, colleges or other institutions is of relatively marginal importance (cf. Fig. 4). In addition, France Telecom entrusts substantial development commissions to industry, and thus also essentially determines the R&D structures established. However, as far as the company sector is concerned, this promotion of industry at the same time also tends to be restrictive as it creates a very strong link with the French market. For the overseas market, industry is frequently obliged to finance separate research and development projects from its own resources, whence derives a noticeable limitation on competitiveness.

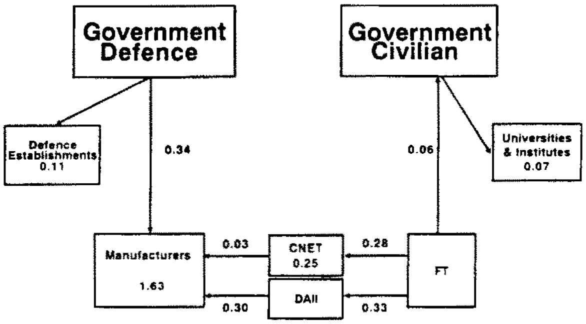

Fig. 4. Most important R&D actors in telecommunications in France, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

In view of this situation, the fact that France Telecom is obliged to deliver substantial funds to the general state budget which only in exceptional cases benefit telecommunications, creates problems. The function of the main purchaser of telecommunications products and facilities is thus seriously affected; the home market orientation of the French telecommunications industry is therefore a particular disadvantage.

Insofar as industrial structures are concerned, France underwent a marked concentration process in the 1980s, the outcome being the accession of CGE subsidiary Alcatel to an overwhelmingly monopolistic situation. In all major concerns, at the moment, an opening to the European market is detectable. At Alcatel, this was achieved by integrating European ITT subsidiaries, whilst lesser concerns achieve this by cooperating with external partners.

Overall, strong state control over R&D in the telecommunications field on the French pattern is definitely beneficial throughout. However, industry is at the same time so restricted that attempts are increasingly being made to move away from the France Telecom network operator. This tendency is explicable primarily in terms of a clearer demarcation by France Telecom between research, development and purchase orders which has been introduced as part of a liberalization policy since 1986. Fresh competition on the French home market is being viewed by industry with great scepticism, although the extent of the negative consequences is apparently exaggerated.

For all the criticisms which are being levelled against the French model in its present form, the many positive aspects of close cooperation between network operators and industry should, however, not be overlooked. Were France Telecom to adopt a more world-market oriented policy, most objections would largely fall by the wayside. This realization is obviously also coming home to CNET, so that the French R&D contribution following the opening up of the European market in January 1993 ought not to be underestimated. A technology breakdown shows a very balanced specializations profile for France in telecommunications, in which only radar stands out positively and picture telecommunications negatively.

3.5. United Kingdom

In a country comparison, very intensive cooperation between carrier institutions and highly concentrated manufacturing industry was a hallmark of R&D in the British telecommunications sector which essentially produces for the home market [23]. Universities tend to be on the sidelines and other research institutes — except in the armaments sector — only play a minor part.

The state, as the vehicle for technological policy, *i.e.* more especially the Department of Trade and Industry (DTI), has hitherto largely remained aloof from wired, civil telecommunications R&D, although information technology, particularly in regard to combined research between colleges and companies, has been given high priority for some years now (Fig. 5). State subsidization of major telecommunications manufacturers in the form of R&D subsidies and procurement measures emanate from the Ministry of Defence on a large scale. So long as the carrier was an integral part of the state administration, its substantial outlays on R&D to industry could be regarded as state subsidies. As far as that goes, development of an independent British communications technology has in the long run been initiated by state organizations, even

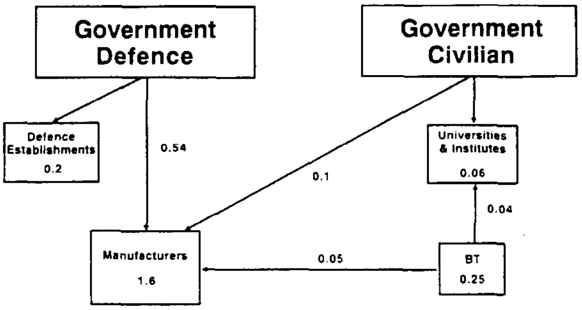

Fig. 5. Most important R&D actors in telecommunications in the United Kingdom, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

though continued and completed in the private sector.

Owing to the change of government at the end of the 1970s, and what in the British context has been an exceptionally long term of office for the former Prime Minister, a whole series of liberalizing measures has been implemented which have, to some extent, influenced the R&D structure profoundly. In particular, the exceptionally fast adaptation of British Telecom (BT) management to the new situation far exceeded all expectations. From the paternalistic role adopted by the state monopolist, who has had a hand in influencing virtually all telecommunications-related technologies, British Telecom has become an aggressive private concern which has become increasingly vertically integrated and operates businesses worldwide, whether services or appliances. However, in the R&D field, BT has remained entrenched in wired telecom technologies (including fibre optics).

The politically much vaunted full liberalization on the pattern of the United States ('Little America') has got stuck in a two horse race in which BT continues to be in the ascendency. The second largest trans-regional network operator, Mercury, has not built up any R&D capacity, while BT is allowing its own capacity to stagnate so that network operators collectively have allowed their R&D quota to go into a decline *vis-à-vis* manufacturers. In addition, they have switched from medium-term oriented work to more near-market projects. This has left a gap in medium-term strategic R&D which even the colleges are unable to fill owing to their present traditions and structures.

From the technological standpoint, armament-related sub-areas of telecommunications can be regarded as the province which is specifically British. In the forefront are radio engineering, high frequency communications and also fibre optical technology. Here not only is there an excellent grounding in fundamentals but also, to some extent, in the 1980s, very marked dynamic trends. Also, taking overall a cross-section of all sub-areas, British research and development is registering above average activity on a world scale, but it places too much emphasis on defence (cf. Fig. 5).

The development of a national British communication System X cannot be rated as a success from the technological standpoint; in view of the fact that R&D structures are changing every couple of years or so, the vendetta between GEC and Plessey and the 'Mitel Affair', namely the acquisition of an equipment producer by the network operator BT, have made for greater insecurity. The long overdue concentration of System X development in a single entity (the joint enterprise GPT) at the beginning of 1988 came very late, and could not be consolidated, because within a year of its formation uncertainty about future R&D work apportionment has again been generated with the takeover bid for Plessey by GEC and Siemens [23].

The influence of the Ministry of Defence on electronics R&D is substantial; it is hard to say to what extent the civilian sections of telecommunications technology are affected by this. On the one hand, there is ever increasing insistence on transfer processes between civilian and commercial technologies, and there are even a number of examples of this; on the other hand, civilian volume markets and highly-specific job lots should continue to cater for few commonalities. The key obstacles from armaments-related telecommunications R&D tend to lie in the diversion of research personnel from the civilian sector, the tying up of facilities for comparatively non-remunerative R&D work, and in the need for extreme secrecy within the companies involved. Whether armament-oriented R&D is efficient, *i.e.* whether it will or will not lead to greater national security (which is the criterion for the success of such R&D), does not manifest itself in terms of economic parameters, and cannot therefore be assessed in this context.

Since British industry in the post-war period at any rate had to overcome a series of problems from which it has only recovered slowly in the 1980s, the difficult international position of the civilian telecommunications industry needs to be understood in general terms. British companies are no longer in the forefront of world events. There is no anticipated improvement in the medium term because, thanks to state policy on technology, responsibility for strategic, oriented research in the medium term in telecommunications is left as a grey area between carrier companies and universities. Whether European community endeavours can permanently fill this gap with comparatively limited means at their disposal remains questionable.

3.6. Italy

In Italy, telecommunications R&D is essentially characterized by three factors: fragmentation of responsibilities in the services area; scant and poorly coordinated public promotion; and the dominance of state organizations in the telecommunications sector [24] (see Fig. 6). By dividing up the networks and network operation into several partly state-controlled, partly semi-state controlled institutions, there is no uniform development and investment programme, which has negative repercussions particularly in regard to new services. However, even in the traditional services and in the technical state of the networks, Italy has been falling behind the rest of Europe since the end of the 1970s.

There is no uniform programme for state R&D development, but mostly only isolated projects. The odd major project promoted in the telecommunications field is spread amongst numerous, often very small research groups and certain industrial concerns. Fundamental research on

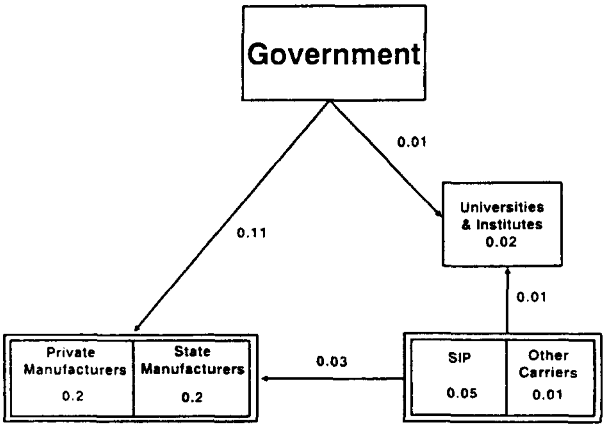

Fig. 6. Most important R&D actors in telecommunications in Italy, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

telecommunications at universities is centred on a few polytechnics, and owing to lack of direction is not very effective.

