Networks of innovators: A synthesis of research issues

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This paper will first summarise some key findings of empirical research in the 1960s on the role of *external* sources of scientific, technical and market information in successful innovation by business firms. This work demonstrated unambiguously the vital importance of external information networks and of collaboration with users during the development of new products and processes. Moreover, the dilemmas of cooperative research in competitive industries were recognised and studied long ago [35,62,76]. What then is new about the present wave of interest in "networks of innovators"? Are there new forms of organisation or new technologies or new policies which justify renewed research efforts since they go beyond those developments already analysed in earlier empirical and theoretical work?

Section 2 reviews the evidence of new developments in the 1980s in industrial networks, regional networks and government-sponsored innovative activities. It shows that there has indeed been a major upsurge of formal and semi-formal flexible "networks" in the 1980s, including some new types of network. It also shows that some older forms of research cooperation have been modified and transformed. The papers at Montreal largely concentrated on the role of regional supplier networks, which are a good example of such "new wine in old bottles". This paper attempts to locate the regional network discussion within a wider context of new developments in networking.

Section 3 discusses the causes of these new developments and whether they are likely to remain a characteristic of national and international innovation systems for a long time to come, or prove to be a temporary upsurge to be overtaken later by a wave of take-overs and vertical integration.

Finally, section 4 sums up some of the other key issues which require further research and debate, and the implications for social science theory.

1. Empirical research on the sources of innovative success

Until the 1960s, most studies of innovation were anecdotal and biographical or purely technical. Although economists had always recognised the great importance of innovation for productivity growth and for the competitive performance of firms, industries and nations, they made very few empirical studies of innovative activities or of the diffusion of innovations. Even those economists, such as Schumpeter, who put innovation at the centre of his entire theory of economic growth and development, did not study the specific features of actual innovations in any depth. He attributed innovative success to a general quality of "entrepreneurship" but recognised that with the growth of large monopolistic firms the nature of this activity had radically changed [60]. Although he identified the growth of professional in-house R&D as a fundamental change in the organisation of large-scale industry he did not examine the interaction between the R&D function and other established functions within the firm, still less with external networks. Moreover, his approach to entrepreneurship as an exceptional heroic act of will disposed him to view the launch of new products as a way of *imposing* the creative ideas of the entrepreneur on passive or unreceptive users. Thus it remained as a task for his successors to put flesh and blood on the bare bones of his concept of entrepreneurship and innovation, and to modify it in the light of the new findings of empirical research.

Geographers and sociologists did rather better than economists in the 1950s, especially in diffusion studies, and it was not until the 1960s that a more systematic, empirical approach to innovation studies took off among economists. Until the early 1970s most, if not all, of the work was concentrated on the study of specific individual innovations. It aimed to identify those characteristics of each innovation which led to commercial as well as to technical success, whilst recognising the inherent element of technical and commercial uncertainty.

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The most effective way to identify those factors which are important for success is by paired comparisons between those innovations which succeed and those which fail, as in project SAPPHO, one of the most comprehensive empirical studies of innovations and representative of a whole generation of research [57]. This project measured about a hundred characteristics of 40 pairs of innovations, but only about a dozen or so of the hypotheses systematically discriminated between success and failure. The most important of these were:

(1) *User needs and networks.* Successful innovators were characterised by determined attempts to develop an understanding of the special needs and circumstances of potential future users of the new process or product. Failures were characterised by neglect or ignorance of these needs. Numerous studies since SAPPHO have confirmed the vital importance of these user–producer linkages, notably the work of Lundvall [38,39] and his colleagues.

(2) *Coupling of development, production and marketing activities.* Successful innovators developed techniques to integrate these activities at an early stage of the development work. Failures were characterised by the lack of adequate internal communications within the innovating organisation and lack of integration of these functions. Again this result has been abundantly confirmed by later research, particularly in the case of Japanese techniques for managing innovation [2,4,32,65]. These integrating activities may be regarded as "internal networks" within the firms.

(3) *Linkage with external sources of scientific and technical information and advice.* Successful innovators, although typically having their own in-house R&D, also made considerable use of other sources of technology. Failures were characterised by the lack of communication with external technology networks, whether national or international.

(4) *Concentration of high quality R&D resources on the innovative project.* Whereas size of firm did *not* discriminate between success and failure, size of R&D *project* did discriminate. Moreover, the innovations which failed not only had lower resources than those which succeeded but also suffered from failures in development leading to lower quality products. Both *quantity* and *quality* of R&D work thus complemented external networks.

(5) *High status, wide experience and seniority of the "business innovator".* The term "business innovator" was used to describe the person chiefly responsible for the organisation and management of the innovative effort–effectively the Schumpeterian "entrepreneur". Contrary to the expectations of the SAPPHO researchers, this individual was generally older in the case of successful innovations than failed ones. This result was interpreted as indicating that, innovation could not succeed without the strong commitment of top management particularly in large organisations, and that the role of network coordination was very important, both within the firm and outside it.

(6) *Basic research.* The performance in-house of basic research was associated with success, particularly in the chemical industry. But this performance was important mainly because of the linkages it facilitated with external networks, and especially universities.

The original SAPPHO Project concentrated on only two branches of manufacturing industry, chemicals and scientific instruments. But later research in several other countries and industries, such as machinery and electronics, confirmed the main results [38,41,47]. Furthermore, almost all these and other studies confirmed the central importance of *external* collaboration with users *and* external sources of technical expertise.

These empirical studies of innovation demonstrated the importance of both *formal* and *informal* networks, even if the expression "network" was little used. Although rarely measured systematically, informal networks appeared to be the most important. Multiple sources of information and pluralistic patterns of collaboration were the rule rather than the exception. Thus the in-house competence of the R&D Department was complemented by occasional or regular links with universities, with government laboratories, with consultants, with Research Associations, and with other firms. Already in the 1950s, Carter and Williams [10,11] had shown that these multiple links were characteristic of the "progressive" firm.

