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Technology-based globalization indicators: the centrality of innovation network data

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Abstract

Useful technology-based indicators are central to efforts to gain insights into the causes and consequences of globalization. But traditional technology-based globalization indicators are of limited use because they are based exclusively on innovation inputs (e.g. R&D spending) or outputs (e.g. patenting). Coming to grips with the globalization phenomenon requires more attention to events taking place in the innovation process itself. Indicators of technological collaboration (e.g. strategic alliances, joint ventures, intimate supplier-producer linkages) help fill this gap. Focusing on these cooperative arrangements places the emphasis where it should be—on the key organizational actors (e.g. firms, universities, government agencies) in the process of globalization. Indicators based on the dynamics of these innovation networks hold great promise for integrating input and output indicators. An example is the development of indicators of social capital—a stock of collective learning. Viewing globalization through the lens of the emergence and evolution of social capital points out that even in the most powerful technological innovation process, success depends as much on social factors (e.g. the key roles of trust, shared values, and community) as on economic, scientific, or engineering variables.

Keywords: Innovation networks; Globalization indicators

1. Globalization

The broadening geographical inter-linkages of products, markets, firms and production factors, with a larger portion of each derived, generated, or available in more countries and regions [1] can be said to have coevolved with rapid and pervasive

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technological innovation. By this it is meant that changes in technological advancement appear to have helped create increasingly global markets and other institutions, and these ever more global political and economic institutions appear to modify emerging technological innovations [2]. Especially important to this coevolutionary process have been innovation networks—the complex webs of relationships among firms, universities, government agencies, and other organizations for generating and sharing knowledge relevant to technological innovation. Innovation networks are intimately related to the process of globalization, which has both been enabled by and promoted rapid technological advance.

But what do we really know about the linkages between technological innovation and globalization? What are some of the major indicators of the globalization/technology coevolutionary process?

To date, answers to these questions have focused on the multinational corporation (MNC), seen as the central actor in globalization, but certainly not the only player. Indeed, the role of the MNC may be changing as network organizational forms emerge. However, the historical primacy of the MNC has caused some problems for globalization indicators. Few countries (e.g. the US, Japan, Germany, Sweden) have collected data on what their firms have done outside the borders of the home country. More countries collect data on the activities of foreign-owned affiliates within their own borders, but generally these data are confined to manufacturing [3]. However, we do know enough to identify categories of technological activities that seem to be linked to increased globalization. Daniele Archibugi and Jonathan Michie have developed the most useful typology of such categories [4]. There are a number of globalization indicators associated with each of these three technology-related categories.

- Technological exploitation. Increasingly organizations (usually MNCs) try to profit from innovation by taking technological processes and products to international markets. This seems to be the most global of technological activities. Markets have become global at a rapid pace, as indicated by several kinds of trade and patents extended to foreign countries. This process has been so striking that many analysts have defined globalization entirely in terms of technological exploitation—as the international integration of markets. Unfortunately, this perspective tends to downplay the role of technology. Often technological change is relegated to a modest, facilitating function (e.g. the process by which the innovation of information and communication technologies lowers the costs of moving goods and knowledge around the world) [5].
- Technological generation. MNCs based in one country often undertake innovation in a host country. The generation of technology outside the MNC's home country has expanded to a modest degree, as indicated by some kinds of Foreign Direct Investment (FDI), the movement of research and development (R&D) facilities to the host country, and patents generated by foreign subsidiaries of MNCs. While the category of technological generation places great importance on all aspects of technological innovation, there has been much less activity here than in technological exploitation. There is no systematic evidence to suggest that widespread

globalization of the generation of technology has occurred. The process of globalizing the generation of technology has expanded only for the very largest MNCs and in only the leading industrialized countries of the triad (i.e. North America, Europe, and East Asia). In truth, most of the globalization of technology generation appears to have been a particularly intra-European phenomenon. Consistent with the earlier discussion of technological exploitation, the most internationalized firms generating products abroad are not in high-tech technological sectors, but are in sectors where adaptation for serving local markets is important (e.g. food, drink, tobacco, construction materials) [6].