Out and out R&D expenditure in the telecommunications field is low in comparison to other industrial countries. The relative R&D outlays by manufacturers relative to turnover are high. All major private concerns working in the telecommunications sector are active internationally, and offer mainly product specializations. The largest domestic manufacturer of telecommunications equipment, on the other hand, belongs — as does the most important network operator — to the state holding IRI. These companies are still not very internationally oriented.

Rising R&D costs for new technologies in the telecommunications field are a problem for industry generally. They can be financed only by large shares of world markets, which Italian companies do not, however, enjoy. The specialization strategy, in conjunction with close links with traditional branches of commerce, appears to offer chances of success, first owing to market proximity, and second as it is comparatively low on cost for R&D. As a result of the comparatively great autonomy enjoyed by both state organizations and research facilities within IRI, and inadequate state planning for telecommunications and research, there are numerous overlaps in telecommunications R&D, and only small scale cooperation domestically. Large private firms, however, have already been working for some time together with foreign partners as part of their targetting of international markets.

Italy sees the European home market as being a great challenge and offering considerable prospects. Therefore, extensive plans are afoot for preparatory activities. This has already been reflected in the rise in R&D expenditure in the telecommunications sector [24].

3.7. Spain

The Spanish telecommunications sector is exposed to strong structural and qualitative changes. Spain's particular historical and political context in Europe, which applied up to the 1970s, has favoured the maintenance of established industrial and social structures, which also cannot be completely overlooked today. On the one hand, many democratic normalizing processes occurred here more quickly than elsewhere — which had nothing to do with the internal needs of the telecommunications sector, although definitely affecting it. Conversely, development of information technology as the expression of a modern, post-industrial society is also accelerating this change [25].

The leading light in telecommunications matters is the most important of the three carriers, Telefónica, a company which has a small vertically-integrated company empire, and which is also playing the minority holdings field. In the independent R&D sector, Telefónica has for decades played a passive part — the business of technological modernization was undertaken by foreign companies, Standard Eléctrica (ITT) heading the field. Telefónica has recently acquired its own R&D subsidiary, TID, and is becoming an increasingly active player in the R&D field. Since the new law on telecommunications of December 1987 upholds the present, virtually monopolistic network structures, Telefónica's R&D-associated risks are covered financially.

The state R&D system hitherto has suffered

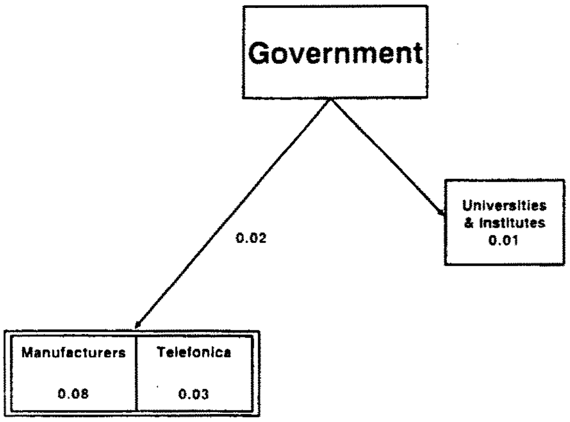

Fig. 7. Most important R&D actors in telecommunications in Spain, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

from the absence of concepts and coordination, and last but not least from a series of reorganizations in recent years. However, so far these have not brought forth any structures which can be assumed to be of a lasting nature. More recent national plans are impressive — disputes notwithstanding — simply in terms of their size. The figure for present day public funds for telecommunications-related R&D is four times higher than the level for the previous year (see Fig. 7).

From technology indicators, Spain is making the largest contributions to progress in telecommunications technology worldwide in the wired telecom sector (via Standard Eléctrica), as well as in radio and radar. Also, the emphasis on quasi-military telecommunications fields in R&D cannot be overlooked in quantitative terms, and is surprisingly clearly identifiable as a subject area from the available source material.

Spain has made a tremendous effort to catch up in telecommunications-related R&D. With a legacy of cultural and structural problems, its position at the outset could not be classified as being outright beneficial, so that the full-bodied initiatives and plans for institutional and financial reforms appear to be very ambitious, and might lose momentum in favour of more straightforward endeavours.

3.8. Republic of Korea

For some years now, R&D activities in the telecommunications sector have been increasing markedly in the Republic of Korea for a number of reasons, as the government is encouraging the setting up of leading-edge industries, including telecommunications [26]. Also, independent domestic R&D activities are all the more important as the importing and imitation of foreign technologies are always subject to limitations. However, Korea still has a considerable amount of catching up to do in R&D. So far, there is only one significant development in the telecommunications sector: the TDX switching system.

R&D structure and contents are largely state-imposed. The government dictates the development of telecommunications services and the basic technologies to be used, plus standards for production and export. State and industrial research facilities have to gear their R&D activities to these plans. Most of the R&D consists of refinements to foreign technologies, reasonably priced end user appliances, or adaptive developments for domestic requirements or export to other Far Eastern countries. Fundamental research (see Fig. 8) is virtually non-existent.

R&D in the telecommunications sector is run mainly by the state owned institute ETRI, the

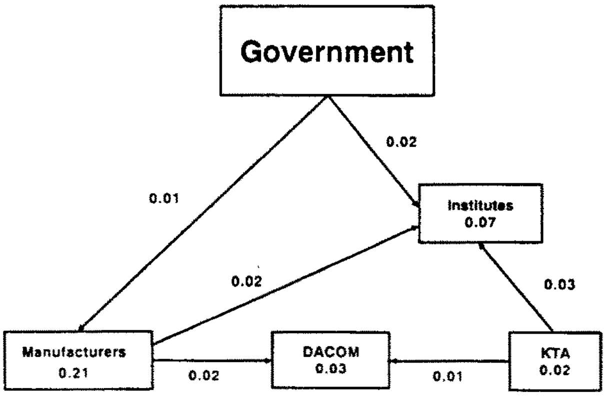

Fig. 8. Most important R&D actors in telecommunications in the Republic of Korea, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

Goldstar and Samsung combines, and OTELCO, a joint venture between the Korean concern Oriental Precision and the Swedish company Ericsson. Intensive cooperation is carried out only under the umbrella of 'national research projects', where it is prescribed by the state as the financier.

The network operator KTA, and also the partly private DACOM, are equally heavily dependent on government plans which they then have to put into practice. The R&D facilities of the network operators primarily consist of offers of services.

South Korea is seeking technological cooperation with foreign countries, but frequently this cannot be achieved in the desired measure because Korea is insufficiently developed. There are only isolated instances of joint ventures in the telecommunications sector.

The Republic of Korea's future development is hard to foresee at the moment. With interventionist policy and population movement, a high technological standard will probably be achieved. However, the country is contending with serious political, economic and social problems which need to be resolved simultaneously.

3.9. The Netherlands

The R&D organization of the Dutch telecommunications sector is characterized in the country comparison by extreme independence of carrier institutions, manufacturing industry and universities or research institutes, the latter playing only a very subordinate role in the overall picture of things (Fig. 9 [27]).

The state, being the vehicle of technology policy, *i.e.* particularly the Department of Trade and Industry, has hitherto largely held itself aloof from telecommunications R&D, although information technology generally represents a priority area for appropriate technological policy measures. State subsidization of large telecommunications manufacturers does not take the form of R&D subsidies. R&D furtherance is mainly undertaken at the European research programme level. Whilst the Dutch PTT was part of the Ministry for Traffic and

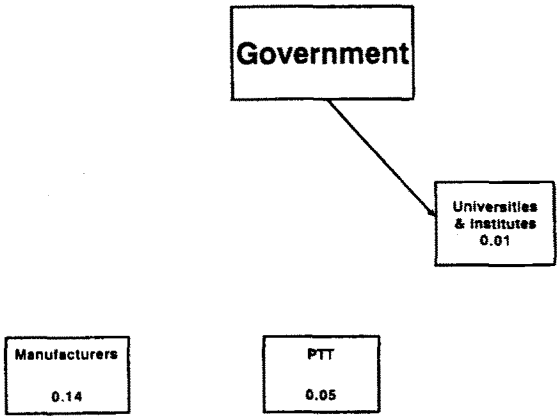

Fig. 9. Most important R&D actors in telecommunications in the Netherlands, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

Water Management, telecommunications policy, including the respective R&D policy, did not come under the auspices of the Department of Trade and Industry. Changes in this area were likely to start after 1989, when the PTT acquired the legal status as a joint stock company.