Although informal networks predominated, formal R&D collaboration agreements between firms were certainly not something which suddenly began in the 1980s. The largest single R&D project before the Mahattan Project was a joint R&D effort by five large oil companies and two plant contractors to develop a fluid bed catalytic cracking process for the oil industry in the 1930s [17]. Both this and many other agreements in the oil, chemical and electrical industries, provided for patent-sharing, cross-licensing and exchange of technical know-how between firms over quite long periods.

There were many other examples of collaborative research programmes and networks during World War II, some of them led by Government. The American synthetic rubber research programme (1942–1956) is one which has been hotly debated by historians and economists for a long time [44,62]. Whereas the success of this programme is still a matter of intense controversy, there is no disagreement on the achievement of the British war-time radar programme, involving a network of innovators from industry, universities and the armed forces around a core R&D programme at the Government Telecommunications Research Establishment [56]. However, these programmes, although sometimes continued into the Cold War period, were essentially transitory arrangements. There were also other more durable forms of continuing cooperation.

Cooperative Research Associations (RAs) were established in the UK shortly after World War I, and in France, Germany and other countries soon afterwards. They were seen as a means of sharing the costs of acquiring technical information and of testing facilities, pilot plant and prototype development. They were thought to be mainly a device for overcoming market failure in industries where the threshold costs of R&D and other scientific and technical services were too high for small firms. In practice, however, many large firms joined RAs in order to take advantage of their information, abstracting and translation services. The most sensitive strategically important areas of R&D remained in-house in the large firms for competitive reasons [35].

The expectation had been that RAs would serve to provide technical support for firms who were lacking their own R&D and that once they had developed an indigenous technical capability they might no longer wish to use the services of the RAs. However, the Federation of British Industries (FBI) [19] survey of R&D showed that the RAs were actually used intensively by firms who *had* their own R&D. The RAs were thus an important ancillary and *complementary* source of scientific and technical information rather than a *substitute* for indigenous innovative activity.

Essentially the same point can be made about licensing and technical know-how agreements. These grew very rapidly after World War II and made a very big contribution to the international transfer of technology. Again, the expectation had been that licensing payments would flow mainly from firms who had no R&D to those who had strong R&D. But the first Netherlands Survey of R&D in the late 1950s and the UK FBI Survey in 1961 both showed that licensing transactions were mainly between firms who already had R&D resources. Since that time, research has demonstrated that the successful exploitation of imported technology is strongly related to the capacity to adapt and improve this technology through indigenous R&D. Again, Japan is an excellent example [22]. It is not just a question of getting a lot of "information"; often there is an overload of information. The problem of innovation is to process and convert *information* from diverse sources into useful *knowledge* about designing, making and selling new products and processes. Networks were shown to be essential both in the acquisition and in the processing of information inputs.

Nor are regional and contractor networks a new phenomenon. Piore and Sabel [55] provide many examples where the externalities generated by regional networks of firms have been historically important since the early days of the industrial revolution. Whilst there are certainly critics who would disagree with their assessment of mass production, there are few who would disagree with this emphasis on the value of regional networks. Alfred Marshall [43] already pointed to the vital role of externalities in "industrial districts" where, as Dominique Foray [20] reminded the Montreal Workshop, "the secrets of industry are in the air". Perez and Soete [54] have also presented similar convincing arguments on the role of externalities for innovation networks in developing countries.

Thus, both empirical and theoretical research has long since demonstrated the importance for successful innovation of both external and internal networks of information and collaboration. Furthermore, it has shown that external networks were just as important for firms who had their own R&D as for those who had none.

What, then, is new about innovation networks in the 1980s and 1990s? The next section is an attempt to answer this question.

2. The growth of networks of innovators in the 1980s and changes in their mode of operation

First, it is necessary both to define "networks of innovators" a little more precisely and to distinguish between various types of network. One of the most interesting recent papers in this field [30] defines innovation networks as follows:

> Network organisation is a basic institutional arrangement to cope with systemic innovation. Networks can be viewed as an inter-penetrated form of market and organisation. Empirically they are loosely coupled organisations having a core with both weak and strong ties among constituent members... We emphasise the importance of cooperative relationships among firms as a key linkage mechanism of network configurations. They include joint ventures, licensing arrangements, management contracts, sub-contracting, production sharing and R&D collaboration.

As DeBresson and Amesse [14] show in their introductory paper, there are many definitions of networks, but the one given by Imai and Baba [30] captures most of the important points in considering networks of *innovators*. Enlarging upon and sub-dividing the types which they distinguish, table 1 shows the categories of network which are relevant from the standpoint of innovation.

Following Camagni [8] this approach does not classify regional (or national) networks as a separate category, but rather treats regional (or national) elements as constituting a "milieu" which may affect any or all of the above, but especially category (6).

> A network may be defined as a closed set of selected and explicit linkages with preferential partners in a firm's space of complementary assets and market relationships, having as a major goal the reduction of static and dynamic uncertainty...

Table 1

(1) Joint ventures and Research Corporations
(2) Joint R&D agreements
(3) Technology exchange agreements
(4) Direct investment (minority holdings) motivated by technology factors
(5) Licensing and second-sourcing agreements
(6) Sub-contracting, production-sharing and supplier networks
(7) Research Associations
(8) Government-sponsored joint research programmes
(9) Computerised data banks and value-added networks for technical and scientific interchange
(10) Other networks, including informal networks

> Network relations of a mainly informal and tacit nature, exist also within the local environment, linking through open chains, firms and other local actors... our proposal is to use the term "network" ("réseau") only in the case of explicit linkages among selected partners and to refer to the former as "milieu relationships" [8, p. 4].