- Technological collaboration. Perhaps the most striking feature of technological innovation today is that only a small minority of firms and other organizations can innovate alone—especially in more complex technological sectors (e.g. bioengineering, microelectronics). Most innovations involve a multitude of cooperating organizations, many of which are international. And many of the international firms and other actors that participate in these collaborative activities preserve their national identity and ownership. Strategic alliances, joint ventures, and other types of technological cooperation are the key indicators for this category.

Each of these technological activity categories and accompanying sets of indicators has played a role in defining the nature of globalization. But technological exploitation and generation are fundamentally limited conceptual categories because they are based entirely on input and output indicators. That is, exploitation and generation activities almost always relate to inputs to the innovation process, such as FDI or R&D spending, or innovation outputs such as patents or trade. None of this says much about process indicators, such as events taking place in innovation itself. Because the formation and evolution of inter-organizational innovation networks are inherently linked to the process of innovation, it is this category that holds the promise of providing a more integrated interpretation of the globalization phenomenon [7,8]. Table 1 illustrates the central role of technological cooperation as innovation networks not only produce new input and output indicators (e.g. inputs such as work groups and teams, outputs such as social capital), but also provide unique insights into the process of technological change.

At this point it should be noted that the placement of any indicator in a particular conceptual box is somewhat arbitrary. Most of the activities captured by the indicators are not exclusively exploitative or generative—they often spill over from one category to another. However, the figure is representative of the ways the relevant literature has generally categorized these activities.

2. Technology-based indicators and dimensions of globalization

Globalization is not an easy concept to pin down. Nor is it easy to specify the ways in which the process of economic, political, and social globalization is not only affected by, it but also itself affecting the production, distribution, and transfer of technology. Nonetheless, this is the objective of the sections that follow.

Table 1

	Indicators of Technological Exploitation	Indicators of Technological Cooperation	Indicators of Technological Generation
Innovation input indicators		Work groups or teams that integrate codified and tacit knowledge	FDI in acquiring control of an existing enterprise abroad FDI in wholly owned facilities abroad Internationalized R&D funding
Innovation process indicators		Purposes of inter-national innovation networks (e.g. exploitation, generation) Members of innovation networks (i.e. government agencies, firms, universities) International R&D performance & other types of learning activities (e.g. learning by interaction)	
Innovation output indicators	International trade Intra-firm trade Technology trade Wholesale trade Patents extended to foreign countries	Transnational social capital	Patents produced by foreign subsidiaries of MNCs

Source: Modified from Ref. [59].

2.1. Indicators of international technological exploitation

2.1.1. International trade

Trade data have a huge advantage in analyses of globalization because the data have been collected over long time-frames and for almost every technology and country in the world. A problem with trade data is that they count only goods and not services [9].

Most countries in the 21st century are likely to keep pursuing trade. Access to larger markets spur innovation. Trade competition prods businesses to do things better and cheaper. Freer trade promotes the movement of people and ideas across borders, increasing creativity. If current trends continue, world exports of goods and services will reach about 28% of estimated world GDP. Trade's share of world GDP was 9.35 20 years ago [10].

The growth in international trade (and FDI) is now cited as evidence that the world economy has changed. There are several ways to look at this assertion. In one sense, we've been global before in terms of this indicator. Since the second half of the 19th century, there have been three major phases of rapid growth in trade (and investment): (1) 1870–1914, when the British Empire dominated the world; (2) 1945–1973, when post-World War II expansion took place; and (3) 1980 to the present [11].

In 1973, in most countries, trade was a lower percentage of GNP than in 1913, due to two world wars and protectionism during the Great Depression. Though trade has been recovering since the 1950s, many countries in 1994 still had not reached the 1913 trade level (e.g. the Netherlands, UK, Japan).To the degree that trade has been recovering, it appears to have been regionalized as much as globalized. There is evidence of regional integration in trade (e.g. the European Union), but regional trading blocs do not seem to be moving toward greater integration globally [12].

A different interpretation asserts that while trade's share of national incomes is indeed modest, this hides the fact that merchandise trade as a share of merchandise value-added is quite high for the US and for the Organization for Economic Cooperation and Development (OECD) as a whole. And this share has been growing dramatically. Thus, in terms of the value-added of trade, the world is much more integrated today than at any other time during the past century [13].