Both the Dutch PTT and also manufacturing industry maintain their own R&D centres, in which long-term research projects and even fundamental research are investigated. The Doctor Neher Laboratory (DNL), the PTT infra-structure research laboratory hitherto, was regarded as the 'TNO Telecommunications Institute', *i.e.* it bridged the activity gaps of TNO, the large Dutch organization for applied research, in the telecommunications sector. After PTT restructuring at the beginning of 1989, there were no longer any guarantees that the DNL would continue to discharge this duty. For with market liberalization, the PTT is exposed to competition in various areas. This is particularly true of the service area. In view of the reorganization and also new technological developments, in 1986 a new research institute, the PTT Telematics Laboratory, was founded. This conducts R&D mainly in the interface area between telecommunications and information technology, and should support PTT Telecom in competition with private service suppliers. An expansion of R&D activity at the new laboratory is planned for 1992.

In the Dutch telecommunications manufacturing industry, the leading light is Philips, particularly its subsidiary Philips Telecommunicatie en Datasystemen (PTDS) and AT&T and Philips Telecommunications (APT). A clear cut R&D work apportionment exists: Philips researches and develops for the business telecommunications area and ATP in the public sector.

Philips has at its disposal an extensive R&D organization in the form of eight laboratories in six countries, the largest being the 'Philips Nat Lab', which covers a broad spectrum of technological disciplines and areas of fundamental research, and is based in the Netherlands. The tightening up of business activities currently in evidence at Philips, with the organization of research included, appears to boil down to greater sensitivity to users' needs. The sanctioning of the greater influence of the international competitor AT&T who, since the beginning of 1988, has held a majority holding in the joint company APT, on public telecommunications, and Philips' concentration on office automation including office telecommunications, are steps in this direction.

National R&D activities are heavily influenced by the Philips group. From the technological standpoint, general image transmission can be regarded as the Dutch specialist area. R&D expansion in wired telecom and in digital communications technology can be expected in the coming years as a result of the intensified engagement of APT. It is generally accepted that telecommunications technology in the Netherlands fulfils a key function in many application areas, but that it does not have a pole position among the main fields of national technology.

3.10. Sweden

R&D organization in the Swedish telecommunications sector is characterized by a high degree of cooperation between participants [28]. Technical universities and research institutes offset the lack of a central interdisciplinary research laboratory at the leading manufacturer Ericsson and at the carrier Televerket by their engagement in fundamental and applied research. Sponsored by the state technology authority STU (since 1991, NUTEK), via appropriate programmes, universities and institutes, conducts combined research both with Ericsson and with Televerket.

In the public telephone and data networks fields, and in private communication technology, even with advanced liberalization, as usual there is close manufacturer-user R&D cooperation between Ericsson and Televerket. The joint development subsidiary Ellemtel, founded in 1970, is a mere rubber stamping of the diverse cooperations between Televerket and Ericsson (Fig. 10). Other areas for cooperation derive from state programmes sponsored either by STU alone, like, for example, the R&D programme in mobile radio, initially involving only the universities and Ericsson, then later on also including Televerket, or the national information technology programme conducted by several state organizations simultaneously.

Both at Televerket and, to an even larger extent, at Ericsson, the internal R&D structure is characterized by divisionalization. On the one hand, this is a reflection of the Swedish sectoral research model in miniature, *i.e.* at company level. On the other hand, this type of R&D organization, at least

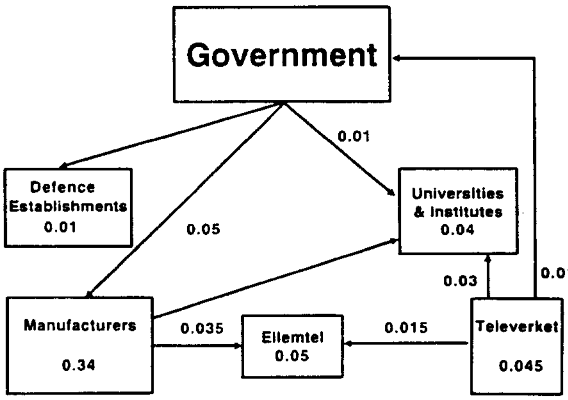

Fig. 10. Most important R&D actors in telecommunications in Sweden, including estimated R&D expenditure as of 1987 (US$1000 million). The meaning of numbers and arrows is explained in the legend of Fig. 1.

as far as Ericsson is concerned, results from the preponderance of concrete product development as opposed to only a minimal proportion of overlapping research relative to the R&D volume as a whole. The advantages of this type of organization lie in high market-proximity product development, the result of individual departments being solely responsible for their own product development. Disadvantages arise where interdisciplinary tasks need to be performed, as the appropriate skills, although available, are scattered over the company.

Televerket's role in the telecommunications R&D process in the new, *i.e.* liberalized, organizational structure is not without its problems. Whereas Televerket as a state establishment is responsible for sectoral research for the entire telecommunications sector, and therefore also for manufacturing industry and other carriers (currently only Comvik), Televerket, particularly the production subsidiary Teli plus diverse software and service subsidiaries, itself is exposed to competition. This means that the results of telecommunications R&D initiated and financed by Televerket are supposed to be made available to the entire telecommunications sector. But in direct competition (confidential), R&D is a company's trump card to be played as circumstances dictate.

The image communication and transmission fields must be regarded as a Swedish R&D deficit area. Imported Japanese competitor products clearly dominate here. The country's technological strength obviously lies in wired telecom.

3.11. European programmes

Altogether, the European programmes are sufficiently varied to allow for a flexible and efficient European research policy. Nguyen [29] published the following overall assessment.

COST is devoted to public research. In the area of telecommunications, the actions have a broad scope but limited resources. There are projects for all aspects of telecommunications: public switching, transmission, mobile telephony and HDTV. The handicap of COST stems from an unfashionable and somewhat less effective way to deal with R&D. Cooperative, multilateral, public research does not fit in with the competitive trend of world markets. On the other hand, COST has several trumps: it is not a Community programme, and the member state participation is not mandatory, while other European OECD countries can easily join the projects. Second, there is a stronger need, even within private firms, for open research, with a strong science-based approach where cross-fertilization would be maximized. Third, since 1970 COST has developed a network of multilateral relationships which might be useful in larger and more ambitious projects.

In EUREKA, telecommunications are under-represented. The HDTV project, which is not exactly a telecommunications programme, does not hide the paucity of true telecommunications projects. There are several explanations for this: on the one hand, telecom manufacturers are used to getting their support from PTTs, who are both their major customers and the main source of subsidies, direct or indirect. But PTTs are not present as such in EUREKA, where subsidies are given by research or industry departments. Also, RACE and EUREKA have been run concurrently, starting in 1985, and the manufacturers have joined the former instead of the latter.

Compared to ESPRIT II, where user-producer integration and joint product development becomes the rule, EUREKA seems to lag behind, at least in the communications industries. This is paradoxical, since EUREKA is supposed to be closer to the market than the 'precompetitive' ESPRIT programme. More generally, Community programmes are now much more 'visible' than the EUREKA initiative, because the management team is much stronger, the public support is higher and more effective, and the decision making procedure easier to follow, since the call for proposals in ESPRIT or RACE gives rise to a general bargaining between the member states: this is a collective decision; in EUREKA, instead, each country has to approve the project presented by the national firm: the result is a sum of individual decisions.

RACE is aimed at a single, well-defined objective, the implementation before 1995 of a prototype of the IBCN (Integrated Broadband Communication Network) taking into account the evolution of the ISDN (Integrated Services Digital Network). The IBC will be made up from fibre optics devices, and will support applications ranging up to the HDTV transmission. RACE has developed a consensual approach with PTTs, manufacturers and some users.

However, RACE has some drawbacks. First, the IBCN will possibly not evolve naturally from the ISDN. The latter, in fact, has a slow penetration pace, and the demand for its services is not clearly identified. There are major initiatives from large users or big service providers to install their own broadband facilities which might be at odds with the RACE conception. Also, the local cable TV distribution networks may offer a possibility for moving quickly into broadband interactive networks. The latter eventuality is strongly investigated by some Regional Bell Holding Companies. Also, the Commission's efforts, expressed in its Green Paper, to promote competition may be contradictory with its consensual approach in RACE. Finally, the target of designing an IBCN prototype by 1995 may be far behind what is done by the major competitors in Japan and the US. In the latter country in particular, some Regional Holding Companies (as well as their common laboratory, Bellcore) take seriously the hypothesis to implement broadband fibre network for residential users as early as 1992. The US benefits from the lead of its fibre optics industry, which is already reaching an overcapacity. Also, the installed base of cable TV subscribers gives them a clear advantage.

