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A Knowledge Asset-Based View of Technology Transfer in International Joint Ventures

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Massachusetts Institute of Technology
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The International Center for Research on the Management of Technology

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Abstract

A knowledge asset-based framework of technology transfer is proposed, illustrated by examples from studies of two international joint ventures. The framework depicts the organization as a collection of embodied knowledge assets. Differences between firms result from the different combinations of embodied knowledge types that are used to accomplish the same ends. Technology transfer is the transfer of embodied knowledge assets between organizations.

Four concepts, Transfer Scope, Transfer Method, Knowledge Architectures, and Organizational Adaptive Ability describe important aspects of the transfer process. Transfer scope describes the extent of embodied information being transferred. Transfer method describes the approaches used to transfer the technology. Knowledge architectures describe types of knowledge assets the firms possesses, and the relationships between them. The organization's ability describes its ability to change its architectures over time. Technology transfer involves selecting the proper transfer method given the demands of the transfer scope, working within the constraints of the existing organization's architectures, and its adaptive ability.

1.0 INTRODUCTION

Increasingly, firms are turning to cooperative agreements with other firms to share knowledge, develop products, exploit markets, or concentrate power, (Friedman, Berg, et al., 1979; Hamel, Doz, et al., 1989; Harrigan, 1988; Kogut, 1988; Ouchi and Bolton, 1987). This trend has been accelerated with increasing global competition. With cooperative work inevitably comes the necessity to transfer technologies or knowledge from one place to another. This is challenging when the technologies being transferred are part of the on-going operations of a firm, such as production technologies. This paper addresses the problem of how to transfer technologies between firms with different, yet mature technological bases. A framework is developed which identifies important considerations in the technology transfer process. Implications of the framework for management are discussed.

2.0 PAST STUDIES

Studies of innovation adoption and technology transfer often examine factors such as the attributes of the technology, of adopting organizations, and the methods used in transfer. Innovation attributes have been extensively studied, and the research has examined how specific technology attributes affect the adoption process. Examples of such attributes include cost (Ettlie and Vallenga, 1979), innovation complexity, relative advantage, trialability, and observability (Pelz, 1985; Rogers, 1983), reliability, scientific status, importance, communicability, and flexibility (Tornatzky and Klein, 1982). The results of innovation attribute studies usually suggest relationships like a negative correlation between innovation cost or complexity and the innovation's likelihood of adoption (Tornatzky and Klein, 1982). In a review of 75 innovation adoption studies, Tornatzky and Klein summarized 30 different measures of innovation characteristics. Their meta-analysis of the research suggests that only innovation complexity, relative advantage, and compatibility conclusively affect the rate of adoption of innovations (Tornatzky and Klein, 1982).

Other studies examine the influence of adopting organization attributes on the adoption of new technologies. Adopting organization attributes include size, centralization, formalization (Ettlie, Bridges, et al., 1984), organizational complexity (Pelz, 1985), centralization of decision-making, exposure to external information, managerial attitudes (Carter and Williams, 1959; Dewar and Dutton, 1986), regulatory or union influence (Ettlie and Vallenga, 1979), and risk-taking attributes (Ettlie and Vallenga, 1979). The results of these studies are similar to those of the organizational contingency theorists, who suggest that organizational attributes like centralization, formalization, and complexity must correspond with the nature (complexity, radicalness, etc.) of the new technology for the transfer or adoption to be successful (Burns and Stalker, 1966; Lawrence and Lorsch, 1967; Ettlie, Bridges, et al., 1984; Dewar and Dutton, 1986).

Yet other studies discuss the procedures and methods used in the transfer of technology, often without mention of the characteristics of the organization or the technology. This literature generally focuses on the creation of some form of linkage between the transferring and receiving organizations. Organizational linkages can be hierarchical or structural (Nadler and Tushman, 1988). Hierarchy is the simplest of linking mechanisms and functions by formalizing the reporting or communication relationships between the sources and recipients of technology or information (Lawrence and Lorsch, 1967). Structural linking mechanisms link people and groups together non-hierarchically, using liaisons, personnel transfers, informal roles, transfer groups, and project structures (see Allen and Cooney, 1971; Roberts and Frohman, 1978; Allen, Katz, et al., 1988; Jervis, 1975; Roberts, 1979; and Larson and Gobeli, 1988). The common element in these studies is that information or technology is integrated or transferred through the use of special roles or structures.

There is generally little overlap between studies that discuss the process (methods used) and the content (the attributes of the technology or adopting organization) of technology transfer. There are some exceptions, however. Some studies suggest that as the complexity of the technology increases, more "intensive" or integrated project structures or relationships with other organizations are required (Allen, Tushman, et al., 1979; Kazanjian and Drazin, 1986; Killing, 1980). Other studies suggest that it is not just the organizational structure that must match the characteristics of the technology, but actually that problem-solving approaches used by the organization must be dictated by the way the new technology relates to the organizational structure (Tushman, 1978; Tyre and Hauptman, 1991). A similar group of studies implies that the firm's relative competency in a particular technical area will determine what types of technology may be transferred, and how the firm will proceed with the transfer (Attewell, 1992; Egelhoff, 1991; Hall and Johnson, 1970).

There are clearly several areas in technology transfer research that need further study. First, while technologies and organizations do have general characteristics that affect adoption, the influence of the interdependencies between the technology and its organizational context has often been neglected, even though it is also likely to affect adoption. More needs to be understood about the relationships between a firm's core competencies and its ability to adopt new technology. For instance, does the possession of a core competency necessarily imply that a firm will be able to adopt a new technology more easily than another? Finally, more systematic study of technology transfer methods is needed, especially where multiple and diverse technologies are being transferred between firms.

