# THE FORMATION AND EVOLUTION OF INTERNATIONAL RESEARCH ALLIANCES IN EMERGENT TECHNOLOGIES: RESEARCH ISSUES

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Access to knowledge is increasingly the driver underpinning the globalization of research. In emerging industries, such access is often managed through alliance structures between small entrepreneurial organizations. The literature on international alliances, however, is dominated by studies of "Triad" nation partners (United States, Europe and Japan) which are often larger firms, collaborating for market access motives and usually with established technologies. In addition, prior research has concentrated on particular aspects, such as motives for, and initial circumstances of, alliance formation. Analyses of the dynamic aspects in the relationship between alliance partners are more scarce. This article describes a study of an international research alliance in which the technology is in the superconductivity industry (which itself is not conforming to traditional notions of an emergent technology), one partner is from a non-Triad nation and the primary motive for formation was access to knowledge. We argue that this study has revealed gaps in current alliance research and hypothesize how some more socially based and process-related considerations could enhance the debate on knowledge-seeking alliances. © 2000 Elsevier Science Inc.

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An earlier version of this paper was presented at the Annual Conference of the Academy of Management in San Diego, August 1998.

**The Journal of High Technology Management Research, Volume 11, Number 2, pages 199–213**

**ISSN: 1047-8310**

## INTRODUCTION

> Interorganizational research contact and flows are an increasingly important element in the overall globalization of research (Howells, 1990: 504).

Interorganizational alliances and networks are a major topic of study for researchers in a wide variety of disciplines. Studies of the formation, evolution, operation and outcomes of alliances have been persued from many theoretical and methodological approaches (Gulati, 1998) which Osborn and Hagedoorn (1997) categorize in three perspectives: the economics-based view, the corporate strategy perspective and the interorganizational field perspective.

This article looks first at the literature regarding international research alliances and the globalization of technology, with particular reference to three aspects of such alliances: those in emerging industries, those involving small and medium-sized enterprises (SMEs) and those in which at least one partner is located in a small industrialized country. Second, the article outlines a case study of one particular alliance between a small U.S. entrepreneurial firm and a research institute in New Zealand, in the very newly emerging superconductivity industry. The morphology of this alliance provides an interesting insight into the place of international research alliances in a preparadigmatic industry that, even at this early stage, is exhibiting unusual growth trajectories and characteristics.

## THE GLOBALIZATION OF TECHNOLOGY

The globalization of technology is a subject that has increasingly captured the attention of researchers in recent years as the trend toward a world of borderless markets becomes a reality. However, the customary notion of technology globalization derives from monopolistic competition theories of large multi-national enterprises (MNEs), operating concentrated supply structures, resulting in global oligopolies which control market demand potentially at the expense of local players (OECD, 1992). The international behavior of these MNEs has been analyzed using foreign direct investment (FDI) models (Chenais, 1992; Florida, 1997) and patenting activity (Cantwell, 1995; Patel, 1995), usually focusing on operations in the Triad countries (United States, Europe and Japan).

Howells (1990) differentiates between the internationalization of R&D as a "demand" or "market control" mechanism, in which R&D and technology are inputs or tools which firms use to defend or develop ownership advantages and market power across national boundaries, and the internationalization of R&D as a "supply-side" necessity, as an input to competitive advantage. The demand-side perspective accommodates the prevalent role of R&D in foreign locales, that is, one of supporting offshore manufacturing investments, whereby, for example, products are modified to meet local tastes. This role perspective has been termed "global localization" but, as Florida (1997) states, "the literature has tended to overestimate the role and importance of demand-side factors (such as size of local markets) in motivating FDIs in science and technology" (p. 101). The supply-side perspective, however, generates different emphases and insights, including, for example, the notion of "tapping" into pools of scientific and technical labour (Howells, 1990: 497). Indeed, as Florida (1997) has noted, "gaining access to human capital, specifically scientific and technical talent, is the central element of the motivation and strategies of foreign-affiliated R&D laboratories" (p. 86).