Before considering each of the main forms of cooperation in greater detail it is essential to make two observations. First, these categories are not mutually exclusive and most large firms are involved in several of these modes of networking and many are involved in all. Even quite small firms may be involved simultaneously in most of these forms of cooperation, as is shown by Acs [1]. Moreover, large firms may have many agreements in each category. The Arpo Database at Milan Polytechnic indicates that almost all of the top 20 information technology (IT) firms in US, EC and Japan made more than 50 cooperative agreements of various kinds in the 1980s and some made more than a hundred [7]. Kodama [36] points out that the leading Japanese electronic firms are members not just of one or two engineering research associations but sometimes of a dozen or more at the same time. Participation in joint programmes and agreements at least for firms in this industry have become quite a normal way of life.

Second, informal networks (category 10) are extremely important but very hard to classify and measure. However, just because of this difficulty it is essential to notice that they have a role somewhat analogous to "tacit knowledge" within firms. It is now very generally recognised that in the technology accumulation process within firms and other organisations, tacit knowledge is often more important than codified formal specifications, blue-prints, etc. [51]. Because tacit knowledge is so difficult to communicate, the movement of people, in addition to documents and drawing, is usually essential for effective technology transfer; hence, behind every formal network, giving it the breath of life, are usually various informal networks. Eric von Hippel [71,72] has analysed informal know-how "trading" in various US industries, particularly in the steel industry, demonstrating its importance empirically and providing an economic explanation for its varying intensity in different branches of industry, and its relationship with formal cooperative R&D and formal licensing arrangements. Few of the Montreal papers dealt directly with informal networks, although they often touched upon them indirectly. However, the paper by Erikson and Håkansson [18] did highlight their importance and the Uppsala group have demonstrated this in much of their other work over the past ten years (see, e.g., [34]).

Personal relationships of trust and confidence (and sometimes of fear and obligation) are important both at the formal and informal level, as many of the Montreal Workshop papers confirm. For this reason cultural factors such as language, educational background, regional loyalties, shared ideologies and experiences and even common leisure interests continue to play an important role in networking. An appreciation of these sociological factors in both formal and informal networks is a necessary complement to narrower "economic" explanations and helps greatly to understand the importance of regional networks, geographical proximity and "national systems of innovation" [39,40].

With these definitions and qualifications in mind, let us consider the changes in networking in the 1980s, both in terms of quantitative indicators and of qualitative changes. Many researchers have attempted to keep track of the new developments [7,9,45,49]. One of the most useful sources is the MERIT Data Bank, originally set up by the TNO in the Netherlands and now at the University of Limburg [25,26]. It is based on public announcements of new agreements and has some bias towards European and North American sources. For obvious reasons it does not cover category (10) of table 1 and its systematic coverage is confined to categories (1) to (6). Nevertheless, it provides a

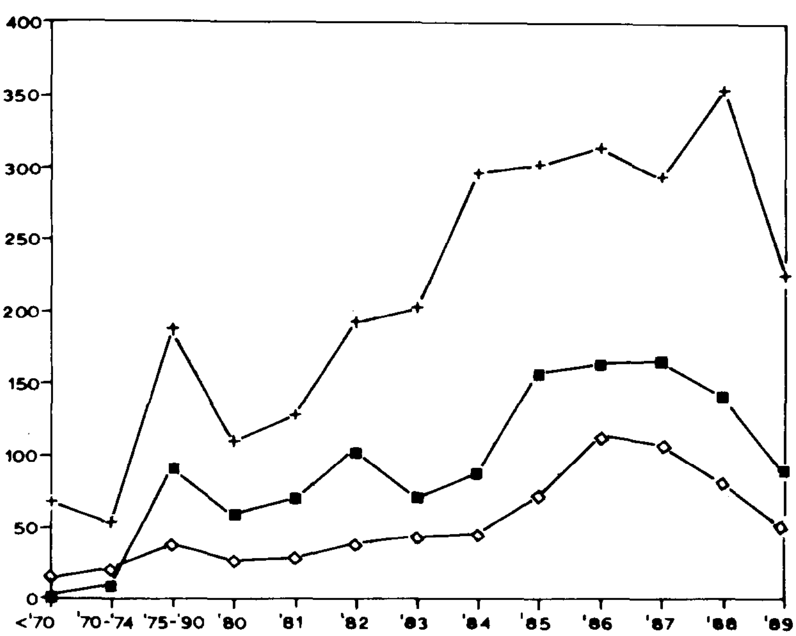

Fig. 1. Growth of newly established technology cooperation agreements in biotechnology (■), information technologies (+) and new materials (□) (Source: MERIT–CATI data bank [26]).

Table 2
Modes of technology cooperation in biotechnology, information technologies and new materials (numbers and percentages)

	Biotechnology	Information technologies	New materials
Joint ventures, research corporations	164 13.5%	458 16.9%	177 25.7%
Joint R & D	362 29.8%	749 27.6%	173 25.1%
Technology exchange agreements	84 6.9%	328 12.1%	54 7.8%
Direct investment	234 19.3%	357 13.1%	65 9.4%
Customer–supplier relations	186 15.3%	245 9.0%	42 6.1%
One-directional technology flows	183 15.1%	581 21.4%	177 25.7%
Total	1,213 100.0%	2,718 100.0%	688 100.0%

Source: MERIT–CATI data bank [26].

clear-cut confirmation of an extremely rapid growth of inter-firm innovative networks in biotechnology, materials technology and information technology in the 1980s (fig. 1) [26].When the MERIT data is broken down by type of agreement, it shows some variation by nature of technology, but in all categories R & D cooperation agreements account for a quarter or more of the total (table 2), with joint ventures also being very important. Several earlier studies [28,45,46,49] had shown that R & D-motivated joint ventures were growing rapidly in the 1970s and 1980s. Mowery in particular demonstrated their growing importance in international collaboration between US and foreign manufacturing firms. The MERIT data bank confirmed Mowery's assessment but also showed that joint ventures and other forms of research cooperation had grown rapidly between European and Japanese firms. In fact, the "Triad" of US, Europe and Japan accounted for over 90 percent of all the agreements recorded and only the Asian NICs entered the picture in significant numbers from outside.