3.0 CURRENT RESEARCH

A research project is currently underway to identify factors involved in the successful transfer of technology. A variety of methods are being used to understand the process, including interviews, archival data, and longitudinal survey data. Two partnerships are currently being investigated. One is a joint venture (JV), Polychem, involving three companies in a chemical-related industry. The product manufactured by the partners is sold to technically-sophisticated industrial customers who process the product further before it goes to final consumers. The companies are located in Germany, Japan, and the U.S. The German and American partners had been involved in mutual technology transfer prior to the formation of the present joint venture. The objective of this joint venture is to establish regional manufacturing capability for potentially all of the product types currently offered by each partner. Each site will also maintain an R&D center of excellence which will be a lead research center in the JV for certain areas of product and process technology. Part of the present effort includes the creation of a new production line in Germany to support both German and Japanese product lines. The second partnership has been in place for much longer, and is a collaboration between two steel companies, one located in Italy

(Italsteel) and the other in Japan (Japan Steel and Foundry, or JSF). In this agreement, JSF has provided process technology and organizational expertise to Italsteel.

The data are being collected through interviews and visits to sites in the United States, Germany, Italy, and Japan. The interviews are both open-ended and semi-structured, and last between one and four hours. Informants are interviewed if they are involved or have been involved in the transfer of technology or information from one site to another. At Polychem, nineteen engineers, scientists, or managers have been interviewed in Germany, including three employees from the Japanese partner and two employees from the American partner. Twenty three engineers, scientists, or managers have been interviewed at the American site (including one employee from the Japanese partner and one employee from the German partner). Twenty eight engineers, scientists, or managers have been interviewed at the Japanese site, including one engineer from the American partner. Sixteen engineers or managers were interviewed at Italsteel in Italy. Several of these people have been interviewed more than once over a period of more than two years. The interview data is used to develop brief case histories of the transfers of individual technologies, and to identify that attributes of the participating organizations.

4.0 OBSERVATIONS

For the purposes of this study, technology is considered to be any form, material or social, in which knowledge has been embodied. This includes hardware, software, products, rules, procedures, organizational structure, and know-how or technical expertise. Many forms of knowledge are important to the functioning of the organization. Knowledge about repetitive actions is codified into forms which reduce processing effort or cost in the future (Nelson and Winter, 1982). Rules of thumb become operating procedures, hand tools become machine tools, and new organizational groups are created to perform specific functions done previously on an ad hoc basis. All of these forms constitute knowledge that has been codified into forms which make effort more efficient or less costly. A broad definition of technology is important in discussing technology transfer, because not everything that is transferred between two firms is necessarily hardware. In fact, our observations of technology transfer activities between JV partners suggests that the transfer of physical hardware constitutes only a fraction of all the different forms of embodied information that are shared.

4.1 Transfer Scope

The large variety of "technologies", or forms of embodied knowledge, used by organizations is transferred between them, and this range of knowledge is captured in a concept called **Transfer Scope.** The scope of technology transfer is determined by how much and what type of a technology a firm seeks to acquire from another source. The "how much" portion of transfer scope is how much information is embodied in the technology. The "what type of technology" portion of transfer scope is really the form in which knowledge has been embodied. The two are actually related since a form of technology such as a piece of manufacturing equipment will almost always embody more information than could an alternate form such as a fax communication. More detailed descriptions of transfer scope follow, with the order of presentation implying an increase in transfer scope.

The most simple form of knowledge transferred between organizations is **general knowledge** about a technology, process, or capability. The transfer of a general awareness of another partner's capability would not allow the recipient to reproduce for itself its partner's capability, but it would allow it to determine whether or not a cooperative relationship would be appropriate, or what type of technology is available for transfer. Typical questions that might be asked to acquire general knowledge might be: "What type of technology do you use to accomplish this task?", "How effective is it?", or "How does it compare with the technology that we use?". Acquiring general knowledge about a partner's technological capabilities is often the first step in transferring a technology from one site to another, and is usually followed by the transfer of what we term **specific knowledge.** The transfer of detailed or specific knowledge is the most common form of transfer observed at the Jvs. Specific knowledge is that knowledge which provides a firm the ability to reproduce (although perhaps with some effort) another's capabilities. Specific knowledge is an accurate codification, to the extent that it is possible, of the knowledge underlying the technology in question.

The example of the effort to create a new Polychem production line in Germany illustrates these two types of knowledge. The effort was started when the Japanese partner wanted to begin producing its product line in Europe. An investigation of the German operations revealed that an existing production line there did not have sufficient capacity or capabilities to produce both the German and Japanese product lines. Based on that knowledge, it was decided to construct a new line there. Much more detailed analyses took place in the design process and several technologies were transferred into the production line. In the process, volumes of detailed drawings and production data were exchanged through the mail by fax transmission, and compared and contrasted in joint meetings. The general knowledge of the types of processes used at each location, and their gross performance characteristics was not sufficient during the equipment design process. In many cases, gaining a general knowledge of a partner's capabilities in certain areas showed that little would be gained by trying to implement one partner's technology at the other's site. In instances involving very complex technologies, however, specific knowledge which involved detailed specification was the only way to accurately assess the capabilities of a particular technology.