While trade has been increasing in all Organization for Economic Cooperation and Development (OECD) countries, there is wide variation in the particular national trade patterns. Small countries (e.g. The Netherlands) exhibit the highest levels of import penetration and export share (as high as 70%), while the lowest levels are in the largest economies (e.g. the US and Japan at 10–15%).

2.1.2. Intra-firm trade, technology trade, and wholesale trade

Much international trade is 'intra-firm' (cross-border transactions between affiliated units of MNCs—trade in products which are sold internationally but stay within the same MNC). Intra-firm trade accounted for one-third of all US exports in 1994, and for 40% of all imports. For all intra-firm trade, the bulk flows from the MNC's parent to the affiliate [14].

Like intra-firm trade, the foreign affiliates of MNCs are key actors in technology trade—the exchange of intellectual property, royalties, and licenses flow through these channels. The US has been a particularly strong performer in technology trade—these activities have provided a substantial positive balance. As with intra-firm trade, technology trade tends to be initiated by parent MNCs.

Sometimes MNCs engage in wholesale trade, importing very large shares of their total output, primarily finished goods, which they then resell. Japanese MNCs, in particular, tend to focus heavily on wholesale trade.

2.1.3. Patents extended to foreign countries

Patent statistics have major advantages over most measures of technological activity. They exist for long time-frames and contain enormous amounts of information that can be broken down by geographic location and technical area. The major liabilities of patent data are: (1) not all innovations are patented; (2) different technologies are patented at different rates; (3) different types of firms may have different propensities to patent; (4) they measure only codified knowledge; and (5) they do not satisfactorily measure technologies covered by copyright, such as software [15–17].

The extension to foreign countries of patents attained in the country where the innovation took place is more likely in fast growing and high-technology sectors. The average annual growth in foreign patent extensions was 13% between 1985 and 1995.

2.2. Indicators of international technology generation

2.2.1. Foreign direct investment in wholly owned facilities abroad, international joint ventures, and building wholly owned facilities in the other countries

Globalization may be better measured by the movement of capital than the movement of goods and services (as is the case with trade indicators). With FDI, longer-term investments are made than the single transactions characteristic of trade relations. These investments are of three broad types: (1) building wholly owned facilities in the host country; (2) undertaking joint ventures, where business enterprises share ownership and control across borders; and (3) acquiring control of an existing enterprise in the host country. Each of these types of FDI are characteristic of technological generation.

National patterns of technology-related FDI differ in volume and composition. These cross-national variations are consistent with variations in intra-firm trade. Differences in national innovation systems (NIS) appear to explain some of these FDI variations. The NIS conveys different degrees of attractiveness to FDI and different degrees of access to foreign MNCs. These differences are partly a function of nationally distinct resources and institutions. For example, FDI policy is much less well developed than trade policy. There are very few tools (e.g. local content requirements) that governments can use to affect incoming FDI. In the US, the most effective controls on FDI have had to do with national security (e.g. defense contracting, limitations on foreign ownership) [18].

Japanese FDI tends to focus on new plants and joint ventures, with few acquisitions of existing enterprises being undertaken. The UK is the reverse. Germany is a mix of both. These differences reflect different motivations. If the motivation underpinning incoming FDI is sourcing technology (sometimes called the technology pull effect of the host country), acquisitions and joint ventures are usually the choices. New plants typically represent using home country capabilities abroad (the technology push effect).

In the late 1980s, the international economy embarked on a process of dramatic transformation in foreign investment patterns. Global FDI stock almost quadrupled from 1985 to 1995 (to $2.7 trillion). More than any other single fact, this growth in FDI explains the current focus on MNCs and on globalization [19]. Yet huge sums that are traded daily on the world's financial markets do little to enhance real economic performance. Indeed, these flows of hot capital can damage technological innovation [20].