Many studies elevate FDI in R&D and technological partnerships to be important strategies in maintaining competitive advantage because of the anticipated shared knowledge production (Casson, 1991; Kuemmerle, 1997; Mytelka, 1991). Additionally, the firm may also be conceptualized as a "knowledge system" (Spender, 1996; Tsoukas, 1996) competing on capabilities (Stalk, Evans, & Shulman, 1992). Coupled with the notions of the "knowledge creating company" (Nonaka, 1991; Nonaka & Takeuchi, 1995) and the "learning organization" (Senge, 1990), the implication is that competitive strategies should focus upon the ability of organizations to seek the knowledge they need from any source. The location of those knowledge sources will be more often found beyond national boundaries, and may even be located outside the dominant Triad nations. "As more and more sources of potentially relevant knowledge emerge across the globe, companies must establish a presence at an increasing number of locations to access new knowledge" (Kuemmerle, 1997: 61).

Governments often have views of technological globalization which may appear to be mutually exclusive. On the one hand, they wish to encourage both inward investment into the nation, and the internationalization of local firms. On the other hand, however, they demonstrate concern about the potential for opportunistic exploitation of local knowledge and for leakage of intellectual capital to the detriment of national competitive advantage (for example, see the introductory discussions in Chenais, 1992; Howells, 1990; Katz & Ordover, 1990; Mytelka, 1991). In such cases, "national" and "global" are seen as opposites (Archibugi & Michie, 1995). Notwithstanding this view, and with the inevitable impact of a "world economy" of production and capital being to reduce trade barriers and to proliferate international alliances, it is increasingly difficult to define a "closed" or "national system of innovation" in relation to globalization (Chesnais, 1992; OECD, 1992). The temptation toward increasing regulatory control of international activity would be seen as in conflict with the practice of withdrawal of the state from intervention in the marketplace that is occurring in many countries, and with the developing practices of fostering collaboration. "A new role for the state in collaboration with the firm is already in the making, and the strategic partnership figures importantly in this process" (Mytelka, 1991: 5), and many governments are promoting "policies that foster collaboration across borders by both the business and academic communities" (Archibugi & Michie, 1995: 121).

## Defining Technological Globalization

The variety of interpretations of the neologisms "technological globalization" or "techno-globalism" is thought to be a root cause of the lack of consistency, variability, and controversy, in research conclusions regarding the globalization of technology (Patel, 1995). Archibugi and Michie (1995) offer three different but related meanings for the concept, that emphasise or distinguish generation from the exploitation of technology, or the process by which knowledge is enhanced through collaboration. The first notion, the "global exploitation of technology" refers to the rise in the proportion of technological innovations in international markets, as a consequence of the increase in international trade. A second notion, the "global generation of technology" covers the spread of MNEs' linked R&D facilities across different countries (usually classified as FDI in R&D) facilitated by the expansion of information networks. Another notion, "global technological collaboration," involves the development of know-how or innovations by partners in different countries, in which each partner retains its institutional identity and ownership. It is the latter definition that we use in this article, for it encompasses the myriad of research alliances between organizations in different countries, in which relationships are driven primarily by a need to access knowledge. Such strategic technology alliances are, indeed, not new, and one of the most commonly cited motives for collaboration is the acquisition of scientific or technological skills or capabilities from partner organizations (Hagedoorn, 1993; Mowery, Oxley, & Silverman, 1996).

For the purposes of this research, it is necessary to offer further comment on the nature of, and motivation for, strategic technology alliances, the state and maturity of the industry, and the nature of the knowledge to be gained. In particular, the importance of tacit knowledge, and its role in shaping an alliance arrangement, must not be overlooked or underestimated (Senker & Faulkner, 1996). Tacit knowledge can be deeply embedded within the organization and, therefore, very difficult to specify or characterize in a formal performance contract such as a sale or licensing agreement. Therefore, "alliances have advantages over conventional contracts or markets for this task because firm-specific technological capabilities frequently are based on tacit knowledge" (Mowery et al., 1996: 79). In summary, the nature and motive of a strategic technology alliance will be strongly influenced by the nature of the technological knowledge to be acquired which, in turn, appears to be determined by the technology's life cycle.