Hardware is knowledge or experience in production or products that has been embodied into a tangible artifact. This includes machine sub-components, parts, software, the machines themselves, products, and entire production lines or plants. The transfer of hardware has an advantage over other forms of knowledge in that hardware can be physically re-located and its operating characteristics generally remain the same in different environments (unless some modification is made by the recipient). Transfers of hardware may be accompanied by manuals or operating procedures, but they are not covered in this category. The reason for this is that a recipient firm may already have that operating knowledge, gained through its own operations, and is transferring hardware merely to parallel a partner's capability. Conversely, a firm may already have hardware similar to that of its partner, and just seeks to adopt new operating procedures without also transferring hardware. There are several examples of hardware transfer in both the Polychem and Italsteel JVs, although in many cases, where a local producer could fabricate the equipment, only the designs have been were shipped. This allows the recipient greater freedom in tailoring the hardware to the requirements of its particular production environment.

Finally, a significant area of transfer activities involved that knowledge that is embodied in people's actions and interactions, and which we refer to as **behaviors**. Best practice behaviors are seen as a potential source of significant improvement in manufacturing performance. One American Polychem manager estimated that fifty percent of the potential improvement in his production yields could result by transferring operator behaviors from the Japanese partner. It takes the operators at the Japanese Polychem facility about one half the time to start up a production line as it does their American counterparts. Italsteel is also trying to transfer Total Quality Management (TQM) problem-solving expertise from its Japanese partner. It transferred several engineers to Japan with the express purpose of learning TQM problem-solving techniques so that they could teach them to colleagues and subordinates upon returning to Italy. Behaviors are not trivial items to transfer, however. Often, they are captured in the tacit actions or routines of workers. They may be social phenomenon that involve large amounts of commonly-understood knowledge, as is found in communities of practice (Brown and Duguid, 1991). For this reason, the behaviors category involves greater transfer scope than the other categories previously mentioned.

4.2 Transfer Methods

The methods and activities used in the transfer process are grouped in a category called the **Transfer Method**. There are three basic approaches to transferring information. They are through the physical transfer of embodied knowledge, through communication in various forms, and through the use of organizational integrating mechanisms. The physical transfer of embodied knowledge amounts to little more than shipping an item from one place to another, so it won't be discussed at length. The communication methods will be discussed under the headings of Direct/Indirect Communication, and Personnel Transfers. Integrating mechanisms will be discussed under the headings of Roles and Bridges. The selection of a specific transfer method will of course be determined by a variety of factors, including the scope of the transfer, the nature of the technology involved, and the relative expertise and resources of the organizations involved in the transfer. Implicit in the discussion of transfer method is that there is a range in the effort expended in using different methods, and that some methods will naturally require more effort than others.

Also implicit is that there is a range in the information carrying-capacity of each method, and that the more simple methods will not be able to convey as much information as the more intensive methods.

4.2.1 Communication Methods: Direct and indirect communication encompasses the most basic types of communication behaviors, including telephone conversation, mail correspondence, video conferences, and electronic mail and fax transmissions. Direct communication uses the spoken medium and may include telephone conversations or video conferences. **Direct communication** occurs in real time and allows for immediate feedback between the participants so that understanding of concepts can be assessed. Unfortunately, direct communication is limited in the amount of information it can communicate.

Indirect communication, on the other hand, takes place through the written word, graphic representation, or a material object. It is able to transfer a lot of information (one "picture is worth a thousand words"), but provides no immediate feedback to indicate whether or not the receiver understands what is being communicated. Indirect communication is especially useful in conveying information which measures or quantifies the identifying characteristics of a technology. For this reason, however, it is limited to types of knowledge that are explicit, and cannot easily convey tacit knowledge. Using written language to communicate also is helpful where there is a difference of native tongues. Many engineers read a second language better than they speak it, especially when they aren't under pressure to respond in real time. Direct communication is somewhat better than indirect communication at building interpersonal relationships and conveying enthusiasm between people, although it is still an arm's length relationship that is being encouraged.

At the Polychem joint venture, much of the technical information flows between the sites by direct/indirect communication methods. Once two partners have agreed to an exchange around a specific technology, detailed lists of questions about the technology are exchanged between the partners. The respective experts at each facility provide answers to these questions for their overseas colleagues. The detailed answers are traded, and follow-up questions are then asked, usually by fax or mail. All of this activity may culminate in a visit to a partner's site for intense discussion about the technology (at which time some information is transferred through the exchange of hardware, products, or materials samples, and by joint problem-solving). The fax has become a preferred method of communication at Polychem because of the three different languages spoken by the partners, and because they can be sent at all hours of the day or night without regard for the local time of the destination. The advantage offered by the fax is that text can be replaced by numbers and figures, which have universal interpretability to those who speak the common technical language. They are beginning to use video conference technology, which potentially offers all the advantages of the short-term visit (including a walk through the plant with a portable camera) but at a fraction of the cost. While some are excited about the potential of the system to facilitate inexpensive technology transfer, others, especially technical people, are somewhat less sanguine. Several suggest that a video conference is probably better for managers than for specialists because it is difficult to cover technical issues with much depth. Much of an understanding of a partner's production technology must come from observing it in action, which involves several of the five senses operating at once.

When using direct or indirect communication methods, one must choose between having feedback or being able to communicate a large volume of precise of information. **Personnel transfers** from one site to another overcomes that tradeoff, albeit at a greater cost (Allen and Cooney, 1971; Allen, Hyman, et al., 1983; Ettlie, 1990; Roberts and Frohman, 1978). Site visits allow face-to-face interaction with others and direct contact with several different forms of information. For instance, an engineer may discuss the operating characteristics of a piece of machinery with another engineer, inspect documents detailing its performance characteristics, and observe it in operation all at the same time. Face-to-face interaction at meetings like this is also associated with the development of interpersonal relationships which facilitate future interaction (De Meyer, 1991). **Short-term transfers** may range from a few days to a few weeks, and they are oriented towards accomplishing a specific goal. On the other hand, a **long-term transfer** may last several months or years and the goals are less well-defined (usually to "learn about another's operations").