In Japan, despite the privatization of NTT and the competition of other common carriers, the plans to implement the INS (Integrated Network System) have not fundamentally been changed. There is even a competition between the MITI (Ministry of Industry) and the MPT (Ministry for Post and Telecommunications) to subsidize the use of broadband services in less favoured (rural) areas (see section 3.2).

To summarize this in a sentence, while the US approach is decisively demand-pulled (big telecom customers and cable TV subscribers will be prepared to pay for broadland services), and the Japanese approach is supply-pushed (for the benefit of the industry), the European approach, summarized by RACE, is research-oriented, and no priority is given to the actual promotion of the IBCN concepts with the customers. On the whole, the European programmes (COST, RACE and EUREKA) offer a variety of perspectives and procedures which are large enough for any economic player to find suitable support from European authorities [29].

4. International comparison of countries

4.1. Financial expenditure

The most important national key data in the R&D field in the international telecommunications comparison are assembled in Table 3. The table differentiates overall according to telecommunication type, *i.e.* including armament-related components and civilian telecommunications. Some data are rounded off or estimated, because — as explained in the data sources section — they have been prepared from extremely diverse sources which are not always defined identically. No internationally comparable data set is available in the telecommunications field.

Spain virtually plays no major part in research and development, while South Korea is almost catching up with Sweden and is even overtaking the Netherlands in civilian telecommunications. There is very little to choose between the major European countries, indicating that in Germany a smaller share of the general national R&D budget is used for total telecommunications-related work. Most of the countries considered quote their national R&D budget for telecommunications as being approximately 10% of their national R&D budget.

This is surprisingly high considering the other important areas in the research and development field apart from telecommunications. Despite the

TABLE 3. Overview of national R&D expenditure on telecommunications for the selected countries in 1987; to some extent rounded off or estimated [12]

	USA	JPN	DEU	FRA	GBR	ITA	ESP	KOR	NLD	SWE
R&D expenditures on *telecommunications* in thousand million $	13	4·7	2·5	2·1	2·1	0·5	0·11	0·41	0·2	0·48
As % of all R&D expenditure	10	10	11	13	13	6	5	9	5	14
Civilian state financial contribution (without network operators) (%)	3	4	4	≈2	5	28	25	10	≈3	≈12
Financial contribution by the Ministry of Defence (%)	36	0·4	5	22	35				≈2	≈3
Execution at network companies (%)	30	16	4	12	12	10	22	16	≈25	10
R&D expenditure on *civil telecommunications* in thousand million $	8	4·7	2·3	1·1	1·4	0·5	0·11	0·41	0·2	≈0·38
State financial contribution (without network operators) (%)	≈2	4	4	≈2	8	28	25	10	≈3	15
Financial contribution made by the most important network companies (%)	50	20	7	60	24	≈18	≈25	≈20	≈25	23
Financial contribution made by manufacturers (%)	48	76	89	38	68	54	50	70	72	62

blurred demarcations in electronics and for information technology as a whole, this is remarkable. In an international comparison, Fig. 11 shows how truly diverse the financial structures actually are.

Carriers play an important part in national civilian R&D financing in 9 out of 10 countries in proportions between around 20% and 60%, respectively. Only in Germany is carrier engagement less than 10%. Then add to this the company-financed contribution. In Germany and Japan where the military field is unimportant, companies have absolute sway. At about 70%, companies in Korea, the Netherlands and Great Britain are also a force in civilian technology to be reckoned with. Less important are the companies financing telecommunications-related R&D in Spain (owing to the state's heavy civilian engagement), in Italy, France (owing to high state engagement in national defence), and finally, in the United States, where manufacturers' auto-financed work (without AT&T which is also a network service company) accounts for a flat 30% (including non-civilian telecommunications).

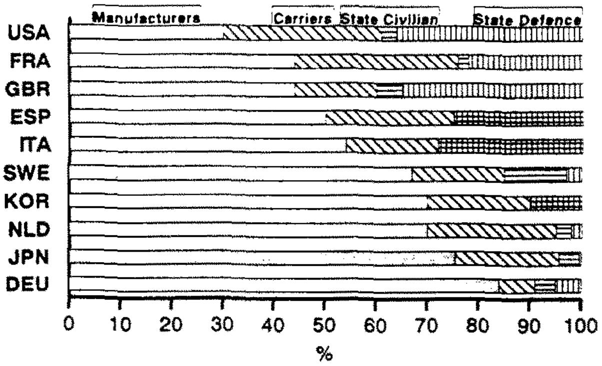

Fig. 11. Sources of funds for telecommunications R&D by sector in 1987 (for country codes see Table 2).

The considerable importance of company-financed R&D in telecommunications is not surprising; for averaging all areas of research and development, the company sector dominates as an institutional R&D supporter, a fact which is often overlooked in the multifarious debates on the importance of state technological policy or the role of universities. Note that in countries like Italy and Spain, state and private companies are put into the same category, thus giving a totally false picture as far as the hypothetical intervention capabilities of the state are concerned. The United States is a special case in that telecommunications-related research and development funds rest on three virtually identical large pillars: on the prominent work of the network operators — first and foremost AT&T; the Ministry of Defense; and private manufacturers. This picture certainly does not apply to the conduct of R&D, as explained in more detail below. Massive state intervention in the telecommunications field is via monetary measures in the case of France, the United States and Great Britain, with a high defence budget well to the fore in each case; only in France are substantial civilian funds also injected.

4.2. Precompetitive R&D

The considerations in the following section relate to the statistical distribution of publications in telecommunications-related research work in the field of fundamental and applied research. Figure 12 shows the distribution of the appropriate indicator in the ten countries investigated, and in four types of institutions: colleges, non-college, mainly non-profit making institutions, carriers and manufacturers.

Carriers who also produce appliances have been included in the carriers in each case. A general glance at the distribution first points to the relevant importance of the university or college sector which does not show up in the finance side. This is because at universities, only so-called 'third party' funds show in the monetary balance sheet, while

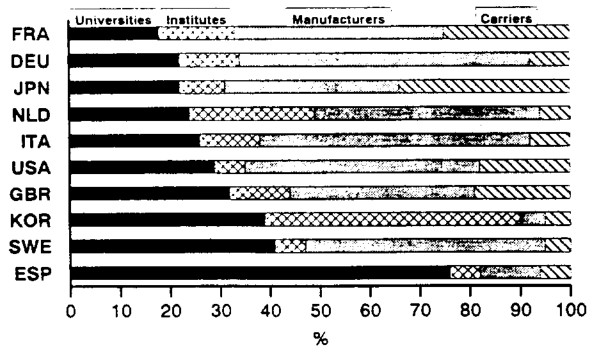

Fig. 12. Division of labour in precompetitive telecommunications research based on publication output by performing sectors in 1986 (for country codes see Table 2).

research projects at colleges which operate on a basic allocation defy detection. Telecommunications is not a field that can be defined in terms of academic specifications, so no inferences can be drawn about work relevant to telecommunications from the distribution of professorships or university staff in various areas of research [15]. Bibliometric statistics are therefore the only route for evaluating the contribution made by universities. It is impossible to say whether the indicator value is reasonable for the volume. It can generally be assumed that the publication propensity in colleges and in academic spheres is generally higher than within industrial companies. Despite these possible distortions, institutional classification of telecommunications-related R&D work based on published statistics at the moment is the only way of covering structural aspects (alternatively, there is also the patent indicator, but owing to the demand for commercial exploitability this again very firmly rules out the college sector, as the financial expenditure has already done).

Figure 12 shows very clearly that the importance of the college sector is greater in smaller countries. In the case of the United States, Japan, Germany, France and Great Britain, its contribution is limited to roughly 30% or less, whereas in Spain it dominates, and in South Korea and Sweden it accounts for approximately 50%. The importance of non-academic research institutes — depending upon the structure of the country — is variable, usually being a safe 10% at least. The part played by non-college, mainly non-profit making institutes in the United States, Spain and Sweden is particularly small, while telecommunications R&D in South Korea and the Netherlands is very reliant on this area. In Korea, this is a direct consequence of state promotion, aimed at raising the research infrastructure of the country quickly, whereas a series of international organizations based in the Netherlands make their presence felt. Carriers, like institutes in most countries, account for 5–10%. In Great Britain, France and the United States they play a more important part, while in the case of the United States, account must be taken of the fact that the powerful carrier AT&T has the world famous Bell Laboratories at its disposal, whose importance must again be attributed to a combination of services and appliance business. The Japanese carriers NTT and KDD are exceedingly important. Although totally or comparatively inactive on the appliance business side, they contribute very substantially towards the crop of publications from Japan.

Whilst the role of the manufacturers is, on the one hand, confined to functions which they safeguard in regard to precompetitive and applied research, on the other, in many cases, it is undoubtedly distorted by the fact that some companies operate a purposive publicization policy which in some cases gives its leading employees freedom, for example, through participation at conferences to disclose research projects, or specifically prohibits this. However, it would not be erroneous to state that in Spain and Korea the corporate sector does not play any more major part than is suggested by the indicator in Fig. 12. In most other countries, the corporate contribution is between 30% and 50%; also a reasonable order of magnitude according to qualitative assessment.