## Alliances and the Technological Life Cycle Model

The dominant motive for, and mode of, the technology alliance varies according to the sector and the stage in the life cycle of the industry or its technological trajectory (Archibugi & Michie, 1995; Cainarca, Colombo, & Mariotti, 1992; Florida, 1997; Hagedoorn, 1993; Howells, 1990; Mowery et al., 1996). Firms in "mature" industries have been found to have alliance motives related to a desire to influence demand and maintain control of market structures. The structures of the resulting alliances are dominated by "non-equity" coalitions, defined as a range of contractual agreements including licenses, subcontracting, joint R&D and manufacturing arrangements, etc. (Cairnarca et al., 1992). Such collaboration structures reflect a variety of strategies, which include the fostering of producer–user interactions, and the forging of alliances between aggressive competitors with "collusive" goals to "scrape the barrel of oligopolistic rents" (Cairnarca et al., 1992: 52).

In contrast to firms in mature industries, or those with mature technologies, firms involved in emerging technologies (e.g., biotechnology), that are generally very dependent on basic science, have been found to be motivated by gaining access to human capital and scientific and technological talent and knowledge (Florida, 1997). Cairnarca et al.'s (1992) model "posits that propensity towards cooperation will be high in the introductory stage, where agreements (mainly of an equity nature) are used by firms to cope with market and technological uncertainly, to lower mobility barriers and risks of sunk costs, and to obtain high adaptive efficiency" (p. 60). Equity agreements are defined as bringing about some change in the firm's ownership structure or the setting up of a joint venture owned by the two partners. Archibugi and Michie (1995: 128) attribute the popularity of such agreements in emerging technologies to the fact that the new technological paradigms which have developed, are more knowledge-intensive than in the past, and that "successful innovative performance relies on the capability to acquire information on what is going on in the field." This is particularly so "for industries in their infant stage" where the need is "to acquire information, and therefore also to share it" (Archibugi & Michie, 1995: 129).

## Access to Knowledge and Learning

The firms' strategies and motivations for technological strategic alliances are portrayed in the literature, as a number of "sensing" metaphors which infer that the organizations are "looking" and "listening" for knowledge. The establishment of alliances could serve the purposes of creating "listening posts" (to monitor the capabilities of domestic firms) or knowledge "generating stations" (which generate new scientific and technical knowledge) (Florida, 1997: 89). Affiliate R&D facilities are framed as "observation posts" that fulfil the desire to "have a window on foreign science" (OECD, 1992: 225). R&D "scanning" agreements are defined as non-equity relationships that aim at monitoring promising fields of science and technology (Cairnarca et al., 1992).

However, these metaphors imply that the firms appreciate what knowledge they require or, at least, can identify and evaluate potentially useful knowledge which they can learn and utilize. Such organizational skill indicates the firms have metaknowledge, which is "an appreciation of what we know and what we do not know" (Russo & Schoemaker, 1992: 8). Metaknowledge reflects a higher level of learning expertise which also encompasses an ability to synthesise new or emergent knowledge with existing knowledge or frameworks (Davenport & Davies, 1998). The ability of an organization to exploit external knowledge is dependent on its absorptive capacity (Cohen & Levinthal, 1990; Mowery et al., 1996). Prior related knowledge in the domain of the alliance is viewed as critical to learning, in that such knowledge "confers an ability to recognize the value of new information, assimilate it, and apply it to commercial end uses" (Cohen & Levinthal, 1990: 128). Prior related knowledge in the form of internal expertise is probably an indicator of why firms tend to seek and establish alliances with partners that have overlapping technological capabilities. As a corollary, a lack of internal expertise, and thus reduced absorptive capacity, is thought to be behind the volatility of some technological alliances based upon R&D scanning agreements, even though the "intent to learn" is present (Mowery et al., 1996). As the development of personal and professional trust between partners, usually via personal interaction between partners' scientists, technologists and managers, has also been found to be important for shared learning between firms (Dodgson, 1993, 1996), it would be expected that cultural and geographical "distance" between partners could also hinder access to tacit knowledge.