Engineering teams transferred to other sites for between a week and a month can be very effective at learning about a partner's technology. First, these teams are very focused in their objectives and generally quite a bit of preparation has gone into the visit to maximize the learning during their stay. They can observe also the technology at a level of detail impossible using arm's-length communication methods. More importantly, while there, the teams can observe the technology in the context in which it operates, and its interaction with other systems in the organization. This is important if the technology must be modified before it can be implemented back at the home site. The teams are able to work closely with their colleagues at the other site on specific technical problems, with immediate feedback on results so that efforts can be re-applied in other areas if necessary. Since short-term transfers are generally less expensive than the longer-term transfers and allow more of the people who work with the technology on a day-to-day basis to experience it first-hand in the other setting.

A long-term transfer assignment might be a step in an organization's management development or training process. This approach allows the managers to learn about a partner's or subsidiary's operations abroad so that there can be more coordination of efforts, as well as allowing them to be in a position to implement that knowledge in their home operations. People working together for an extended period also are able to form personal, trusting relationships, sometimes allowing them access to otherwise guarded information. Finally, actually living and working in another environment may be the only way to understand completely why another organization does thing the way it does. One disadvantage of long-term transfers is that they are expensive and logistically difficult. Repatriating the employee and capturing benefits from the learning experience at home operations can also be problematic. Both JVs have had difficulties in this. Managers have complained about returning from an assignment abroad with ideas to improve their own operations, but were unable to make changes. This happened when they could not transfer the enthusiasm they had for new technologies to others, or because the types of changes they recommended were too radical for the existing organization to accept. Finally, their responsibilities in their new jobs left them with little time to worry about implementing new technologies. One potential solution to this problem is the dual career ladder used at JSF, with tracks for line managers and the technical staff. Line managers are primarily responsible for meeting production demands, while staff engineers act as internal process engineering consultants and are concerned primarily with process improvement. At JSF, the staff career ladder has a higher status than does the line management ladder. Engineers who have been sent abroad to learn are rewarded by being assigned to the staff career ladder when they return. This way the knowledge they gain in other organizations is not lost by them having to divert their attention to meeting production demands.

4.2.2 Integrating methods: An employee functions in a technology **transfer role** if any of the transfer methods described here are part of his or her designated work routine. Such roles might include champions or opinion leaders (Chakrabarti and Hauschildt, 1989; Dean, 1984; Ounjian and Carne, 1987; Souder and Padmanabhan, 1989; Rogers, 1983), gatekeepers (Allen, 1977; Allen and Cooney, 1971), or other organizational roles that facilitate the spread of information (Kazanjian and Drazin, 1986; Roberts and Fusfeld, 1981; Jervis, 1975). These roles form links between organizations or groups and facilitate the flow of technology or other forms of information, and so they are considered to be an integrating mechanism. Often, a primary qualification for these roles (at foreign sites) is the ability to work and communicate in the English language. Another important role is what is referred to at Polychem as a bridgehead. A bridgehead is someone who has been given with the responsibility to transfer a specific technology, and fulfills that responsibility at the site where the technology is destined to be transferred. This may require that the person be transferred abroad for an extended period or it may involve a person who is a part of the staff of the destination site. The bridgehead serves as a gatekeeper for communications flows, engages in engineering problem-solving, and assists teams from the other organization during their short-term visits. The bridgehead role is distinguished from the long-term transfer in that these responsibilities are oriented towards the transfer of a specific technology, while an employee on a long term transfer may not have any specific objectives other than just learning about the other organization's operations or developing future management abilities.

Bridges are procedural or organizational mechanisms which facilitate the flow of technology. Examples of these include special technology transfer groups, standing committees, or procedures which facilitate the sharing of technology between different organizational units (Roberts and Frohman, 1978; Roberts, 1979). Like a bridgehead, a bridge places knowledge or technology from both organizations into a common environment.

Bridges are more complex than a bridgehead because organizational procedures or structures are set up to form that common environment, instead of simply transferring a person to another site. Polychem has established common product quality measurement standards between all three partners so that direct yield comparisons can be made between the different production lines and process technologies used. Each partner had similar process equipment, but took different process measurements according to the troubleshooting philosophy used at each site. Other organizational groups have been created with the express role to integrate information from many sources and re-route it where appropriate. Polychem has standing committees composed of members from all three sites that coordinate strategic planning and R&D work on a global basis. Individual partners also have standing technical councils in specific areas, that integrate information from different functional disciplines, business units, or sites.

4.3 Knowledge Architectures

One of the Japanese Polychem engineers working in Germany commented that it was difficult to transfer technology from Japan to Germany because the approach to production in Japan is designed around Japanese workers with their particular work behaviors and attitudes. Differences in the workers between the sites required that the technology be adapted when it was transferred. The interdependencies that exist between different organizational systems (which we refer to as **knowledge architectures**), can have a profound affect the transfer of technology. Architectures are the forms and functional relationships between the structures and artifacts in which knowledge has been embodied in the organization. They are knowledge that has been codified into technology, rules and procedures, or organizational structures.