As table 2 indicates, direct investment was particularly important in the area of biotechnology. This is primarily due to the special type of symbiotic relationships between large (mainly chemical) firms and the new (biotechnology based) small firms, which have characterised the early developments in this technology. Minority equity stakes provide a special form of "cooperation" in these circumstances.

What are described by Hagedoorn and Schakenraad [26] as "one-directional technology flows" are more important for the more mature information technology and materials technology industries than for biotechnology. Their importance in these two areas is partly due to the rapid growth of second-sourcing agreements. Ordinary licensing agreements have been growing rapidly for a long time; from the standpoint of networking the growth of cross-licensing and technology exchange agreements is of greater interest. It should be noted, however, that classification of an agreement as "uni-directional" does not necessarily mean that cooperation is unimportant, especially in the wider context of a multiplicity of networking arrangements and a variety of strategic alternatives. Nevertheless, if forms of cooperation were ranked according to the degree of intensity and equality in the relationship then the order of ranking would probably be from highest to lowest (1) Joint ventures, (2) Joint R&D agreements, (3) Technology exchange, (4) Direct investment, (5) Customer–supplier contracts, (6) Licensing and second-sourcing [25]. Moreover, the MERIT Data Bank almost certainly understates the number of one-way licensing agreements between firms in the "Triad" and firms in the Third World since these are far less frequently the subject of public announcements.

So far, we have indicated a few of the more important sources which confirm a very rapid growth of various types of R&D cooperation in the 1980s, especially in the newer generic technologies (categories 1 to 5 in table 1). When it comes to category 6, far more important than sheer *quantitative* increase in the number of agreements has been the *qualitative* change in the content of the relationships. This is difficult to demonstrate statistically, but the evidence from numerous case studies and from the papers at the Montreal Workshop is strong. So, too, is the evidence from the analytical studies of new developments in management technologies and productivity trends, such as the Report of the MIT Commission on Industrial Productivity [15].

What all these studies show is that a lot of new wine is being poured into old bottles in sub-contractor and supplier networks. The clearest case is undoubtedly that of Japan. Attempts are being made almost everywhere to imitate some features of the Japanese model and it is also being spread by direct Japanese investment. A great deal of attention has been paid to the Japanese automobile industry and to the workings of the JIT, or Toyota-Ohno, system in that industry. But perhaps still more interesting is the example of the Japanese electronics industry, which has grown even faster in the past three decades.

A recent study of Japanese electronic networks supporting small and medium-sized enterprises (SMEs) shows that whereas in the 1950s sub-contracting firms were viewed in a somewhat condescending way as low-cost suppliers who could absorb business fluctuations, this attitude changed profoundly over the next three decades, partly because of shortage of capacity and skills [70]. This analysis is also confirmed by the Japanese economist, Mari Sako [58] in her studies of the Japanese electronics industry and the historical development of sub-contracting in Japan.

Modification or innovation of a part or component of a product or process by one sub-contractor inevitably affected the manufacturing process of the whole. Especially in electronics, innovation among sub-contractors is subject to the constraint of compatibility with the customer's (or parent company's) technology. Therefore, the sub-contractor must supply a product according to detailed specifications which can only be modified within certain limits. To a degree this compels parent companies to offer advice and supply the necessary technology to sub-contractors so as to increase their economic and engineering capabilities. This results in a higher dependence on upgraded sub-contractors because of their specialized technology and equipment instead of the traditional low cost approach.

As fig. 2 shows, technological specialisation was given as the main reason for the use of sub-contracting by large enterprises in the Japanese electronics industry, and the proportion was highest in the case of firms involved in *mechatronics*. Cost and scale of inventories were relatively trivial in comparison. This is particularly interesting in view of the great emphasis placed on inventory control in the JIT system in the automobile industry.

As the technical competence of sub-contractors

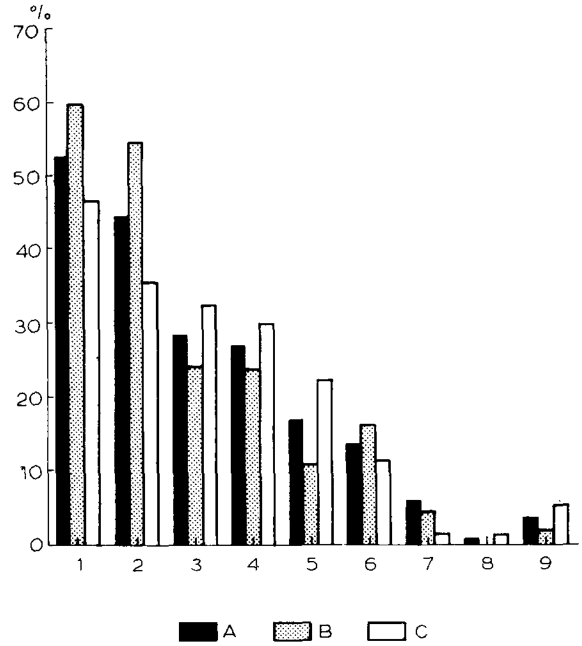

Fig. 2. Reasons for large enterprises to use sub-contractors. Source: Small and Medium Enterprise Agency, "Shitauka Kigyo Jittai Chosa" (Survey of the State of Sub-contracting Enterprises'), December 1981 and Van Kooij [70]. (■) = All manufacturing enterprises; (▨) = parent companies which have introduced mechatronic equipment; (□) = parent companies which have not introduced mechatronic equipment; 1 = sub-contracting enterprises have specialised technology and equipment; 2 = parent company's production capacity is insufficient; 3 = production lot is small and outside orders are more efficient; 4 = reduction of personnel costs and the unit price of products; 5 = use of sub-contractors enables more flexibility toward fluctuations in lot size; 6 = enables saving of capital for plant and equipment investment, etc.; 7 = strong capital and personal ties with sub-contractors; 8 = parent company does not have to hold excess inventories; 9 = others. Note: Total exceeds 100 due to some respondents giving more than one response.