2.2.2. Internationalization of R&D

Most national science and technology debates are dominated by research and development data. But foreign R&D only became an issue for a few academics in the 1970s and was not a priority for most industrialized countries until the mid-1980s. For example, the 1989 OECD Science and Technology Indicators did not mention the topic and the US National Science Foundation's (NSF) Science and Engineering Indicators did not focus on it until 1991 [21].

Expanding learning opportunities appears to be the key reason for internationalizing research and development programs, but while there is some correlation between R&D spending and technological innovation, the relationship is not always direct [22]. Moreover, R&D is only one pathway to the generation and acquisition of the knowledge (i.e. learning) underpinning innovation. Learning by doing, learning from spillovers, learning from advances in science and technology taking place in other sectors and/or other countries, and especially learning by interaction (with suppliers and users, as well as with competitors) may be just as important as R&D-based learning [23].

The majority of large international enterprises performing R&D are still following the strategy of keeping the competence base for their core technologies in their country of origin. There is some change underway, however. Small, developed countries (e.g. Sweden, The Netherlands, Switzerland) have internationalized their R&D the most. Many countries are considering concentrating some portion of their core technologies in centers of R&D excellence abroad.

The aggregate volume of overseas R&D by corporate affiliates of MNCs has increased in recent years. Studies show that European firms have the highest proportion of R&D abroad (about 30%), with the emphasis on locating R&D units in other European countries. By comparison, about 10–12% of US R&D and about 10% of Japanese R&D have been internationalized.

Research and development by foreign affiliates in the US has been expanding, concentrated in pharmaceuticals, electronic equipment, and chemicals. US affiliates in foreign markets mirror these trends, especially their concentration in drugs. Most foreign expansion of R&D in the US has been established through mergers and acquisitions, not through new investments dedicated to R&D.

2.2.3. *Patents generated in foreign subsidiaries of MNCs*

About 15% of patents granted in the US are generated by foreign subsidiaries of multinational enterprises. By comparison, the share of patents generated by foreign MNC subsidiaries in Europe is about 30%. The most internationalized patenting takes place in older manufacturing sectors, such as food and paper products, while the least internationalization is in more complex sectors like semiconductors [24].

2.3. *Indicators of technological collaboration*

As noted above, most innovations involve a multitude of organizations [25]. This is especially the case for the most valuable, most knowledge-intensive, and most complex technologies (e.g. computers, semiconductors, telecommunications equipment, aircraft, biotechnology) [26]. The past couple of decades have witnessed the explosion of cooperative innovation agreements involving firms, universities, other research institutes, as well as intermediate organizations (e.g. professional and trade associations, think tanks) in various combinations.

Examples of complex networks are to be found in the strategic alliances, joint ventures, and intimate supplier-producer relationships that are proliferating around the world. For example, over 20 000 corporate alliances are said to have been formed during the period 1988–1992 in the United States alone, with annual growth rate in corporate alliances of 25% since 1985 [27]. Internationally, the same trends are underway. The Economist reported that some 32 000 new business alliances had been formed in the three years prior to April 1998 [28]. More conservative estimates—focusing exclusively on innovative activities—identify the establishment of more than 10 000 such technology partnerships over the period 1980–1994. Perhaps 10–15% of these partnerships involve R&D cooperation [29].

Such collaborative agreements encompass a wide range of activities, including: joint ventures, research corporations (e.g. research pacts, joint development agreements), technology exchange agreements (e.g. technology sharing, cross-licensing, mutual second-sourcing), direct investment, minority/cross-holding, customer-supplier and customer-user relationships, R&D contracts, one-directional technology flow agreements (e.g. licensing, second-sourcing), manufacturing agreements, marketing agreements, or services agreements. The term strategic alliance is often used to describe cooperative arrangements that are more stable and long term than these categories, or to encompass collaboration that extends over a series of projects [30].

At least since 1990, international cooperative arrangements—linking organizations from different national economies—have always been the majority. On average, there are about two international partnerships for every domestic one [31].

The premise, stated earlier, is that this category of technological cooperation is the most useful for developing the next generation of globalization indicators. There are three reasons to believe a focus on cooperative arrangements—innovation networks—holds this promise: First, innovation networks are becoming the major scientific and technological actors in the process of globalization. Second, innovation networks provide critical information about the other two categories of globalization indicators—technological generation and exploitation. Third, innovation networks provide a useful way to integrate input and output indicators of technological advancement.