### Other Partner Parameters

Technological overlap is not the only characteristic found in studies of partners in strategic technology alliances. Studies of MNE alliances have shown that the partners are usually of equal size and stature, with complementary assets and operating in different market segments but drawing upon common generic technologies (OECD, 1992). Small and medium-sized enterprises (SMEs) have innovatory advantages in alliances, derived from their necessary experiences with external networks and their inherent organizational flexibility. However, problems arise in collaboration, particularly for the smaller partner, when there is a mismatch in size and resources between the alliance partners (Rothwell & Dodgson, 1991), and when cultural and institutional rigidities exist in the large partner (Lawton Smith, Dickson, & Lloyd Smith, 1991). Further parameters include the "community" to which the partners belong, for example, whether they are a business or academic institution, having different propensities to transfer know-how (Archibugi & Michie, 1995).

Lastly, the partners may be resident in countries with quite different technological resources, infrastructures and regulatory frameworks. Scientific organizations in countries with a smaller scientific community have a higher tendency toward collaboration (Archibugi & Michie, 1995). Smaller industrialized countries, defined as having populations of less than 25 million (Walsh, 1988) with weaker technological bases, "may have a particular interest in, and face particular constraints with respect to, international technological cooperation" (OECD, 1992: 232). Small industrialized countries are more dependent on foreign trade than larger countries and, therefore, "factors which increase the propensity of a country to turn towards the world market must be favourable" (Walsh, 1988: 38). Yet very little research has been undertaken on cooperation involving small firms and small countries (OCED, 1992). It has been postulated that the chance that a small country organization has of breaking into an international market via an alliance "is likely to depend on its bargaining power; this is related to its experience and the degree of dominance it exercises in its market, the appropriability of its technology, the extent to which successful innovation depends on complementary assets and whether the technology is dominated by a dominant design or by technological flux" (OECD, 1992: 232).

## THE RESEARCH PROJECT

The case study reported in this article forms part of a larger research project applying qualitative, case-based approaches to the evaluation of scientific research. The methodology used is based upon research approaches used extensively in such applied social sciences as education and anthropology (Denzin & Lincoln, 1994; Wolcott, 1994). This approach was chosen over more traditional approaches to research evaluation (for example, peer review or bibliometrics, or economic evaluation instruments such as cost-benefit analyses), in order to generate a richer description of the more indirect or intangible impacts and outcomes of the scientific research under study (Kostoff, 1993; Link, 1996).

The historical description or case study was developed from 20 semi-structured interviews carried out with participants and collaborators in the superconductivity research programme at Industrial Research Limited (IRL): 11 scientists; five research managers; two managers from the New Zealand's public research funding agency, the Foundation for Research, Science & Technology (FRST); one intellectual property lawyer and one manager from the international alliance partner, SuperWire Corporation (SWC)[1], facilitated by electronic mail. The transcriptions of the interviews were coded using the programme NUD*IST™ (Richards & Richards, 1994). The interview data was supplemented with secondary material gathered from the general literature on developments in superconductivity since 1986, and information from scientific and company internet sites. The full interpretation of the case study and the evaluation of the research outcomes form the basis of a master's research thesis (Miller, 1998). Material relating to the research alliance between IRL and SWC was selected for further interpretation.