Complex technologies are often aggregated systems of smaller sub-components. The way the sub-components are organized and interact with one another defines the architecture of the system (Clark, 1985; Henderson and Clark, 1990). The knowledge architectures of the firm include technologies, operating procedures, social and organizational relationships, or organizational structure. Knowledge architectures have both asset and structural qualities. Architectures are like assets because they are the firm's inventories of embodied knowledge. Architectures are structural because the all the systems in the organization are interdependent. They represent the way an organization both stores and processes information. The organization's various systems interact like a jig-saw puzzle and determine the specific (and perhaps tell-tale) approach it uses to solve design problems, interact with a certain type of customer, or produce a specific product. The organization's knowledge architectures assume their distinctive patterns over time as the organization meets new challenges in the market, develops new products or procedures to cope, or adapts to changing conditions (Kogut and Zander, 1992; Orlikowski, 1992). Such knowledge architectures are sometimes referred to as organizational routines (March and Simon, 1958; Nelson and Winter, 1982), and in the context of an organization's ability to implement new technologies, the organization's absorptive capacity (Cohen and Levinthal, 1990).

The importance of knowledge architectures to technology transfer becomes apparent when an organization tries to implement a new technology. Like substituting one piece of a jig-saw puzzle with a piece from another puzzle, trying to substitute a radical new technology into the existing architecture of an organization often meets with failure because the necessary relationships are challenged, or do not exist at all (Tushman and Anderson, 1986; Henderson and Clark, 1991). A common explanation for this is that the organization has too much inertia in the current systems that define and support its current technology (Nelson and Winter, 1982). More specifically, however, a firm develops problem-solving techniques over time that allow it to be more effective (Tyre, 1991; Orlikowski, 1992) or more ineffective (Katz and Allen, 1982) at acquiring certain technologies (see also Cohen and Levinthal, 1990). An organization's problem-solving approaches may be a reflection of the emphasis it places on specific areas of expertise in its staff members. Organizations also have cultural philosophies that influence their ability to adopt new technologies (Kedia and Bhagat, 1988; Tezuka, 1991; Aoki, 1990). Finally, every new technology implementation is subject to a political process which affects the decisions and outcomes of efforts (Thomas, 1991; Dean, 1989; Barley, 1986) and contributes to or detracts from an organization's ability to successfully adopt new technologies. All of these elements constitute the architectures with which any new technology must interact in the organization. Four such architectures have been observed to influence the technology transfer process.

Technology **Hardware** is transferred more easily between sites if the technology hardware at the donor site is relatively similar with that at the receiver site. This is because technology hardware often functions in interdependent relationships with other technologies in the organization. Technology transfer at Polychem has been made much easier by the fact that all the partners are working with a mature technology and that each partner's technology shares a common technical ancestry. The similarity means that teams from one site can visit another facility for a period of just a few days and gain a fairly detailed understanding of what technologies are being used and how they affect product characteristics. Rather than having to describe the technology in detail, details about equipment and processes can be described in terms of differences between them. An extreme case of compatibility or overlap between sites is seen in the case of the Italsteel plant, which was designed to be a sister plant to one operated by JSF. During its initial construction, much of the technology was either transferred physically from Japan in the form of hardware, or was produced locally under license. In the latter case, the technology was transferred using blueprints and technical specifications, with some short-term visits and long-term transfers from JSF engineers. Since the Italsteel plant is now nearly identical to that operated by JSF, many of the problems that develop at the Italian works can be solved by telephone or fax communication with engineers at the Japanese site, usually without the need for travel. The opposite is true in some instances at Polychem. The German and Japanese polymer production technologies are similar to each other, but quite different from the system used by the American partner. The choice of those specific technologies has had an influence on the other production technologies also used at each site. Because of these differences, collaboration in some technical areas between the partners is impossible.

Procedures are the formal or informal rules of operations that define the way routine effort takes place in and is coordinated throughout an organization. They can be a source of significant competitive advantage if they make the interactions between people and technology, for instance, more efficient. Procedures also have an architectural nature because they are often closely related to the technologies, worker skills, or other architectures that differ from organization to organization. For this reason, procedures being transferred from another site may conflict with the new organizational environment unless either the organization or the procedures themselves (or both) are modified. For example, an Italsteel engineer who had been transferred to JSF had trouble implementing JSF TQM procedures at Italsteel because of fundamental differences between the two organizations. He said that JSF people view their organization as an information generating and processing structure, where people at every step in the operations produce and process information, and then furnish it to others in the organization. Production employees at Italsteel don't have similar procedures or training for producing and using information. Furthermore, information that is produced often isn't shared with others, nor is it sought after when it is produced elsewhere in the firm. JSF procedures were often in direct conflict with existing procedures, the experience base, and the power structure of Italsteel.

Italsteel engineers also observed that JSF workers were involved in the formulation and writing of their own operating procedures. The Japanese Polychem partner uses the same approach. In both cases, engineers from other sites observed that there was a dramatic difference between the Japanese procedures and their own (which typically are written by engineers). The procedures written by the workers were short, concise, and included only relevant information. They were clearly written to be used. But they were also written by experienced users. The Japanese Polychem partner relies heavily on worker expertise to attain quality and output targets in the production process, so the workers have a lot of expertise that is relevant for writing procedures. On the other hand, at the American and German Polychem operations, relatively more emphasis has been placed on the role of technology to attain quality and output targets, and less on employee skills. Therefore, at these sites, workers have relatively less expertise to contribute to procedure formulation.