3. Innovation networks as central globalization actors

One of the earliest definitions of networks of innovators was put forth 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 weak and strong ties among constituent members . . . We emphasize 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 [32].

These innovation networks have emerged because economic success in knowledge-intensive industries now requires the commercialization of technologies that require constant organizational learning and the synthesis of a wide variety of know-how, skills and capabilities. The centrality of learning (technological, organizational, market oriented) as the prime mover in the knowledge-based economy puts a premium on collaborative organizational relationships. Fragmentary evidence suggests most innovation networks are organized in complex technological sectors. It was noted above that this may suggest that networks and technologies co-evolve. In other words, changes in networks may lead to changes in the innovation of technologies; and those technological changes may modify the network [33]. Many knowledge-intensive technologies have become so complex they can only be innovated by complex organizational networks, rather than by individual firms. For these reasons, many observers are now arguing that the network is replacing the firm as the dominant actor in the increasingly globalized, knowledge-based economy [34,35].

The increase in all kinds of inter-organizational—particularly inter-firm—collaborative agreements has been documented by several investigators using various, though fragmented, sources of information. Facilitated by the rapid and widespread diffusion of information and communication technologies, all kinds of alliances appear to have become quite common, involving government agencies, universities, and organizations, as well as firms [36].

Within the rapidly developing literature on network creation and development, the most promising perspective lies at the intersection of what has been termed the organizational learning and complementarity perspectives [37,38]. This view begins with the idea that innovation networks have three important characteristics: existing core capabilities, existing complementary assets, and the capacity to learn. Existing core capabilities include the knowledge and skills that give the network the ability to innovate technologies uniquely well. A network core capability may be as broad as the mastery of systems integration or as focused as the ability to conduct R&D in a particular field [39,40] Existing complementary assets are those additional bodies of knowledge and skills that have to be accessed to take full advantage of core capabilities [41].

A learning capability depends on both the accumulated knowledge and skills of the network members plus the knowledge and skills of the entire network. Networks develop learning heuristics (e.g. how to do things) and routines from the history of interactions among network members [42].

Network core capabilities and complementary assets are constantly modified by a range of network learning processes (e.g. learning by interaction, learning by using, learning from R&D) in the pursuit of solutions to innovation problems and the identification of innovation opportunities [43]. A critical part of the learning resource is the capacity to continue to learn.

Network learning encompasses a mix of explicit (codified) and tacit (uncodified) knowledge and skills. In general, as knowledge gains in complexity (e.g. combinations of different disciplines or group experiences) its tacitness increases and its diffusion becomes more limited. It is only when complexity is reduced (e.g. by increase of codification, or by abstraction) that explicitness and diffusion are increased. Examples of tacit knowledge include skill with instruments (e.g. in engineering design) and manufacturing experience [44].

Thus, network formation is largely about accessing new resources to augment existing core capabilities and complementary assets and to engage in new learning activities in order to innovate. Complex networks are a response to the inability to innovate complex technologies with yesterday's simpler, rigid, and hierarchical structures and processes. The formation of innovation networks reflects an increasingly globalized environment characterized by exploding costs, accelerating time pressures, and ever more complicated technical systems. Box 1 provides a brief description of an international innovation network.

4. Innovation networks as sources of globalization information

As noted above, collaborative innovation efforts encompass a bewildering array of purposes. The conventional ways of trying to categorize such inter-organizational relationships have focused on various kinds of cooperation. Some of these collaborative categories are defined in terms of descriptions of modes or mechanisms (e.g. joint ventures, consortia, standards-setting, second-sourcing, while others describe activities or the nature of cooperation (e.g. research, development, manufacturing, marketing).

The high level of confusion over the terminology and meaning of existing categories of cooperation is reflected in the increasing use of the label strategic alliance to cover part or all of these collaborative endeavors.

A different perspective is proposed below—based on (1) the general purposes for

Box 1.