improved, a more equal relationship between large and small enterprises began to develop in many cases. Instead of the rigid hierarchy within groups with great prestigious firms at the top and small weak ones at the bottom, the parent-firm transformed its position into a nucleus within an industrial combine of "Kogaisha" ("children" or "daughter" companies). To accomplish this gradual transformation parent companies undertook a series of activities, of which the main aim was the improvement of the flow of information from "parent to child" and back, and among the "children" themselves. This was achieved by assigning the function of liaison to a special department within the parent company.

As illustrations, van Kooij gives examples from Toshiba TV and VCR manufacture, from Mitsubishi's R&D meetings and Hitachi's project groups. In these cases, the object of the association was research cooperation and improvement of managerial and technological competence, even though the leadership of the large enterprise continued to prevail. New small high-technology firms, on the other hand, combined together in a more independent way, forming networks of cooperation for new product and process development and research interchange. Van Kooij's account suggests that technological requirements played a big part in transforming the Japanese sub-contractor networks.

The new developments described by Saxenian [59] in her paper on technological cooperation in Silicon Valley in California show some striking resemblances to these Japanese developments, particularly her example of the upgrading of printed circuit board manufacturers. However, the cooperating firms in her investigation more often had the characteristics of the relatively small number of new high tech firms of the Japanese electronics industry as portrayed by van Kooij. In both cases technological competence and specialisation were the basis for rather equal and trusting relationships between firms who needed each other's special capabilities in new product and systems development.

Imai [29] has argued that the evolution of Japanese corporate and industrial networks has gone so far as to constitute a new type of production system. He traces the qualitative changes in the forms of networking from the old pre-war Zaibatsu networks, based on ownership and control, to the fuzzier and more flexible type of networking, based on information exchange between more equal partners, who may or may not be affiliated to the same business groups.

In the case of Research Associations (category 7 in table 1), an analogous process of qualitative change can be seen in Japan. As we have seen in section 1, these were originally established over half a century ago in Europe, mainly with the object of strengthening the technical capability of small firms who lacked R & D. When the Japanese imitated these European developments much later they also had in mind assisting small firms. The law passed in 1961 to set up the "Engineering Research Associations" (ERAs) envisaged cooperation between government laboratories, especially MITI's Mechanical Engineering Laboratory, and various makers of parts and components, especially in the automobile industry. The first four ERAs were in filters, suspensions, indicators and engine parts and shared the MITI laboratory facilities [37].

As Japanese industry advanced technologically, there was some doubt in the late 1960s as to whether the ERA type of organisation would be needed any longer and after the first twelve had been set up in 1961–65, no more were created in 1965–70. But this was followed by a veritable "boom" in creating ERAs, especially in the early 1980s (25 between 1981 and 1983). However, as Levy and Samuels [37, p. 32] point out: "both their raison d'être and nature of their participants were transformed". The new ERAs were mainly in electronics, information technology, materials technology and biotechnology and their objects had shifted to broad areas of advanced technology. Large firms came into the ERAs and 30 firms accounted for nearly one-third of the memberships by 1985, with Hitachi participating in 18 and Toshiba in 16. Government support doubled between 1977 and 1982, but funding is shared with industry and industrial associations often collaborate with MITI in administering the projects.

The total *amount* of Japanese government support for industrial R&D is, of course, far less than in USA or many European countries. But the mode of support is particularly interesting. Much of the support comes through special loans or through tax benefits and these are strongly geared towards collaborative "networking" projects. By the late 1980s, four-fifths of all government R&D loans were going to joint projects which included not only the ERAs but many other types of "centres", "consortia", "forums" etc.

The apparent success of many of these collaborative projects and programmes led to widespread imitation of this technique of organisation and funding, both in Europe and the United States. The British Alvey Programme (1983–87) was established as a direct result of a study of Japanese initiatives in "5th Generation Computing", and similar programmes were started in several other European countries and in the United States [3]. They were all based on the principle of the ERAs temporary coalitions of large (and some small) firms, with participation of universities and government laboratories and joint funding by industry and government.

So prevalent did this new mode of funding become in the 1980s that by the end of the decade about two-thirds of the European Community Research Budget was disbursed in this form for the support of the new generic technologies. Mytelka and Delapierre [48] and Sharp [61] have shown the very important role of ESPRIT in the development of new strategic alliances and networks in the European electronic industries.

Finally, there remains to consider the 9th category (table 1) of research collaboration, computer networking. Unfortunately, very little research has been done on this aspect of innovative networking, perhaps because it is the most recent type. But Bar and Borrus [5] given an informative account of the use of various forms of computer networking by innovative US firms, particularly Hewlett-Packard. It also plays a very important part alongside other networks in the Japanese system and is specifically mentioned by van Kooij [70] in relation to the Toshiba VCR network. Thomas and Miles [68] have given a general account of the rapid growth of telematic services in the UK in the 1980s and of their relevance to innovation and diffusion of innovations. Jagger and Miles [33] show that scientific data and economic information were the main growth areas in the 1980s. But in-depth case studies of the experience of data banks and value-added networks are still few and far between.