Adopting a new procedure may mean making changes to existing architectures in what can be a difficult and time-consuming process. Italsteel engineers adopted a JSF data log sheet to record production process data. The JSF log sheets were noticeably clearer and easier to use than the ones used previously by Italsteel. Even so, the Italsteel workers were not used to logging process data on a regular basis. For the space of a few months, an Italsteel manager had to strictly enforce that workers fill in the log sheets in an accurate and consistent manner, before the workers finally began to comply. The same thing happened at the U.S. Polychem site when a new product quality database was implemented. One manager had to conduct several workshops with operators and rejected incorrectly completed log sheets for several months before operators began to comply. Sometimes, existing operating routines are too ingrained in employees to allow changes. For instance, the only significant success that Italsteel engineers have had in implementing TQM procedures at Italsteel has been among newly-hired interns from a technical program that teaches those techniques. In each of these cases, existing procedures and employee experience have had to be modified to successfully adopt new procedures.

An organization's **Experience Base** represents the organization's knowledge stored in its employees, and can have a strong influence on the transfer and adoption of new technologies. In some cases an experienced workforce can be an asset, and in other cases a liability. At Italsteel, a downturn in the steel industry required that the company downsize dramatically. The union agreement stipulated that layoffs had to begin with the most senior workers and proceed though to the more junior workers. In one move, Italsteel lost its most experienced workers. Sophisticated process control automation equipment was installed to compensate for the lack of operating experience. But the lack of experience has become a burden when operators must diagnose and solve problems, or assist in integrating new technologies into the existing technologies. The U.S. Polychem partner has a similar problem with continuity of experience. Frequently, when people demonstrate competence or skill in their work, they are promoted to a higher position in the firm and they are not in position to apply that experience where it can be best used. Polychem in Germany and Japan relies more on a seniority-based system where experienced workers are still involved with production. This ensures that experts are available to diagnose problems, and that younger, less-experienced workers are taught the production process by knowledgeable mentors. The American partner has come to rely relatively more on automated production technology to compensate for less-experienced workers, which makes its process control technology very sophisticated relative to that of the Japanese partner. The implications of this for technology transfer are interesting, however. The U.S. technology and hardware can be transferred relatively easily to Japan, whereas the Japanese experience base is much more difficult to transfer to the U.S.

Another problem posed by organizational experience to technology transfer is that there sometimes is little or no overlap in some areas of the experience base of the cooperating organizations. This creates a dilemma in that a solution to a problem at one site may exist at another, but the potential recipient may be unable to recognize that the solution exists. Or, the potential recipient may not have the expertise to implement that solution in its own operations. Polychem partners hold semi-annual R&D coordination meetings to apprise partners of each other's work and to exploit synergies between research projects at each site. While it does keep them up to date on research done elsewhere, some of the researchers have commented that the meetings seldom serve as a source of new ideas because their own research and that of their colleagues are so different that they seldom find a common basis for discussion.

One final element in this discussion of architecture is the organization's **Power Structure**, and how it relates to technology. An organization's power structure determines what knowledge is valued, and how and by whom it will be processed. Changes in technology can prompt shifts in the relative power of groups within an organization. This can have two effects on the technology transfer process, depending on how the different groups in the organization are affected, and how much power they have to intervene in the process. First, affected groups can filter information about the potential of technologies at other sites by focussing on or "turning a blind eye" to them. This is a concern for R&D managers at Polychem who may be faced with having to sponsor product development research at another site, especially if the product is clearly out of the markets in which the other partner competes. In another case, the influence of a group at Polychem was weakened because of changes mandated by the formation of the JV. In interviews with people from this group, several were initially very cautious about accepting their partners' technologies, or were skeptical that their firm would ultimately benefit from the partnership.

The second way that changes in the power structure of the organization can affect technology transfer is by actively intervening to facilitate or interfere with the transfer of specific technologies. In general, Polychem groups who saw immediate payoffs from technology transfer with partners were much more enthusiastic to begin transfer at the beginning of the JV. The Japanese Polychem partner experienced a "halo effect" at the beginning because of demonstrable strengths in certain production technologies. This allowed it to gain the upper hand in some negotiations early in the JV, especially relating to determining whose technologies would be used at the different sites. Over time, the relative power positions have changed, especially as the true capabilities of each partner has become more clear. However, the relative power positions of the different groups clearly affects what technologies were to be transferred, and by whom.

Individual incentives provide a final poignant example of power balances affecting technology transfer. Information is seen as a source of power and a way to advance in the organization by some managers and hourly employees at Italsteel, so it is often not shared with others. Managers who demonstrate the greatest knowledge, and have the highest individual performance (which may simply mean not doing as poorly as peers) receive the promotions. On the other hand, promotions in the Japanese organizations in this study are based on tenure, so the incentive to distinguish oneself is weak. In fact, the social norms that encourage employees to be a part of the group appear to be much stronger motivators. This means the incentive is to share information, so that the group's performance is improved. Because of such differences in the power associated with possessing information, implementing technologies which rely on the sharing of information at Italsteel or the other Western organizations is difficult and sometimes even resisted.