### Synopsis of the Case Study

Superconductors are perfect carriers of electricity, but the widespread implementation of this technology in practical applications has been hampered by the extremely low temperatures at which the previously known superconducting materials operated, necessitating the use of expensive liquid helium (4K or −454°F). However, in 1986 the first "high temperature superconductivity" (HTS) materials were discovered, which required liquid nitrogen as a coolant to operate (77K or −320°F). Considerable excitement was generated in laboratories around the world, as well as in the industries, such as the energy, computing and communication sectors, that stood to be revolutionized by the use of these materials.[2]

Toward the end of the first decade following the discovery of HTS materials, the first prototype applications began emerging. In March 1997, one of the first pre-commercial HTS applications, a demonstration ion-beam steering magnet, attached to a particle accelerator, was unveiled in Wellington, New Zealand. The next day, Asea Brown Boveri launched a demonstration HTS transformer at a Geneva substation. The wire for both of these products was produced by the SWC organization from an HTS compound discovered and developed by New Zealand scientists at IRL. SWC, a company formed in 1987 by four professors based on their proprietary HTS wire production technology, first learned of IRL's material, the most suitable for turning into HTS wire, from a patent battle in the U.S. courts. In 1992, a five-year agreement was signed between IRL and Superlink Developments (a joint venture between IRL and New Zealand's major electricity generator, ECNZ) which gave SWC strategic access to the HTS compound, but also included a significant ongoing technical commitment to the development of other promising HTS materials. In 1997, a further agreement was signed, cementing increased commitment from SWC to its New Zealand-based global research partner, and extending the technical relationship to include research on SWC's core HTS wire processing technology.

## THE MORPHOLOGY OF A RESEARCH ALLIANCE

The superconductivity "industry" has displayed characteristics of both preparadigmatic and paradigmatic technologies (Teece, 1986). For example, in the preparadigmatic stage, there is "no single generally accepted conceptual treatment of the phenomenon" (Teece, 1986: 287), which is certainly true of the theoretical frameworks used to build understanding of the superconductivity phenomena (Chu, 1996). However, the emergence of dominant designs and commercial prototypes could signal the onset of the paradigmatic phase and the "lock-in" of the technology (Arthur, 1989; Teece, 1986). For example, no new HTS materials were discovered in the five years between 1993 and 1997, which resulted in the current wire materials, particularly SCW's wire (using IRL's HTS material) becoming the favoured standard in the emerging industry prototypes. Furthermore, the speed with which HTS prototypes were emerging appeared to be further "locking-in" the use of these current wire materials in manufacturing options as more firms invested capital into production facilities, creating seemingly irreversible barriers to entry for future HTS wire materials.

It is likely that this mix of preparadigmatic and paradigmatic traits was a characteristic of the development trajectory of this technology. Despite the fact that the phenomena of high temperature superconductivity was not yet fully understood, the promise of applications had existed for many decades causing significant anticipation in the potentially affected industries. Subsequently, with the discovery of the first HTS materials, the major players in, for example, the energy industry moved very rapidly into a developmental phase of research, in parallel with the theoretical research.

The superconductivity industry was also characterized by a myriad of alliances, particularly between the large MNEs and entrepreneurial HTS firms. This is probably another reflection of the steep trajectory of the technology, in that the intense "race" to produce the first prototypes, and to set standards, prompted organizations to search for knowledge from any source as "learning via alliances and networks is faster since it may not call for individuals and units to unlearn traditional routines" (Osborn & Hagedoorn, 1997: 270).

The SWC/IRL alliance also displayed some interesting characteristics (Table 1). From an analysis of the attributes of the "home" countries, there would seem little prima facie reason for a U.S.-based firm to ally itself with an organization in New Zealand, a small industrialized country. For example, the New Zealand domestic market is not an attractive size, however, its population's demographics and their propensity to be early followers in the uptake of new technologies have attracted MNEs to use New Zealand as a "test-market" for new technologies. Furthermore, New Zealand's manufacturing base is very small. However, it has an international reputation for developing niche products in industries such as electronics and software. Additionally, the scientific and technological infrastructure is insignificant in comparison with the resources available to U.S. firms at home.