An example of an innovation network: Hewlett Packard-Philips cardio-imaging technology

Hewlett-Packard's (HP) development of an ultrasound-based cardio-imaging technology (CIT) began in the early 1970s and the technology dominated by the early 1980s. Over the course of the decade and a half following its initial innovation, the CIT went through five significant incremental innovations, based on a HP-centered network that included a number of medical schools (e.g. Stanford University, Duke University, Oldelft, University of Aachen) and hospitals (e.g. Houston Memorial). In the early 1990s a technological transition took place with the development of new magnetic resonance imaging (MRI) technology. A prototype of the MRI-based CIT had been successfully demonstrated by 1995.

The transition from ultrasound to MRI resulted from at least two developments. One was the search by HP for new markets. The second was the development of technical capabilities that would allow the cardio-imaging technology to replace invasive diagnostic techniques with non-invasive ones.

The potential benefits of substituting an MRI platform for ultrasound were part of an emerging set of expectations within the broader cardio-imaging community. MRI was a developed technology in widespread use for other kinds of diagnosis. However, HP did not have state-of-the-art capabilities in-house, or within any of its existing relationships with suppliers or users. For HP, the choice was either to develop its own MRI expertise or to link with other holders of these capabilities.

HP chose to find a partner with MRI capabilities because it did not want to spend the time engaging in an intensive learning process where some of the required knowledge was tacit and experience-based (e.g. synthesizing product and process designs and debugging them). Following discussions with several firms, HP joined forces with the Dutch firm Philips, primarily because the two companies' cultures were believed to be compatible. Both sides assumed there would be many problems that had to be overcome, but both felt they could develop a sufficient level of trust to carry out the innovation rapidly. Reflecting this confidence, the two firms signed a 'statement of principles', which specified that they would evaluate their relative contributions to the innovation after it was on the market and divide the profits of the initial innovation and all follow-on incremental advances based on that evaluation.

Box 1 continued.

The HP-Philips linkage actually involved the creation of two established sets of suppliers and lead users (e.g. existing networks) to create a new network. Philips was the holder of most of the MRI hardware capabilities (e.g. magnets, systems of integration), while HP was the holder of specialized electronics and signal processing capabilities. Lead users in hospitals and medical schools (e.g. Washington University of St. Louis, Iowa University) also became part of the network. As had been the case with the earlier ultrasound CIT trajectory, these network members were mostly located in the US health care system and they supplied critical complementary assets, such as knowledge about health care needs.

When the new technology had been demonstrated in prototype form, a corporate decision in HP resulted in its withdrawal from the network, turning the technology over to Philips. This decision was made as part of a redefinition of priorities within HP, even though the innovation was a technical success and was expected to be a commercial success.

Source: Ref. [61].

which member organizations choose to participate in innovation networks, aggregated under the two broad categories—generation and exploitation—outlined above, and (2) the types of organizations that choose to become network members. In every instance, the networks may involve equity (e.g. joint ventures) or non-equity relationships. Table 2 illustrates this perspective.

4.1. Purposes of innovation networks

Some innovation networks focus on technological generation. These are generation networks. This category includes R&D and manufacturing cooperation. Research and development cooperation includes licensing and cross-licensing agreements, tech-

Table 2

Exploitation networks	Generation networks
Marketing and service cooperation (i.e. procurement, sales, and servicing agreements)	R&D cooperation (i.e. licensing and cross-licensing, technology exchanges, visitation and research participation, personnel exchanges, joint development, research consortia) Manufacturing cooperation (i.e. original equipment manufacturing, second sourcing, manufacturing, assembly and testing agreements)

Source: Modified from Ref. [60].

nology exchanges, visitation and research participation, personnel exchanges, joint development, and research consortia. Licensing agreements involve legal permission to use patents or proprietary technology for an up-front fee and/or royalties. Cross-licensing agreements are when two or more organizations give legal permission to use each other's patents or proprietary technology. A technology exchange is a swap of proprietary technologies, which may or may not involve a transfer of money. Visitation and research participation involves the dispatching of researchers to visit, observe, and participate in the R&D activities of partners. Personnel exchanges and reciprocal programs are ongoing where researchers from two or more organizations work at each other's facilities. Joint development features two or more organizations joining forces to develop new processes or products, and research consortia are defined as the pooling of resources by direct competitors in order to pursue relatively long-term research.