4.3. Industrial property rights

Since patent rights have a finite lifetime dependent on the payment of fees and generally can run for some 20 years, and as the fast drive towards innovation has hardly been fully utilized, the so-called 'five year patent potential indicator' has been selected for the next evaluation. This sums up the patent applications made over the last five years prior to the moment of assessment, so that the potential of the existing patent rights can be estimated [9]. An economy which at this point in time is not very lively, but can look back over a large volume of protective cover, is graded high in this assessment, in comparison to a newcomer who has remained passive for a long period and has only recently begun invention activities.

Figure 13 shows the change in technological potential since 1979 in the entire field of telecommunications for the five major economies

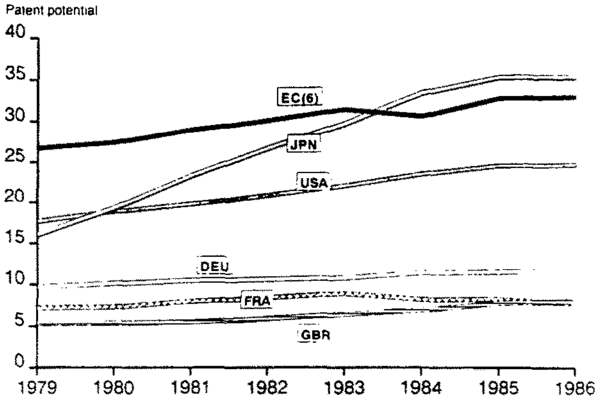

Fig. 13. Technological potential (indexed arbitrarily) in telecommunications 1979–1986 based on patent potential by five larger countries and six major European Community countries combined (for country codes see Table 2).

considered here. Japan has elevated itself to leader status in industrial patent rights, its progression being sharper than that of the United States, which has also been able to improve its position, although not to the same extent as Japan. Japan 'overtook' the United States roughly in 1980; however, since 1984, the markedly increasing international patent volume appears to have slowed down in both countries. Germany has also registered growth rates but at a lower level and with a lower rise. Great Britain's being even lower still. The trend in France was upwards until 1983, but since then the diagnosis has been one of declining patent potential.

Figure 14 shows the trend for the telecommunications field as a whole in the smaller economies. In contrast to the situation for precompetitive research trends, among these countries the Netherlands clearly has the ascendency over Italy which, in turn, was outstripped some years ago by Korea. Sweden remains roughly constant, while patent activities in Spain (at any rate, those of international importance) are negligible.

4.4. National trade performance

International competitiveness figures for telecommunications have not been surveyed in a systematic manner. Data are available for wired

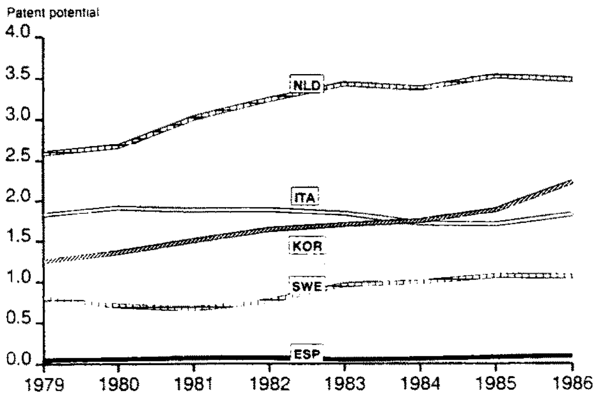

Fig. 14. Technological potential (indexed arbitrarily) in telecommunications 1979–1986 based on patent potential by smaller countries (for country codes see Table 2).

communications (so-called. line equipment [30]). The national shares of exports in total world trade in line equipment are given in Table 4. The table includes 1985 world export shares (WExS) as well as the increase in exports (d Ex) since 1978. To what extent export shares are a valid indicator of competitiveness is discussed elsewhere [14, 31, 32]. There, it is concluded that the decisive factor is not the absolute level of exports, but rather the world market share. An unequivocal, simple definition of competitiveness, however, is not in sight in current economic modelling [14].

TABLE 4. World export shares and increases 1978 and 1985 in line equipment by countries

Country	World export share (WExS) 1985 (%)	Increase in exports (d Ex) 1978–1985 (%)	Increase in world export share (d WExS) 1978–1985 (%)
Japan	23·1	21·1	12·0
Sweden	15·8	8·2	−3·0
Germany	12·7	4·6	−6·6
USA	8·3	8·1	−1·6
France	7·8	12·9	1·2
Canada	6·5	21·7	3·5
United Kingdom	4·9	5·6	−2·1
Italy	2·5	4·6	−1·3
Netherlands	2·4	−7·3	−5·9
Others	16·0	—	—
World	100·0	10·6	0·0

The export indicators are linked to technological performance figures by means of patent statistics. The Patent Potential (PP) indicator is employed for the year 1985. The data are similar to those of Figs. 13 and 14, but limited to relevant inventions for line equipment (see below; data source is Grupp and Schnöring [16]). For the sake of brevity, data compilation is not explained here in detail [9]. In short, the PP indicator reflects international patent output by correcting several distortion factors: home advantages (domestic patenting) in the country of residence, market preferences due to corporate sales strategies, and attractiveness and size of export markets. The PP indicator must be based on patent data from more than one patent office, in this case the USPTO, EPO and DPA. As there is a time lag for market success indicators as compared to patent indicators (by priority dates) of two to four years [9] in modern areas of technology, the PP priority years 1981–1985 would best correspond to exports in 1985.

Table 5 lists the numerical results of several regressions. First, patent indicators in the subfield

TABLE 5. Correlation of competitiveness (various export indicators) in line equipment, technological performance (patent indicator for wired, image, digital and fibre subfields) and R&D input structure (funds by sectors)

Regression variables	t	Significance level (%)	No. countries compared
PP5 (85), WExS (85)	2·612	<5	9
d PP5, d Ex	2·532	<5	9
d PP5, d WExS	3·613	<1	9
NRD (87), WExS	−0·170	—	8
NRD (87), d Ex	0·009	—	8
NRD (87), d WExS	−0·026	—	8
NRD (87), PP5 (85)	1·771	—	8
NRD (87), d PP5	1·002	—	8
GRD (87), WExS	−0·889	—	8
GRD (87), d Ex	−0·645	—	8
GRD (87), d WExS	−0·231	—	8
GRD (87), PP5 (85)	−1·729	—	8
GRD (87), d PP5	−1·034	—	8
MRD (87), d Ex	−1·133	—	7
MRD (87), d WExS	−1·386	—	7
MRD (87), WExS	−2·537	≈5	7
MRD (87), PP5 (85)	−0·068	—	7
MRD (87), d PP5	−0·684	—	7

of wired telecommunications (as defined in Table 1) do not correlate with exports in line equipment (no regression results are given in Table 5). The reason is that these exports nowadays include products for image transmission (*e.g.* facsimile) and optical transmission (*e.g.* fibre cables). Indeed, the combination of wired, image, digital and optical subfields (see Table 1) yields some correlations with exports (Table 5). Thus, it is R&D in these four subfields in the countries compared which lays the ground for economic success in line equipment nowadays.

Further, a considerable number of correlations between R&D input structure (from Table 3) *versus* technology development (patents) and competitiveness (exports) have been computed (see Table 5). Preferably, R&D figures preceding the export and invention years were required, but are not available. Therefore, with the assumption of a fairly constant relative national R&D expenditure structure, the 1987 data were taken from Table 3.

The results are very simply summarized: there is nearly no correlation independent of the arrangement of indicators. The share of network operator's R&D execution (NRD) within the national activities as of 1987 does not explain national competitiveness. The same is true for the national share of governments in civilian R&D funds (GRD). Only in the case of military R&D funds (MRD) contributed to the national budget, among many insignificant correlations one fairly negative one was found: the higher the defence R&D shares in telecoms are, the lower is the expected world export share (see Table 5). These results must be rather disappointing to those who claim that privatization and network operator deregulation are prerequisites for international economic success.

4.5. National R&D efficiency and export performance

Linear and non-linear programming immediately suggest themselves as appropriate tools for efficiency measurement. However, the measures of scientific and technological excellence are non-monetary in nature — they do not represent labour-hours or capital dollars, but rather comparative metrics. This makes conventional programming models unusable [6].

A version of linear programming exists, however, that was explicitly built to measure the efficiency of 'decision-making units' (which could be countries, industries or individual firms), and that does allow qualitative inputs. This approach, devised by Charnes and Cooper in 1978, is known as Data Envelopment Analysis (DEA). Essentially, it examines which decision-making units (DMUs) are on their production possibilities frontier, or isoquant, and which are not [32–35].