It is therefore most plausible that, as would be expected in an emergent industry, the U.S. firm allied for supply-side considerations, that is, access to scientific talent and knowledge. The characteristics of the two organizations indicate that, despite the differences and underpinning resource bases of both countries, SWC and IRL were relatively compatible alliance partners, a factor which should enhance the exchange of tacit knowledge. Scientists and engineers with superior technological training, focused on superconductivity applications, continue to populate both organizations, facilitating the matching of absorptive capacities and enhancing the learning potential of the alliance. In addition, their organizational goals meshed, with

**TABLE 1**
**The Morphology of a Technological Alliance**

| | *Attributes* | *SWC in the US* | *IRL in NZ* |
|---|---|---|---|
| Country | Population | 263 million | 3.6 million |
| | Technological base | Strong | Relatively weak |
| | Industrial strength | Strong | Relatively weak |
| | Export markets | Extensive, broad, easily accessible | Targeted, niche, distant from main markets |
| | Access to venture capital | Very good | Poor |
| | Scientific base & resources | Extensive | Limited, pockets of excellence |
| Superconductivity | Science | Many teams in universities and commercial laboratories | One main collaborative team based at IRL |
| | Industry | Pre-commercial, many players—entrepreneurial firms and MNEs | No dedicated HTS companies (but SMEs in related niche manufacturing in electronics, magnets and semi-conductors) |
| Organisation | Type | Entrepreneurial technology and emerging manufacturing firm (Nasdaq listed) | Crown Research Institute (CRI), government owned but structured and operating as if a company |
| | Industry | Energy applications of superconducting materials | Broad range of research to support industry in three areas: energy, manufacturing and natural products. |
| | Size (full time equivalents) | 130 | 350 |
| | 1997 Revenue[a] | US$7.2 million | NZ$42 million |
| | 1997 Profit[a] | (US$10.4 million) | NZ$2 million[b] |
| | Superconductivity expertise | Engineering, processing, energy applications and manufacturing | Materials science and processing to early prototypes |
| | Intellectual property | Processing patents and licenses | Several key materials patents |
| | Reputation | International leader in first energy applications | International in the basic science |
| | Resources | Many sources, government and private research contracts | Few sources, mainly government funding |

[a] 1 NZ $ = 0.57 US $ in 1998.
[b] The New Zealand CRIs have two ministerial shareholders and, generally speaking, are driven by broader performance indicators than purely financial motives, with any profit reinvested.

SWC wishing to access the key material for wire production, while IRL's wish was not only to further the research, but also to explore commercial application opportunities, for example, through SWC's other alliances, that were not available in New Zealand. Thus from the IRL side of the relationship, there were elements of demand-side parameters in the alliance. Although not a production company, IRL, as a government-owned institution, continues to be charged with performing research for the benefit of New Zealand. Potentially, the most direct way in which IRL could accomplish this, with the superconductivity developments, was to provide access for New Zealand firms to the emergent industry and the HTS wire via its alliance with SWC. Thus SWC and IRL are recognised to have had co-specialised complementary capabilities or assets (Teece, 1986). In short, SWC needed IRL's material for its wire production, while IRL could not successfully commercialise its technology without a firm such as SWC.

## The Evolution of the Alliance

The primary reason for SWC to enter into this alliance in 1992, was the strategic access to the IRL patent, in order to capture the license for the HTS wire material. This form of ex-post agreement (Katz & Ordover, 1990), that is, buying the already completed results of scientific research, is an example of a non-equity agreement, which is more typical of agreements in more mature industries. However, it is not surprising that the agreement was primarily non-equity in nature, as a licensing agreement would carry less risk than an equity agreement, and provide an opportunity for the partners to learn about each other.

As the SWC and IRL teams worked together over the years, a significant amount of trust built up in the relationship. The second agreement put more emphasis on future research collaboration, particularly regarding SWC's core processing technology. This shift to a primarily ex-ante research agreement, that is, buying the future results of research in advance, indicated a substantial evolution in the relationship between the two partners. The alliance remains, however, primarily non-equity in nature, in contrast to that predicted in the literature for emerging technologies.