To sum up this discussion of the changing patterns of collaboration in innovative networks in the 1980s: there have indeed been some major changes both quantitatively and qualitatively. In quantitative terms there is abundant evidence of a strong upsurge of various forms of research collaboration, especially in the new generic technologies (categories (1) to (5) in table 1), involving extensive international collaboration as well as national and regional networks. There is also ample evidence of a *qualitative* change in the nature of the older networking relationships which have existed for a long time: sub-contracting networks (6), Research Associations (7), government R&D projects and programmes (8). Finally, computerised data banks and value added networks (9) provide entirely new possibilities for networking which however have been very little researched.

3. Causes of the changes in networking for innovation

The last section has brought together and summarised some of the available evidence relating to the growth of innovation networks and the qualitative changes in their mode of operation in the 1980s. This section discusses the underlying causes of these changes and their implications for theory and for research in the 1990s.

When Hagedoorn and Schakenraad [26] analysed the motives for firms to enter into cooperative agreements with each other, they found that strategies relating to technological competence and market positioning predominated. Simple lack of financial resources to fund design and development accounted for only a very small number of cases, mainly in new biotechnology firms. Even in these cases, of course, whilst the small new firms were motivated by the need to finance R&D, their larger partners were often primarily motivated by long-term strategic considerations.

Especially in information technology and materials technology agreements, technological complementarity and reduction of lead times were very frequently diagnosed as the dominant motives for R&D cooperation. They were also important for joint ventures, but in this case the strongest single motive related to market expansion and strategic positioning in new markets. In general, Hagedoorn and Schakenraad found that, in contrast to much of the previous literature, considerations of cost-sharing and cost-minimising appeared to play a relatively small role in comparison with strategic objectives relating to new technology and markets.

Most of the papers at the Montreal Workshop also testify to the importance of technological complementarities, shortening lead times and strategic objectives. Saxenian [59], in particular, brings out these factors very strongly in relation to the development of new computer systems in Silicon Valley. She argues that firms would have simply been unable to compete if they had not been willing to enter into a variety of forms of technological cooperation. Because of the extremely rapid pace of technical change and the broad range of specialised technological capabilities needed for system development, there was simply no time to go it alone. The work of Camagni and Gambarotto [9] and of Cainarca et al. [7] reinforces these points, whilst Mowery [46] concludes that:

> Technological developments in a number of industries also have increased the importance of access to new or unfamiliar technologies... Collaboration can provide more rapid access to technological capabilities that are not well developed within a firm and whose development may require a large investment and considerable time [46, p. 25].

Taking this together with the quantitative evidence from the MERIT Data Bank, it is abundantly clear that the main source of change underlying the new developments in networking for innovation lies in the rapid development and diffusion of new generic technologies and especially information technology. Imai and Baba [30] sum it up as follows:

> Information Technology exerts a strong impact on the entire range of existing products and services. Eventually it renovates the total system. The dominant mode of innovation is systemic... The interactive process of information creation and learning is crucial for systemic innovation. Interaction includes three dimensions: between users and suppliers, between R&D, marketing and manufacturing and between physical products, software and services.

Table 3 illustrates this point in the case of the transport sector. The change in the patterns of innovation from the energy-intensive products and systems of the 1950s and 1960s to the computerised control systems of the 1970s and 1980s is very striking. *Systemic* innovations, such as containerisation, were of course very important in the early post-war period and so, too, was the energy-saving achieved by scaling up. But the technical complexity of containerisation was not great and intensive *technical* collaboration between firms was not the main requirement for its successful development. In the case of the systemic innovations of the 1970s and 1980s on the other hand, innovation networks were necessary

Table 3
Innovations in the transport sector 1940s to 1980s

(1) *System innovations and economies of scale to take advantage of low cost oil-intensive technology (1940s to 1960s)*
Containerisation
Unitisation
Roll-on, roll-off
Oil and gas pipelines
Dieselisation of railways
Scaling up size of trucks (to 38 tons)
Scaling up size of aircraft (from DC3 to 747)
Scaling up size of tankers (from 20,000 dwt to 500,000 dwt)
Scaling up of port facilities to handle large tankers, roll-on, roll-off, containerisation and unitisation
(2) *Information and control innovations to take advantage of increasingly low cost electronics and computing (1960s to 1980s)*
Radar and computer-controlled airport traffic
Computerised airline booking systems
Aircraft instrument landing systems and flight control systems
Computerisation of railway marshalling yards
Computerisation of railway signalling systems
Computerisation of road haulage and delivery systems
Unmanned trains
Tachograph
Computerisation of travel agencies
Computerisation of road traffic control systems

Source: derived from Working paper by IM Brodie, Transport, TEMPO Sector Study, SPRU, (mimeo) March 1984.

for the development of the original electronic equipment (circuits, hardware, peripherals, instruments, etc.) and even more so for the new applications, especially in relation to customised software.

We therefore have to consider some of the specific features of information technology which have led to the more technology-intensive and more numerous innovation networks of the 1980s. Here the theory of techno-economic paradigm change developed by Carlota Perez [52,53] offers the most convincing explanation. Whereas other writers (e.g. Dosi et al. [16]) used the expression "change of technological paradigm" to describe fundamental changes in the technology of a particular industrial sector, she pointed to the fact that some changes of paradigm are so *pervasive*, because they offer such a wide range of technical and economic advantages, that they affect the behaviour of the entire system, changing the "common-sense" rules of behaviour for engineers, managers and designers in many sectors or in all, as well as their inter-sectoral relationships and technological complementarities.