For a set of decision-making units, in this case, eight countries, a vector of inputs measuring R&D resources (in this case total R&D expenditure 1987, civil R&D expenditure 1987, actual foreign patents (1982–1984) and long-term patent potential (1975–1984) as well as actual scientific publications (1985–1987) and long-term scientific stock of publications (1973–1987)) and a vector of outputs (in this case export shares in 1985) must be defined. Efficiency is achieved by obtaining the maximum value of output per unit of input. The problem is precisely framed by Grupp *et al.* [6] and not displayed in its mathematical form in this paper. It is six-dimensional input-wise and one-dimensional output-wise in this case.

This model seeks to maximize the ratio of weighted outputs to weighted inputs, for an arbitrary decision-making unit, subject to the constraint that the same ratio for the other decision-making units should not exceed unity (which is maximum efficiency).

By solving this programming problem (n + 1) times, each time with a different DMU serving as the referent unit, the efficient hyperplane can be identified and measured, and each DMU's distance from it can be measured in various ways (n is the number of DMUs). The input and output weights chosen are those that minimize the distance between each DMU and the efficient hyperplane. They have the economic interpretation of 'shadow prices'. The two main scalar measures of inefficiency, for this input-minimizing model, are

- θ, the proportional reduction in inputs possible in order to obtain the projected input values;
- σ, the summed weighted value of the output slack (difference between actual and efficient output), weighted by shadow prices, and excess input values, also weighted by the corresponding shadow prices.

Thus, θ measures only that portion of economic inefficiency that could be eliminated by *proportional* reduction of inputs. It is the proximity to the facet of the piecewise linear envelopment surface. Even after reducing inputs by θ, however, some inputs may still exhibit slack. σ measures the weighted Euclidean distance between the actual input and the efficient input.

By using the above-mentioned vectors and corresponding data from Tables 3 and 4, together with related patent and publication data (see Figs. 12–14 [16]), for eight of the ten countries examined in this paper, efficiency indices may be obtained (Table 6).

The results indicate that only Sweden is most efficiently directing its R&D towards exports in line equipment. Measured by θ, the Netherlands are next, followed by Germany, Japan, Italy, France, and finally the United Kingdom and the USA. From this analysis it is quite clear that the most deregulated national telecommunication systems, like those in the USA and Britain, do not have any pronounced advantage in R&D efficiency as measured by trade performance. Japan is less efficient on international markets, which is to be explained later in the text. Measured by σ, however, Japan's disadvantage is less balanced across the six input variables than that of the US.

TABLE 6. Efficiency measures for eight countries in converting R&D excellence into export advantage in telecommunications line equipment

Country	θ	σ
USA	0·03	1627
Japan	0·15	2568
Germany	0·15	1175
France	0·17	643
United Kingdom	0·08	1434
Italy	0·15	887
Netherlands	0·36	844
Sweden	1·00	0

DEA places no restrictions on the functional form of the production relationships and makes no *a priori* distinction between the relative importance of any two outputs or of any two inputs. While DEA is non-parametric, it is not free of the necessity for further modelling and theory. For example, assumptions about the underlying relationships between the input variables essentially influence the efficiency measures. At this point, the above results are not further assessed entirely; merely the less efficient input variables per country, each taken alone, are discussed in a qualitative way.

For the United States, a too large R&D budget is characteristic. With the civilian part being close to the efficiency benchmark, this is nearly entirely caused by defence-related activity. With the patent potential being fully efficient, there is some excess in more recent patenting. Compared to its export sales, the United States produced very many scientific papers in the 1970s (stock of papers), but less so recently. For Japan, both paper and patent production exceeds the efficiency facet. Both France and the United Kingdom operate with large defence-oriented R&D budgets, whereby the civilian part is efficient. In addition, France tends to produce too many patents, and Britain too many papers, if measured against the respective export shares. Germany and Italy are a little bit in excess of efficient inputs for each of the input variables except the non-civilian R&D budget, whereas the Dutch foreign patent production is much too strong compared to the other countries and Dutch exports.

On the national level, it is difficult to look for reasons for good or fair efficiency of telecommunications R&D, as the various sectors may perform very differently. Therefore, a similar analysis broken down to network service and manufacturing companies follows. (The terms 'common carriers', 'carriers', 'network companies' or 'service companies' are used with identical meaning, differentiating these telecommunication companies from manufacturers.)

5. International comparison of carrier R&D

In the previous section, it was stated that in most countries, carriers are behind manufacturer R&D activities, yet they have a substantial bearing on the progress of technical development in telecommunications — at least insofar as procurement, prescription of standards, and the like, are concerned. Carriers are therefore considered separately in this section in regard to financing and execution of R&D. Table 7 gives an international overview of internal and external R&D expenditures, R&D intensity and staffing levels.

By cross-referencing with Table 3, it can be seen that in the United States and France, half of the national civilian expenditure is financed by network operators. In the case of the United States, this is attributable to R&D by AT&T, who largely do their 'own thing', and is geared to the manufacture of new equipment. None of the other carriers maintains its own telecommunications goods production facility on this scale, and therefore no corresponding R&D needs to be carried out along these lines. The special financial situation applying in France is ascribable to the interlinking of France Telecom into the national structure. Network operators from all other countries contribute up to a maximum of 25% towards the financing of the civilian telecommunications sector. Although NTT in Japan projects itself as being a more powerful and centralized carrier, its financial clout is of the same order of magnitude; Japanese business largely favours self-financed R&D which is, however, coordinated with NTT. Such processes cannot be expressed in monetary terms. In the international comparison, the expenditure by the German postal service shows up as being strikingly low, which ties in with the fact that companies, as in Japan, rely very heavily on self-financed work.

Applying DEA analysis for the carriers of Table 7, turnover (or sales) data for 1987 may serve as the output variable. On the input side, the R&D budget, the R&D personnel, as well as foreign patents from 1984–1985 and scientific papers from 1986 are selected. Table 8 presents the efficiency measures similarly to the preceding section.

Four carriers form the efficiency envelope: the Regional Bell Operating Companies (RBOC), the German Bundespost Telekom (DBP), the largest Italian carrier Società Italiana per l'Esercizio delle Telecommunicazioni (SIP), and the Spanish Telefónica. They have in common a very low R&D operation, and make profit from external innovations. In the case of RBOC, obviously AT&T technology was transferred, at least for the time around the divestiture (the data used for DEA

TABLE 7. Overview of R&D expenditure and personnel of selected network operators in 1987 (partly rounded off or estimated)

Group of companies	Internal and external R&D expenditure ($ million)	R&D intensity (as % of sales)	Own R&D personnel
AT&T	2 600	7·3	25 000
NTT	940	3·8	6 000
RBOC	910	1·5	6 000
France Télécom	603	4·1	4 300
BT	330	2·1	3 300
GTE	250	1·6	1 800
DBP	168	1·1	1 800
SIP	90	0·9	160
Televerket (TV)	90	3·7	400
KTA	70	2·4	180
PTT Telecom BV	45	1·4	750
Telefónica (T)	30	0·6	300
KDD	25	2·0	190

TABLE 8. Efficiency measures in converting R&D resources into turnover

Common carrier	θ	σ
AT&T	0·09	347
GTE	0·42	6
RBOC	1·00	0
NTT	0·25	275
KDD	0·35	36
DBP	1·00	0
France Télécom	0·20	37
British Telecom	0·29	103
SIP	1·00	0
Telefónica	1·00	0
KTA	0·96	52
PTT Telecom BV	0·43	132
Televerket	0·47	67

analysis are all reflecting the mid-1980s). The DBP is a very low in-house R&D performer and procures innovative equipment from manufacturers, which are paid for their R&D performed. The Mediterranean carriers are traditionally linked to powerful multi-national companies supplying them with the required technology (the state-run IRI/STET group in Italy, Standard Eléctrica, formerly ITT, in Spain).

Least effective appear to be AT&T for the special reasons given above, but also BT, France Télécom and NTT with their many R&D activities dedicated towards new products which are manufactured by other British, French or Japanese companies, respectively.

Table 9 provides a summary of the role of the major carriers within their national R&D systems as given by Grupp and Schnöring [36]. In the case of vertical integrated carriers, in the USA, Canada, Italy and Sweden, close cooperation is an inevitable consequence of the enterprise structure. In the other countries, various different mechanisms regulate the existence of more or less evolved R&D cooperation between the carriers and one or more large domestic manufacturers. In France, Japan and Korea, the mechanisms are so closely meshed that a quasi-vertical integration of the R&D activities of the carriers and dominant national manufacturers can be said to exist in many areas of technology. The extent of R&D cooperation and scope of influence of the carriers on the R&D endeavours of the major national manufacturers are (now) less pronounced in the UK, the Netherlands and Germany. In these three countries, the common carriers and manufacturers are increasingly pursuing mutually independent R&D policies. In all countries, the level of cooperation between carriers and manufacturers is more extensive in the case of complex systems, such as those associated with telephone switching technology, than with simple network components and terminals with largely standardized network interfaces [36].