The collaboration has evolved from an alliance based on access to a patent, to an alliance based on access to scientific talent, that is, one based on trust and faith in the skills and ability of the IRL researchers. The IRL researchers earned the trust and respect of SWC, so that the perceived risk profile of the alliance has favorably changed from SWC's perspective. In turn, IRL has become involved in SWC's core proprietary research, and will thus be able to learn about the leading process technologies in superconductivity. The evolution of the alliance indicates that the co-specialization of the assets has increased as the relationship developed. IRL has become more integrated into SWC's research effort and SWC was increasingly exploiting IRL's expertise.

In effect, the alliance evolved from being an arrangement that enabled access to embedded organization knowledge to become an embedded social tie between the two organizations. This embeddedness eventuated because of the development of trust in the relationship, despite the geographical distance, and the resultant depth of co-specialization or mutual dependency of assets. In his study of embedded social ties, Uzzi (1997: 43) found that "trust promoted the exchange of a range of assets that were difficult to put a price on but that enriched the organization's ability to compete and overcome problems" and that "information exchange in embedded relationships was more proprietary and tacit" (Uzzi, 1997: 45). While Uzzi's (1997) study focussed on social ties in retail sales, which would have had completely different morphologies from the subject alliance of this study, the embedded social tie of this relationship between the two highly specialised research and technology organizations was found to exhibit similar trust traits.

## DISCUSSION

High temperature superconductivity is a fast moving early technology in which prototypes are proliferating, standards are becoming set and manufacturing capability is being "locked-in" to current states of the technology. With commercial products likely to emerge in the near future, we propose that the successful use of alliances is likely to be a factor in determining which organizations survive into the paradigmatic stage of the industry.

**Hypothesis 1:** Organizational survival in the emerging superconductivity industry will be positively related to the quality of alliances in which the organization is involved.

While this hypothesis will not be able to be tested until the industry has matured substantially, early signs suggest that alliance usage is an important characteristic of the industry. Alliance quality will be a multi-faceted variable. From one perspective, measuring quality will involve some judgement on the outcomes and success of the alliances as it is likely that the sheer number of alliances will not necessarily be a survival indicator. Given the earlier discussion of the global nature of knowledge generation, alliance quality will also need to include, for example, coverage and penetration of the appropriate international research base in order the capture and exploit, in a timely manner, the necessary skills and knowledge.

Alliance quality equates not only to success measures, but also to effectiveness measures. Essentially this hypothesis posits that an organization's survival will be partly dependent on the social capital of its alliances (Walker, Kogut & Shan, 1997). In other words, alliance quality will also be embodied in the structure of contacts in the network of alliances and the resources each partner holds and shares through the alliances. Such networks have been observed extensively in the biotechnology industry as facilitating industry growth, so it might be expected that similar networks would be necessary for the emergent superconductivity industry.

Where critical knowledge is deeply embedded, and speed and urgency may be a key to competitive advantage, flexibility must be built into a multi-faceted alliance to manage risk for both parties without constraining opportunities for learning. In this case study in the superconductivity industry, the compacted trajectory of the technology's development has necessitated the use of a predominantly non-equity relationship which is counter to that predicted for a pre-paradigmatic industry. Non-equity alliances are more typical when the risk to each party is seen as low, for example, with more mature technologies and in market or demand driven alliances. While, in this case, the alliance had remained non-equity in character, the reduction in perceived risk is inherent in the move from an ex-post to an ex-ante research agreement. We suggest that the development of mutual trust, and recognition of the co-specialised nature of the partners' tangible and intangible assets, has offset any otherwise adverse risk profile.

**Hypothesis 2a:** Alliance risk in the superconductivity industry is related in inverse proportion to the level of mutual trust.

**Hypothesis 2b:** Alliance risk in the superconductivity industry is related in inverse proportion to the level of co-specialization of assets.