4.4 Organizational Adaptive Ability

The adoption of a new technology usually requires that some modifications or adaptations take place to both the adopting organization and the new technology (Leonard-Barton, 1988; Pelz and Munson, 1982; Rice and Rogers, 1980). The ability of the adopting organization to marshall resources to make adaptations (either to itself or to the new technology) as a new technology is adopted is referred to as the **Organizational Adaptive Ability** of the adopting organization. While organizational adaptive ability might be thought of as a component of organizational architecture (ie, codified knowledge about adaptation), it is viewed here as a separate category to highlight the importance of architectural adaptation. Knowledge architectures are considered to be relatively static structural relationships in the organization (in the short term, at least). The organization's adaptive ability is its ability to use its resources to change those architectures. For instance, an organization may not have the architectures necessary to support the new technology (perhaps experience base or procedures), but it may have the resources available to adapt new supporting architectures. This is a different concept than that argued by Cohen and Levinthal (1990), where an organization's pre-existing set of abilities do not change during the time scale elapsed in the adoption of a new technology, and therefore ultimately determine the success of implementing the new technology. While it is important to recognize that an organization can only change so much in the short term, it is also important to recognize that it can still change somewhat. Adaptive ability is separated into **staffing flexibility** and **production flexibility.**

An organization that has relatively more people than are required for normal operations (a rare occurrence in lean industries) can redeploy them for problem-solving or implementing new technology. More important than just being able to assign people to work on new technology adoption is the ability to direct the specific skills that are required to solving the problem. Firms seldom have excess people waiting to be re-assigned. In fact, staffing pressures were cited repeatedly by managers as a hinderance to technology transfer. Engineers at Italsteel complained that they were too busy to act as technology transfer agents once they returned from JSF because of the demands of their daily responsibilities. First, they had no time to train other people in the behaviors they had learned at JSF because of pressures to keep the existing production system up and running. Second, they didn't have any extra people to train even if they did have the time. One German Polychem manager made similar comments, and added that because of shortages of personnel in his organization, he could not even afford to transfer any people to other sites so they could learn about different technologies. One solution that is being tried at Italsteel assigns recently-hired interns to managers for training. Those assigned to the managers who worked at JSF are being trained in the JSF statistical process control and Total Quality techniques. Experience available at one Polychem site is also being "lent" to another where it is lacking. The German Polychem partner is actively using expatriates from the other partners to fill understaffed positions in its process engineering groups. This allows it to benefit from skilled engineers immediately without having to wait out the long process of building its experience base through hiring.

People that are available can sometimes be used more effectively through job re-design. In the short run, effort can be focused on certain areas of production by shifting people from other areas temporarily. This is possible only if workers are cross-trained with multiple skills. Polychem in Japan uses in some cases fewer production line workers than its partners, but they are able to move from line to line and position to position so that their effort can be concentrated at critical moments (for instance, when a production line is being started, it is helpful to temporarily have more workers on hand than are needed for routine operations). Furthermore, since Japanese Polychem operators are highly skilled, they are able to assume some of the responsibilities that might otherwise be assigned to a production engineer. Finally, the fact that the operations there are relatively smooth-running means that less effort has to be spent on routine problem-solving and that more effort can be devoted to technology implementation or transfer.

Longer-term deployments of people and expertise to specific areas can increase the likelihood that technologies will be transferred there successfully. For instance, if the most technology transfer occurs in process technology areas, then expertise should be massed there if possible. The Japanese Polychem partner uses about the same number of engineers in its operations as do the German or American partners, but of those engineers, a larger proportion are process engineers. Engineers not assigned to the production are assigned to R&D groups where they are engaged in product development. More engineers are therefore available at the Japanese site for process technology improvement, and process technology improvement is the major focus of effort in the JV currently. Because relatively fewer engineers are assigned to process engineering in the German Polychem, the process engineering group often has to make formal requests of the R&D group for problem-solving help. This causes delays and suffers additionally from potential conflicts in research priorities.

Production flexibility is the relative availability of production time that can be used for engineering problem-solving, equipment modifications, or product trial runs. A plant that must operate at full capacity obviously cannot shut down for such activities. No firm in a competitive industry can build excess capacity just for the luxury of having production flexibility, either. One way to make the most of the available production capacity is to schedule several activities in parallel, however. This usually requires that the organization also have staffing flexibility. The Japanese Polychem partner uses its annual scheduled production line maintenance time for extensive equipment work and problem-solving. Contractor personnel are used so that many maintenance functions can occur at the same time, and the time allotted is used more efficiently. The same parallel activities approach is responsible for dramatic differences in the time required between Polychem partners to start up their respective production lines. The American partner's operators perform the tasks required for start-up sequentially, while the Japanese partner's operators perform the tasks in parallel. The resulting savings in time can be used directly for working on other tasks.

One way of alleviating the problem of binding production demands on technology transfer is by using pilot or non-production lines for experimentation with process improvements and implementation. Each of the facilities involved in the study have pilot production lines of various capabilities. One Italsteel manager saved an obsolete facility from being scrapped so that he could use it for technology and product development. This facility was used to test and prove a piece of technology that was transferred from the JSF plant. Because a test facility existed in Italy, the technology was transferred from Japan with only minor effort. Oddly, this is the only such test facility at the Italsteel plant. Italsteel does have a state-of-the-art pilot test facility located several hundred miles away near its central R&D facilities, but it is seldom used by engineers at the main production plant, and is even sometimes idle. The Polychem partners have made extensive use of their pilot production lines to test new products from their partners, or to test hypotheses about why one technology has higher performance than another. Often a test of a partner's product can be made by shipping raw materials from one site to another and providing the state conditions for the process. New parts or technologies are also tested first on the pilot lines before they are installed on regular production lines. Most of the Polychem engineers interviewed who had transferred technologies from their partners mentioned the use of the pilot production lines as part of the process.

The four categories, Transfer Scope, Transfer Method, Knowledge Architectures, and Organizational Adaptive Ability, and their contents are summarized in Table 1.