TABLE 9. Vertical integration and R&D cooperation of major carriers at the end of the 1980s (Source: Grupp and Schnöring [36])

Carrier	Vertical integration	Intensity of R&D cooperation with national manufacturer
AT&T	+	
Televerket	+	++
SIP	+	
Telefónica	(+)	+
France Télécom	–	+++
NTT	–	++
KTA	–	+++
BT	–	+
PTT NV	–	+
DBP	–	+
RBOC	–	–

The common carriers are charged with relatively clear technological and industrial policy objectives in France, Spain, Sweden, Korea and Japan, a fact reflected in their R&D strategies. Especially as far as France, Korea and Japan are concerned, it must be assumed that decisions on the scope and structure of R&D expenditure by the carriers are taken not only according to entrepreneurial objectives, but also with a view of furthering the development of domestic manufacturing industry and its international competitiveness [36].

It is impossible to decide which integration model is most efficient. The data from Table 8 point to efficient carriers with and without vertical integration and with and without close cooperation with national manufacturers. However, those carriers with a very strong cooperative environment (France Télécom, KTA, Televerket, NTT) tend to feed considerable R&D activities into the manufacturing sector, so that their own R&D efficiency balance sheet in the service sector appears to be less effective. Again, as on the national level (section 4), the quantitative findings are rather discouraging for technology policy and R&D management. Most of the current preconceptions are not justified when measured carefully. This means that expectations in the future technological competitive position remain the same whether there is more or less government intervention via state-owned carriers in the national R&D system. In particular, technology competition is not influenced by the amount of R&D executed by the network company (companies) in comparison to other national R&D performers. In other words, deregulation or privatization of common carriers might be pursued for other reasons, but are not necessities for technological competitiveness.

There is great variance between common carriers in the four dimensions of input. Figure 15 plots only two of them (external and internal R&D expenditure as the mixed input variable reflecting at least partially external inputs and patents for self-produced technology or purely internal inputs) and indicates a reduced — in this case — two-dimensional efficiency envelope (without AT&T).

In the two-dimensional plot, only three of the four most efficient carriers are located on the efficiency envelope (Telefónica, DBP, RBOC). They are efficient insofar as they manage to make use of innovation resources in their environment, and thus avoid internal R&D activities. France Télécom and NTT channel funds or R&D results, respectively, to national manufacturers, as does Televerket, and thus appear be less efficient in the R&D/turnover dimension, whereas British Telecom (BT), because of the company's strong commitment to digital switching (System X, see section 3) took out too many patents compared to the other carriers and to BT's network-related turnover.

In the R&D personnel dimension (not included in Fig. 15), AT&T, PTT Netherlands and Televerket seem to be overstaffed with all the reservations made above on special settings, while NTT, KDD and — again — BT publish many scientific papers compared to turnover and their competitors.

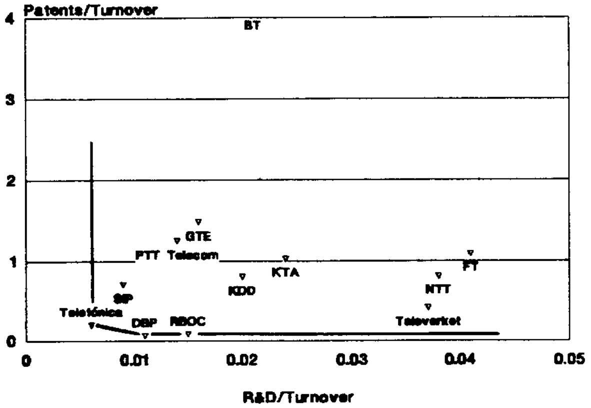

Fig. 15. Schematic view of carrier isoquants of DEA efficiency reduced to two inputs.

6. International comparison of manufacturer's R&D

As far as manufacturers are concerned, R&D investment represents venture capital spending on future competitiveness. The financial contributions of the manufacturers indicate their level of participation in R&D costs and the associated risk. According to this argument, German manufacturers are more strongly committed to the costs and risks of R&D than those of the other countries (cf. Table 3, section 4). The difference between Germany and neighbouring France is especially marked. All other things being equal, a high financial contribution hinders a manufacturer's ability to compete in the international marketplace because greater costs are inevitably reflected in higher product prices. This argument is cited by German manufacturers in particular when referring to competition from France. But the undoubted plausibility of this standpoint needs to be put into perspective, since an equality of peripheral conditions cannot exist in reality [36].

Another noteworthy point is that stronger direct participation of common carriers in R&D expenditure is generally accompanied by exerting a greater influence on the content of R&D work. This may have a detrimental effect on the export scope of new systems. This suggests that the French R&D system, with France Télécom being the dominant force and Alcatel-CIT the controlled national market leader in the manufacturing sector, will be put under pressure by the formation of Alcatel NV, an international group of companies. Since the acquisition of the European subsidiaries of the ITT group by CGE and Alcatel in 1987, Alcatel NV has generated over 70% of this turnover outside France, and has therefore been forced to align its R&D activities more firmly with foreign market requirements. This shift in emphasis is calling the leading role of CNET and France Télécom into question, and has already caused considerable friction between France Télécom on the one hand and Alcatel-CIT and the Alcatel group on the other in connection with some development projects [22].

The various arguments have to be seen in context if a general assessment is to be made. Competitive implications cannot be linked exclusively to the financial contributions of manufacturers even in cases where the differences are as great as those illustrated by Table 3. It is equally apparent, however, that an isolated international opening of carrier procurement procedures, as envisaged by the Commission of the European Communities for implementation within the Single Market by 1993, could lead to an appreciable distortion of competition between European manufacturers if the R&D financing systems of the member countries are not brought more into line at the same time.

Table 10 gives an overview of the estimated R&D expenditure of the 12 largest manufacturers of civilian telecommunications equipment in 1987 [16]. AT&T has by far the largest R&D budget. The firm's R&D spending on telecommunications amounts to more or less the same as that of the next four manufacturers together. This mirrors the clear supremacy of AT&T's R&D capacity compared with its principal competitors, but extensive R&D spending does not necessarily equate with R&D earnings, and does not guarantee market success [36]. On the other hand, successful R&D work is becoming an increasingly important precondition of favourable results on the telecommunications market.

In the comparison of R&D budgets in Table 10, note that some manufacturers have access to R&D activities in other associated business sectors. Unlike the groups which specialize in telecommunications, namely AT&T, Alcatel, Northern Telecom and Ericsson, these enterprises — Siemens, NEC, Motorola, IBM, Fujitsu and Philips — benefit from synergetic effects that can have a positive influence on their innovative capabilities. Note that Table 10 lists turnover figures for *telecommunications goods* only. Total AT&T turnover including services is quite different. The country-specific studies (section 3) also reveal that all the major manufacturers cooperate to a greater or lesser extent with the large carriers in their countries. Exclusive know-how transfer takes place within the framework of such cooperation; this is also a significant factor when evaluating the innovative potential of the leading manufacturers. For these reasons, the estimated R&D budgets of the principal telecommunications manufacturers can provide only an incomplete picture of their relative innovative strength.

To throw some light on the relation of R&D activities and market success, a DEA analysis

TABLE 10. Overview of R&D expenditure and turnover by major manufacturers of civilian telecommunications goods in 1987

	Telecommunications turnover ($ billion)	R&D intensity of all business sectors (%)	R&D expenditure on telecommunications ($ million)
AT&T	11·9	7·3	2 600
Alcatel	8·2	10·0	800
Siemens	5·1	12·5	650
Northern Telecom	4·8	12·1	588
NEC	4·1	10·0	561
Ericsson	3·3	9·9	300
Motorola	3·1	7·8	270
Bosch	2·5	9·1	220
GPT	2·3	12·0	210
IBM	2·1	7·4	80
Fujitsu	1·6	8·0	234
Philips	1·5	7·0	100

similar to the previous sections is performed. In this case, R&D expenditures (1987; Table 10), foreign patents 1984–1985 [16] and scientific publications (1986, same data source) are combined input-wise, whereas 1987 turnover is the output. Table 11 presents the efficiency measures.

According to Table 11, four manufacturers are efficient, among them AT&T. As it is impossible to partition AT&T's patents, papers and R&D funds between the manufacturing and the carrier businesses, total turnover was used for output measuring. Taking product-oriented turnover alone would place AT&T behind the efficiency facet. Alcatel is efficient because France Télécom (Table 8) is not — these are two sides of the same coin. IBM (and also Motorola) perform well; here, the cross-fertilization from other business areas might be important.

The two German manufacturers included in Table 11, with their burden of the German carrier DBP doing very little R&D, results in medium efficiency scores, which is also true for the two Japanese, NEC and Fujitsu. As NTT does feed R&D into the Japanese manufacturing business, this seems to be contradictory. However, the problem of all Japanese manufacturing of complex systems lies in the fact that the companies are too strongly oriented to domestic markets, and have had little success in export markets, in particular in the USA [20].