The identification and measurement of interorganizational trust is an inherently difficult research proposition (Tyler & Kramer, 1996) but considerable effort has been made by organizational researchers to develop suitable variables in recent years (for example, Das & Teng, 1998). The level of co-specialization of assets could be viewed as one measure of the evolution of trust as, if this co-specialization is carried out in a purposive manner, then trust is likely to be a catalyst for such a strategy. Assessing increased co-specialization is likely to be more achievable for tangible than intangible assets. For example, increased co-specialization in tangible production assets would be observed if one organization decreases manufacturing overlap with the partner in order to more efficiently make use of the overall alliance assets. However, observing where one partner reduces an intangible asset, such as part of a tacit skill-base, in favour of the partner's capability, may be less obvious.

As the co-specialization deepened in this case study, the mutual dependency of the partners caused the relationship itself to become an embedded social tie for the organizations. It has been argued that embeddedness can derail performance, by "making firms vulnerable to exogenous shocks or insulating them from information that exists beyond the network" (Uzzi, 1997: 35). However, we propose that it is unlikely that an embedded research alliance, such as in this case, would be a threat to organizations acting in a preparadigmatic industry, in which fluidity and the search for critical knowledge underpins all economic activity. In the worst-case scenario, the fact that the alliance is non-equity in nature would give the alliance partners the capacity to more easily dissolve this relationship should any detriment to performance, or a more attractive opportunity, become apparent.

**Hypothesis 3:** Social embeddedness will reduce the higher inherent risk of non-equity knowledge seeking alliances in the superconductivity industry.

Assessing the impact of the level of social embeddedness of the partners on the alliance risk also would not be an easy research task, but should probably include the study of failed alliances. The demise of an alliance may expose the counterfactual to the hypothesis, that is, it could be assumed that the risk in such alliances became too great to be moderated by social embeddedness. With the assumption that embeddedness will be reflected in the manner of partner interaction, a comparison of management procedures in various alliances may uncover differences that could reflect embeddedness. For example, it could be assumed that embeddedness would be inversely related to the level of use of control and compliance procedures (rather than the existence of such procedures, which would solely reflect a lack of embeddedness at the beginning of an alliance).

## CONCLUSION

The evolution of new technology is increasingly reliant on the use of alliances as vehicles for accessing essential embedded tacit knowledge. While this article presents a case study on one alliance, it highlights some gaps in the current debate on the emergence of new technologies on a global scale that are ripe for further investigation.

Our search of the literature uncovered the geographical and organizational size limitations of current published research. First, in a technology with such a compacted trajectory, the critical knowledge could be located in any part of the globe, including small industrialized and developing countries, yet most debate focuses on alliances between Triad partners. Second, the international research alliance literature focuses mainly on MNEs, often with demand-side objectives. Yet in any pre-paradigmatic technologically based industry, it is often the entrepreneurial SMEs that are generating most of the economic activity and determining the technological trajectories, with supply-side alliances aimed at gaining access to critical but embedded tacit knowledge. Further investigation of such supply-side alliances would be a worthy addition to the current debate on the globalization of technology.

Our study of one such international supply-side alliance in the superconductivity industry has also uncovered the importance of studying the evolution of alliances, rather than just the alliance initiation or failure stages. First, the traditional categorization of alliances in emerging technologies and pre-paradigmatic industries do not seem to entirely apply in the case of superconductivity. Non-equity alliances may be becoming more prevalent even though the risk of these knowledge-seeking alliances is perceived to be high. We have hypothesized that social processes, such as the development of trust and social embeddedness between the partners, which can, in turn, result in increased co-specialization, allow the risk of such alliances to be reduced. Initial suggestions for future empirical tests to explore these hypothesized relationships have been made in the hope that a more process-based understanding of international knowledge-seeking alliances in emergent technological industries might evolve.

## NOTES

1. For the purposes of this study, the identity of the American alliance partner has been changed. SuperWire Corporation is not the real name of the organization.
2. For a comprehensive report of the HTS discoveries, see Hazen (1988). For an introduction to superconductivity, see Chu (1996).

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