Clearly, information technology is such a case. Not only has it found applications in every manufacturing and service sector, often changing profoundly both products and processes, but it also affects every *function* within each firm: design (CAD); manufacture (robotics, instrumentation, FMS, control systems, CIM, etc.); marketing (computer-based inventory and distribution systems) accounts and administration (management information systems, etc.). Finally, it affects, through its convergence with the telecommunications system, the network of communications within the firm and between the firm and its supplier networks, technology networks, customer networks, etc. In this last area it provides entirely new possibilities for rapid interchange of information, data, drawings, advice, specifications, and so on between geographically dispersed sites via fax, VANs, electronic mail, teleconferencing, distance learning, etc. It is hardly surprising, therefore, that taking into account both the pervasiveness of IT and its systemic characteristics, most of the new developments in networking in the 1980s have been associated in one way or another with the diffusion of this technology. Not only is the IT industry itself characterised by intensive technological networking for the development of its own products (through complementarities in materials, components, circuits, sub-assemblies, instruments, final products, software, peripherals, etc.), but its diffusion throughout the economy to new sectors of application depends on the development of new networks in every sector (banks, machine-tool makers, travel agents, consultants, airlines, law firms, accountants, hospitals, chemical engineers, etc. etc.). Finally, it provides the technical means for improving communication networks everywhere and for making them feasible in areas where they could hardly have been introduced before. It is a networking technology *par excellence*.

The world-wide diffusion of this new techno-economic paradigm has led not only to intensified technical collaboration within supplier networks and between users and producers of IT products and systems, it has also engendered a fierce competitive struggle between the suppliers of these products and systems. Characteristic of periods of change of techno-economic paradigm is the rise of new firms associated with competence in the new technologies and the strategic re-positioning of many established firms as they try to cope with the rapid structural and technical change affecting their markets and their very existence. If we take into account also the international aspects of production, marketing and technology development, then clearly a period of great turmoil could have been expected in the 1980s, with many new strategic alliances and networks. This is, indeed, the picture which emerges from the MERIT Data Bank and other similar sources. The need for firms in the "Triad" countries to gain access to partners in each of the three main areas (EC, Japan, USA) was one of the main driving forces. Hagedoorn and Schakenraad [26] have suggested that the apparent downturn in numbers of new networking agreements in the late 1980s (fig. 1) may have been due to the fact that a great deal of strategic re-positioning for the single European market had already been completed. By the same token, a new wave of agreements affecting the East European countries may be anticipated in the early 1990s.

Even though the Japanese market is far more homogeneous and smaller than either the US or the EC market, strategic factors have certainly influenced the networks of European and US firms in their desire to gain access to Japanese technology and markets. *Within* Japan, as we have seen, a growth in the technology-intensity of supplier networks, and government sponsored programmes have been a major feature of internal development in the 1970s and 1980s. The desire of the Japanese government to promote the transition to an "Information Society" as rapidly as possible has been a major factor in the acceleration of this process [22]. One of the participants in the Montreal Seminar, Walter Stohr aptly described the Japanese economy as "nothing but networks of innovators". The desire to emulate Japanese achievements in technology has been another major factor in the international acceleration of innovation networking in the 1980s and of qualitative change in the supplier networks of industries.

However, it would be quite wrong to interpret the new developments in networking as primarily a Japanese phenomenon or exclusively a phenomenon associated with information technology. The empirical evidence is perfectly clear that similar developments affect all the leading industrial countries and indeed "globalisation" is an important aspect of the growth of new types of network. Moreover, even if information technology is the driving force behind most of the new agreements and networks, a similar process affects other rapidly developing generic technologies, such as materials technology and biotechnology (fig. 1, table 2).

Again, as emphasised in section 1, networking for innovation is in itself an *old* phenomenon and networks of suppliers are as old as industrialised economies. Ann Markusen's [42] Montreal paper gave a clear reminder that many aspects of the most recent wave of networking agreements were already clearly evident in the networking of the US military–industrial complex from World War II onwards. Particularly interesting is her point that short product life, reduced lead-times, high technical performance standards, higher quality of components and materials, accelerated development and diffusion of new techniques such as NC and CAD through supplier networks, etc. were all major features of the US "networks for innovation" in weapon systems well before the 1980s.

Despite these very important qualifications, information technology has led to the widespread diffusion of modes of networking which were previously far less common. Whether this is a temporary phenomenon, to be superseded by a new wave of vertical integration and industrial concentration, is a fundamental issue for research to which we turn in the final section.

4. Conclusions

Here we will briefly indicate a few major problems for further research and debate, which have important policy implications. To begin with, it will be important to keep track of the trends in networking in the 1990s. In one view the upsurge of new networking arrangements is a transitory phenomenon of adaptation to the diffusion of new generic technologies; as firms become more familiar with these technologies they will wish to shift the strategically sensitive areas under their direct and immediate control, i.e., to internalise some of the networks which are now the subject of cooperative arrangements. According to this view, the proliferation of new high tech small firms in such areas as CAD, software, instruments, personal computers, biotechnology, etc., which was characteristic of the 1970s and 1980s, will be followed by a new wave of rationalisation and industrial re-concentration in the 1990s and first decade of the twenty-first century.

A few of today's small and medium-sized firms will become giants of the next century through growth. But some key small firms are already being taken over by larger ones (e.g. Genentech by Hoffmann Laroche or Apollo by Hewlett-Packard) and even quite large firms like Nixdorf or Plessey have been swallowed up by even larger firms such as Siemens and GEC. Examples were given at the Montreal Workshop of small firm networks which have already been displaced by networks under the control of a large firm. Bressand and Kalypso [6] suggest that a number of service networks are electronic cartels in the making, particularly airline reservation systems.

This process of renewed concentration in the ICT industries may be compared with similar waves of concentration in the evolution of the automobile industry after World Ware I or the electrical industry in the 1890s (table 4). In the early formative period of any major new technology system, almost by definition there are no dominant designs or standards and a state of organisational flux. Innovator–entrepreneurial firms flourish and since there are no standard components labour-intensive techniques are characteristic. But as the technology matures, economies of scale become more and more important and standardisation takes place. The pattern of innovation tends to change in ways which Utterback and Abernathy [69] have indicated and the number of firms falls dramatically, as has occurred successively in the electrical, auto and computer industries. This whole long cycle of development may be plausibly related to Schumpeter's long wave theory, as in the work of Carlota Perez [52].