Ericsson may be compared to Alcatel: because of close links to Televerket (which does not perform well in terms of DEA analysis, see Table 8) the company has a perfect turnover with comparatively few of their own R&D resources.

Altogether, the distances from the efficient envelope are much smaller in the case of manufacturers as compared to carriers (cf. Tables 8 and 11). There is no really weak firm in this business among the 12 leading companies, despite distinctly different national environments. The regulative framework — once again — seems not to matter so much as anticipated in many economic policy assessments. Firms can adopt many ways of operation, and thus get along with truly divergent national R&D and regulation systems.

Figure 16 finally plots a two-dimensional envelope only for the R&D expenditure and scientific paper production inputs. In this way, along with the R&D dimension the scientific or basic dimension of R&D is depicted. The strong science involvement of Philips, GEC and Plessey (GPT) comes as no surprise [23] but the — often neglected — attempts to become more basic in Japan are clearly visible [20]. Because of France Télécom and Televerket's labs, Alcatel and Ericsson, respectively, have no reason to invest more in less applied aspects of R&D, whereas the positioning of AT&T in Fig. 16 in the vicinity of Motorola is misleading due to the mixing of carrier and manufacturer tasks in the data used.

TABLE 11. Efficiency measures in converting R&D resources into turnover

Company	θ	σ
AT&T	1·00	0
Alcatel	1·00	0
Siemens	0·57	92
Northern Telecom	0·74	8
NEC	0·49	68
Ericsson	1·00	0
Motorola	0·93	23
Bosch	0·83	29
GPT	0·66	62
IBM	1·00	0
Fujitsu	0·43	16
Philips	0·64	11

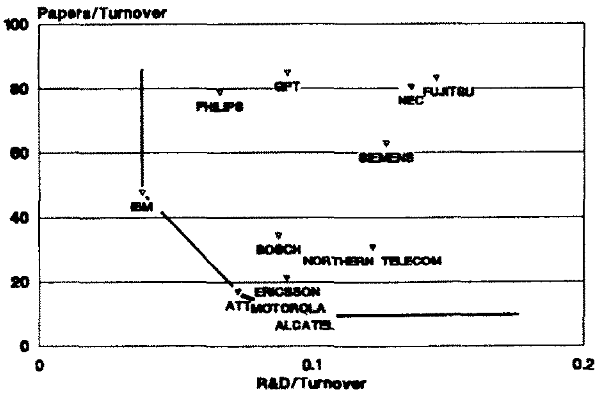

Fig. 16. Schematic view of carrier isoquants of DEA results reduced to two inputs.

7. Conclusions

Differing national R&D policies in general and distinct regulations and market structures in the telecommunications sector have created R&D systems that look quite different from each other. This in the past was sustainable because of the relatively isolated situation of each national market. Liberalization of the telecommunications markets, however, brings pressure on the old national divisions of labour in R&D.

In all countries the government is — directly or indirectly — involved in the telecommunications R&D system. In the USA, France and the UK, the governments finance R&D for communications equipment for military use, which may have spill-over effects to equipment for civil use. In Japan, Germany and the UK, the government finances R&D programmes directly oriented towards civil telecommunications, but the amount of money involved is small compared to the national R&D budgets. Stronger commitments of governments to R&D in telecommunications are the case in Sweden, Italy and Spain. The Japanese government has a particularly strong influence on civil telecommunications R&D through its government guidance of the R&D activities of carriers and manufacturers. In France, the government has a strong influence through the dominant role of France Télécom and its industrial policy objectives. This also applies to the Republic of Korea. All these government policies tend to create market distortions.

The role of the carriers differs substantially between countries. According to the above estimations, they perform and finance from 7% of the civil telecommunications R&D budget in Germany up to 60% in France. This situation has a strong impact on the international competitiveness of the manufacturers because they have to bear very different R&D costs. Thus, the efficiency of converting R&D activity into commercial success differs considerably. As long as the national equipment markets were closed, the different systems had no international consequences. Carriers which did not finance R&D directly had to pay for it (indirectly) with the price of the equipment. But the situation changes when the carriers' equipment markets are liberalized. Manufacturers which have to bear R&D expenditure themselves have a disadvantage compared to manufacturers which get all their R&D expenditure, or a substantial part of it, directly paid by the carrier. Therefore, *ceteris paribus*, German manufacturers would lose the competition with French manufacturers in a totally liberalized European equipment market for carrier equipment as long as France Télécom holds on to its R&D system.

Of course, reality is more complicated than such simple models suggest, and so are predictions of the outcome of a total liberalization of the carriers' equipment market in Europe. Market success depends not only on R&D funding but on R&D efficiency, production, marketing and service as well, and considerable entry barriers for telecommunications systems (like R&D for the adoption of the systems, marketing facilities and a service network) limit the amount of international competition anyway. But the observed differences of the national R&D systems are certainly a problem for the European Commission in its attempt to create a liberalized European carriers' equipment market. The author would expect that at least some harmonization of R&D financing between Germany and France will be a precondition for any further liberalization of the carriers' equipment market in the European Community.

However, the quantitative findings are rather discouraging for technology policy and R&D management. Most of the current preconceptions are not justified when measured carefully. Cross-wise, all possible correlations between government and network R&D contributions (input structures) *versus* telecommunications world market shares, patent positions and their respective increases in time have been checked. Among the many regressions there was not one highly significant one. This means that the expectations in the future technological competitive position remain the same whether there is more or less government intervention in the national R&D system. In addition, vertical integration and the intensity of

R&D cooperation between national common carriers and the related manufacturers, both do not result in typical success patterns between R&D and commercialization. More and less efficient carriers and manufacturers can be found in all modes of business operation: there is no optimum and no really disadvantaged setting of regulative or business environments. In particular, technology competition is not influenced by the amount of R&D executed by the network company (companies) in comparison to other national R&D performers. In other words, deregulation or privatization might be pursued for other reasons, but are not necessities for technological competitiveness.

Only one of the many input-related correlations was fairly significant: world export shares and R&D efficiency are negatively correlated with defence R&D in telecommunications, which is quite natural because it does not aim at success on civilian markets but rather at improvements in national security.

Overall, R&D management, technology policy and, in particular, deregulation do not seem to influence technology development and competitiveness much. At least, the current preconceptions are not supported by data.

From a stricter economic perspective there are two questions left. First, the advantages of vertical integration for R&D in telecommunications has to be questioned. There are theoretical arguments for both sides. Empirically, one observes vertical integration or quasi-vertical integration in most countries, but no success or failure trial of this structure can be supported by the data in this paper. With the liberalization of the telecom markets the situation has changed to some extent. Divestiture has separated the Regional Bell Operating Companies from the manufacturing sector. In Europe, BT and the Deutsche Bundespost have loosened their relation with the national manufacturers in R&D, and many carriers have started a policy of second sourcing from foreign manufacturers. In principle, this development may open market opportunities for foreign manufacturers, but there is no empirical evidence yet to answer this first question — perhaps, there never will be.

The second question concerns the competitive situation of manufacturers not being vertically integrated when their vertically (or quasi-vertically) integrated competitors have a monopoly or dominant market position on the service side. In such a situation, the 'service division' can cross-subsidize the 'manufacturing division' by over-investing in R&D. But it is difficult to know what the 'service division' should spend on R&D under normal market conditions, and what would be an over-investment. This shows that the liberalization of the services market and the R&D policy of the dominant carriers are closely related to the liberalization of the carriers' equipment market. The different national approaches to the services market and the distinct R&D policies of carriers (and governments) are related to a liberalization of the carriers' equipment market.

The most interesting and perhaps most challenging country included in this comparison is Japan. The Japanese R&D system, with its complex structure of collaboration and competition of all sectors, differs substantially from that of all the other countries. The system realizes substantial economies of scale and scope in the R&D process at the national level. During the past ten years, Japan has invested a great amount of resources in R&D for telecommunications. She has acquired a large stock of proprietary knowledge in telecommunications and in more basic R&D, and has taken the leading position from the USA in a number of fields which are important in future development. If the country succeeds in its attempt to upgrade its software and systems engineering capabilities, it is quite likely that Japanese companies will become strong competitors to US and European companies in all telecommunications equipment market segments, not only in the customer premises equipment market. Yet, the peculiarities and seclusion of the Japanese telecommunication service and equipment markets have made the industrial actors focus on the domestic arena, on what concerns more complex equipment. Therefore, exports from Japan have not been so successful as in other industries, and thus the efficiency measures used in this paper do not place Japanese companies in top positions.

Finally, it is important to note that the introduction of the formal framework of science and technology indicators within the wholly sensitive area of modern telecommunications R&D may also be regarded as a facility to assist subjective assessments derived from expert interviews, and may enlighten economic studies of the Schumpeterian type.

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