Manufacturing cooperation includes original equipment manufacturing (OEM), second sourcing arrangements, manufacturing, and assembly and testing agreements. OEM cooperation involves manufacturing a product for another organization, which puts its label on the final system and handles all other activities. Second sourcing is an agreement whereby an organization is given permission to manufacture a product designed and developed by another organization as a second source of supply for customers.

Manufacturing (or fabrication) agreements involve the use of another organization's manufacturing facilities to make a product because the partner either lacks manufacturing facilities or wants to subcontract the task of manufacturing. Assembly and testing agreements encompass a process in which components and parts are manufactured elsewhere and sent to another organization where they are assembled and tested.

Other collaborative activities lead to the creation of exploitation networks. This category encompasses marketing and service cooperation, which includes procurement, sales, and servicing agreements. A commitment to purchase certain quantities of goods or services over a period of time is a procurement agreement. A sales agreement is the exclusive or nonexclusive right to sell the partner's original products in specified markets. The provision of follow-up service in specified markets is a servicing agreement.

4.2. Membership in innovation networks

Both exploitation and generation networks are comprised of a range of organizational members. That is, they are 'inter-organizational'. As noted above, three major categories of organizations have been identified in networks involved in technological innovation: firms, government agencies, and universities.

Firms are widely recognized as the key members of innovation networks. In fact, until very recently inter-firm linkages have been the major organizational focus of the network literature. Two broad categories of inter-firm networks have dominated thinking: vertical and horizontal. Vertical networks are the relationships among chains of suppliers, producers, and users that have proliferated in many technological sectors. Horizontal networks feature cooperation among firms that are competitors, rather than being involved in the innovation value chain [45]. We may have entered an era characterized by greater flexibility in terms of the ways firms develop not only horizontal and vertical network relationships, but combinations of the two. Indeed, it may be appropriate to refer to the relational (as opposed to the transactional) firm, having the option of pursuing a wide variety of inter-firm relations, including full cooperation (networking the entire innovation process) [46]. Some research indicates that successful innovation networks are likely to have at their strategic center an organization holding many of the core capabilities and having the ability to alter the overall form and nature of the web of relationships. Often large MNC appear to perform this strategic management function [47].

Having the firm at the center of the study of innovation networks makes a good deal of sense, because companies are central to most innovation processes. Everywhere in the developed world, business funds and conducts most R&D. And the primacy of business in technological innovation relates to at least three other factors: (1) they use technology directly and are likely to understand where R&D and other kinds of learning will be the most fruitful; (2) they can profit from innovation because they can integrate these learning processes with marketing; and (3) they often have unique tacit knowledge that is derived from experience. But, as noted above, we have entered an era when even these capabilities do not guarantee that any firm can go it alone in innovating complex technologies.

Thus, the structure of innovation is increasingly characterized by linkages between firms and other organizations. But for a long time, the focus on inter-firm cooperation obscured the need to analyze the broader process of inter-organizational networking [48]. One reason for greater attention to non-firm network participation seems to be the shift of governments toward encouraging public-private cooperation.

Governments everywhere have become active members of innovation networks. For example, in the US this ongoing process now includes a host of initiatives such as Cooperative Research and Development Agreements (CRADA) that link the public labs to their corporate counterparts and supply public matching funds for industry-led consortia [49]. Much more elaborate government participation in innovation networks has been underway in many other countries. Indeed, the Japanese national innovation system relies so much on innovation networks it has been termed alliance capitalism [50].

Universities have also become more active participants in innovation networks. A mix of university–government and university–industry linkages now characterizes many technological sectors. For instance, inter-organizational innovation networks have had great success in the biomedical area [51].

The example of the Hewlett Packard-Philips cardio-imaging network (in Box 1) makes the point very well. The two large multinational firms (one American and the other Dutch) needed university partners (e.g. medical expertise at Washington University of St. Louis and Iowa University) for their knowledge of cardio-imaging technology (i.e. learning by using) and their experience in dealing with the US health care system.