An alternative (and not necessarily contradictory) view is that networking between autonomous firms will grow still more important and will become the normal way of conducting product and process development. Even if some small firms are swallowed up, many more new ones will be born and will develop such specialised competences that they will be able to enter new networks on rather equal terms with large established organisations. Networking of various kinds was a normal feature of the industrial and regional landscape long before the advent of modern information technology. IT not only greatly facilitates various forms of networking, but has inherent characteristics, such as rapid change in design, customisation, flexibility and so forth, which, together with its systemic nature and the variety and complexity of applications, will lead to a permanent shift of industrial structure and behaviour. This will assign to networking a greatly enhanced role in the future.

Clearly, there is here a rich area for theoretical and empirical research in the 1990s. Longitudinal case studies on the evolution of networks could be particularly valuable. But it is also essential to continue the type of data collection on networks of all kinds represented by the MERIT data bank, so that we can keep track of the main trends in network formation and decay.

Longitudinal case studies would enable us to gain a better understanding of such complex issues as power relationships within networks. Some authors have stressed the rather equal relationships within networks of innovators, whilst others have pointed to a tendency for the strongest firms

Table 4
Long waves in the development of new technologies

Major features of successive techno-economic paradigms	Formative stage of new technology system	Rapid growth of techno-economic paradigm. Structural crisis of adjustment	Consolidation in new dominant technological regime
Electric power steel heavy industry	1840s–1870s	1880s–1890s	1900s–1930s
Automobile and IC engine oil assembly line	1880s–1910s	1920s–1930s	1940s–1980s
Computers chips telecomms	1940s–1960s	1970s–1980s	?
SMEs	Inventor–entrepreneur Innovator–entrepreneur Spin-offs	Many new SMEs in supply networks and services	Many mergers and take-overs, deaths. A few grow big. Some niches survive.
Large firms	Diversification into new technologies by a few large firms	Large firms come to dominate supply of key products and materials	Oligopolistic global industries
Technology	Radical innovations Establishment of scientific principles	Scaling up for main products and systems. Intense science–technology interaction	Established systems. Mainly in-house R&D. Mainly incremental innovations
Factor-intensity	Mainly labour-intensive	Becoming capital-intensive	Predominantly capital-intensive
Management	Flux. Organic. Few management principles	Emergence of new models of management and new conventional wisdom	Established textbook management style and practice
Standards and design	Hardly any established standards or designs	De facto standards of strong suppliers sometimes conflicting	Increasingly de jure standards and international standards
Infrastructure	Not yet in place. Competing ideas for what is needed	Heavy investment in new infrastructure with robust designs	Consolidation of global infrastructures
Political institutions and social institutions	Informal. Rapidly evolving. Partnerships mobility	Lobbies and professional associations emerge. Formal networks. Early lock-in	Political–industrial complex inertia and rigidity. Lock-in

to exploit their position at the core of the networks.

Clearly this debate about the future of networking and of industrial concentration is closely related to the debate in theoretical economics about markets, hierarchies and transaction costs [74,75]. It is notable that many papers and books about networks carry a main title or a sub-title such as "Beyond Markets and Hierarchies" [21] or "Transcending Markets and Hierarchies" [30]. Several of the papers at the Montreal Workshop also showed this dissatisfaction with the market/hierarchy dichtomy (e.g., Foray [20], Storper and Harrison [63]) and urged that networking should not be explained primarily in terms of "costs", whether transaction costs or others, but should rather be examined in terms of strategic behaviour, appropriability, technological complementarity and other complementary assets [66,67] and sociological factors such as inter-personal relationships of trust and confidence, and professional ethics of cooperation.

It is not without interest that the idea of networks as a "third form" intermediate between markets and hierarchies was originally suggested by Williamson himself in a footnote about the Japanese *zaibatsu*. But Goto [23] points out that he regarded this as a "culturally specific" Japanese phenomenon. Goto himself argues that although networking modes of organisation have been especially important in Japan, they have a much wider economic significance:

> In the case of the post-war Japanese economy, with its high overall rate of growth and rapid changes in its inter-industry structure, associated with a high rate of technical change, there was a favourable situation for the group mode of transaction to be relatively more efficient than the market mode or internal organisation mode of the carrying out of transactions.

It is notable that Japanese economists and historians have particularly stressed the importance of alternatives to markets and hierarchies and their growing importance with the rise of information technology [29,30,37]. But many European and American economists and geographers have also stressed the importance of either displacing Williamson's theory or developing it further [64].

A second major set of issues relates to the geography of networking at the regional, national and international levels. Here the study of informal as well as formal networks is particularly important, as well as the trends of innovation networks and strategies within multinational companies. Studies of regional and national systems of innovation could throw a great deal of light on the persistence (or otherwise) of geographically circumscribed networks and the reasons for their rise (and decline). Patel and Pavitt [50] have maintained that innovation activities are an important case of "non-globalisation" whilst *Business Week* (1990) runs a special feature on the "Stateless" Corporation. The statistics on R&D performance by multinationals outside their main base are still very inadequate, but this does seem to be increasing from a very low base. However, purely quantitative analysis is inadequate here. The nature of R&D and other technical activities performed in each location are clearly of great importance in relation to the large companies' own networks and their external linkage, agreements and strategies.

This whole area of research has very direct relevance to policy-making at the regional, national and international level, as shown by DeBresson [13]. It is one where the contribution of economists is vital but which cannot be left to economists because of the many subtle questions of a sociological and political nature, both in relation to informal and formal networks. As in most of the major issues a network approach by social scientists themselves is essential. The Montreal Workshop showed that such an approach, particularly between geographers, economists and organisational theorists can be very fruitful.

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