5. Innovation networks and the integration of globalization indicators

Networks engaged in technological innovation provide both a conceptual and empirical opportunity to link input indicators, such as R&D spending, and output indicators, such as patents, with specific organizations (i.e. network members). John Scott emphasized the need for such integration in a paper he prepared for a recent NSF workshop on strategic research partnerships (SRP):

> We have many outstanding individual efforts to assemble data about SRPs . . . However, for just one example, consider how much more understanding could be developed if the remarkable data about the incidence of SRP's over time . . . were augmented with good measures of the inputs and outputs of those SRPs . . . Multiple measures, each reflecting the particular circumstances of a type of SRP, are useful and appropriate [52].

Movement in this direction is underway on two parallel fronts. The NSF and the European Commission are funding separate, but similar, efforts to integrate alliances and patents (and in the European case, bibliometrics). The future goal is to link the projects, initially through coordination of data collection and cooperative trans-Atlantic publications and later through the outright integration of the databases. Each of these databases will extend to thousands of alliances, thousands of companies, universities, and other organizations, and hundreds of thousands of patents and patent applications over the past 20 years.

6. Toward appreciative theorizing, globalization, and innovation networks

Future efforts to understand the very complicated relationships between technological innovation and globalization would do well to follow the suggestion of Richard Nelson that understanding 'quite complex causal arguments' can be gained by using appreciative stories (i.e. told by those who appreciate the details) [53]. There has been a proliferation of such stories, but the use of any analytical categories or particular indicators inevitably simplifies and abstracts the facts regarding the roles of innovation networks as a cause and consequence of scientific and technological globalization. Nonetheless, the language and descriptions developed in the sections above seem to be true to the facts, as currently understood. An example is appreciative theorizing about social capital.

6.1. The story of the emergence of social capital

It is becoming obvious that the learning that takes place in complex innovation networks is as social as it is technical. This social dimension is most obvious in the role trust plays among organizations in network learning processes, but other norms, values, and habits underpinning appropriate behavior, such as reciprocity and a reputation for not behaving in opportunistic ways also facilitate learning. Trust and reciprocity lead to cooperative patterns of behavior that, in turn, increase the productivity of knowledge. In part, this is because much of what must be communicated and used is tacit and often demands sophisticated, intimate, trust-based organizational arrangements [54].

The networks that are based on trust and shared social norms go beyond simple market transactions or formal authority relationships. Often they confer benefits without expecting immediate benefits in return. Trust allows network members to interact in ways that generate a form of social capital (e.g. a stock of collective learning that can only be created when a group of organizations develops the ability to work together for mutual gain [55]. As technological and organizational complexity increases, and a network expands, a shared sense of values and community among network members becomes more pressing. Shared norms and a community orientation allow network members to transcend rivalry and focus on learning [56].

Relationships (it is sometimes called relational capital) make social capital important for innovation. The evolution of inter-partner cooperative relationships, based on trust and reciprocity, often replace formal controls with informal codes of conduct as effective network governance mechanisms. But how do we know this trust exists, since trust itself is difficult to observe and measure? And how do we know interactive learning takes place? With regard to trust, some researchers have focused on a factor that likely produces trust and learning as a proxy, namely repeated partnerships. A prior cooperative history, usually manifested as repeated memberships in the same alliances and other networks, is assumed to indicate a high degree of trust and interactive learning among partners [57].

Other efforts to measure social capital have focused on the possible relationship between national social capital and economic growth. For example, indicators of social capital (e.g. measures of trust and civic norms, obtained from the World Values Survey) have been correlated with average annual growth in per capita income. They found that trust and norms of civic cooperation are stronger in countries with formal institutions that effectively protect property and contract rights, and in countries that are less polarized along lines of class or ethnicity [58].

Ideas like social capital allow one to address large portions of the increasingly globalized technological landscape (e.g. the centrality of international network learning in the generation not only of many complex technologies, but also distinctive learning and innovation cultures) that are commonly ignored when one uses traditional terminology and models. This process of appreciative theorizing seems to provide some clues as to why and how increasingly globalized innovation networks are becoming the central actors within and among the most powerful economies of the twenty-first century.

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