Table 1
Categories and Sub-categories of Technology Transfer Framework

4.1 Transfer Scope	**4.2 Transfer Method**	**4.3 Knowledge Architectures**	**4.4 Organizational Adaptive Abillty**
General Knowledge Specific Knowledge Hardware Behaviors	Communication Personnel Transfers Roles Bridges	Hardware Procedures Experience Base Power Structure	Staffing Flexibility Production Flexibility

DISCUSSION

The knowledge-asset framework describes how the extent of the technology transferred, the effort required for transfer, the fit of the technology with the adopting organization, and the ability of the adopting organization to adapt to changes required by new technology interact in the technology transfer process. However, the greatest value of the knowledge-asset framework is not necessarily to be found in the definitions of the categories themselves, but rather in the logic it provides to describe the interdependencies between the categories and to help understand the technology transfer process as a whole. Several relationships can be hypothesized using this logic.

The resource-based view of the firm holds that only assets that are not easily copied by competitors will provide long-term competitive advantage (Connor, 1991). These include so-called invisible assets (Itami, 1987), reputation, management skill, knowledge gained through learning-by-doing, and distinctive organizational culture characteristics (Connor, 1991). These assets (or technologies) are complex, and involve large amounts of potentially tacit information. They represent a substantial transfer scope compared with technologies embodied hardware or information. As the amount of embodied knowledge increases, more intensive transfer methods, with greater information-carrying capacity, must be used (this media richness argument is similar to that made by Daft and Lengal, 1986). This suggests the first proposition:

P1: The greater the scope of the technology being transferred, the more intensive the transfer methods that are required for successful technology transfer.

Assets or technologies that represent a substantial amount of embodied knowledge have the appearance of being uncopyable. The reality is more likely that the intensiveness of the methods required to transfer them from one firm to another create a barrier to transfer unless the participants are collaborating with one another (and even then it may be difficult).

Contingency theory holds that specific organizational structures or attributes are better suited than others to manage specific technological types, and that organizations best suited to work with, for instance, incremental technological innovations, would not do well with radical innovations (Burns and Stalker, 1966; Ettlie, Bridges, et al., 1984; Dewar and Dutton, 1986). Technological systems often function in interdependent groups of components or architectures. When a technology is transferred between organizations with very different knowledge architectures, it may have to be adapted significantly in order to function in its new environment. This adaptation of transferred technologies to the knowledge architectures of their new setting may require the transfer of "bundles" of supporting or complimentary technologies along with the focus technology, or changes to the architectures in the new setting. Either approach involves greater effort, and therefore an increase in the transfer scope[1].

P2: The greater the difference in knowledge architectures between firms, the greater will be the scope of the transfer of a given technology.

In addition to increased transfer scope, technology transfers between organizations with significantly different architectures may naturally require additional transfer effort. The adaptation of a technology transferred into a new setting will require an understanding of its interdependencies with different organizational systems. The greater the differences between the knowledge architectures of the donor and receiver organizations, the more important the knowledge of its interdependencies with the organization is to the transfer. Obtaining this knowledge may involve on-site investigation of technological interdependencies, the codification of that knowledge into explicit terms that can then be transferred, and the re-interpretation of it into the new organizational setting. This type of interpretation must be done by placing the architectural knowledge of both organizations in a common context, which usually involves the transfer of personnel. This means that generally more intensive transfer methods would be required for the transfer.

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[1] Changes to existing organizational architectures will probably still require additional information to be transferred from the donor organization, as a reference for changes to the architectures.

P3: The greater the difference in the knowledge architectures between organizations, the more intensive the transfer methods that will be required for successful technology transfer.

Not unlike contingency theory, P2 and P3 propose that bridging differences in knowledge architectures between firms and technologies may be difficult. The additional effort and cost required can serve as barriers to diversification of firm scope, and suggest that firms with very different backgrounds (technological, cultural, operational) may not easily benefit from each other's experience.

It has been claimed that organizations can increase their capacity to absorb or adopt new technologies through investments in technological competence (Cohen and Levinthal, 1990). Merely possessing expertise may not make an organization more "absorptive" if that expertise is not consistent with new technology that is being adopted, however. This suggests that it is not only expertise that is needed, but also the ability to respond to circumstances beyond what is considered to be routine for the organization. Experts trained in multiple skills or functions are more likely to respond effectively to non-routine conditions than those with narrowly-defined skills and responsibilities. They would do this by using more intensive transfer methods. Such methods are better able to carry more extensive information resulting from differences between knowledge architectures (Proposition P3). They also require greater effort, expertise, and resources, which are in relatively more abundance in an organization with staffing flexibility. Thus,

P4: The greater the organizational adaptive ability an adopting organization has, the greater the difference between the donor's and its own knowledge architectures that it will be able to tolerate in technology transfer.

P5: The greater the organizational adaptive ability an organization has, the more intensive the transfer methods it is able to use.

A similar argument can be made about transfer scope. As transfer scope increases, the amount, and possibly the tacitness of the information increases. Increased scope does not imply that the technology is necessarily unique and in need of exceptions to normal routine, but that the volume of the information has increased. An organization of a given size and structure should theoretically be able to process only so much information, especially given its on-going demands of production. However, firms with production flexibility can re-deploy their resources to cope with greater demands and workloads in engineering problem-solving, and accommodate greater transfer scope in a given technology transfer effort.

P6: The greater the organization's adaptive ability, the greater the scope of technologies it is able to transfer.

Propositions P4, P5, and P6 suggest that the absorptive capacity results not only from the development of architectural knowledge in technological expertise, but from the development of flexibility in using that expertise in unique or non-routine situations. Firms interested in developing additional absorptive capacity should consider the importance not only of the development of knowledge, but also the ability to adapt and reconfigure it.

Finally, the technology transfer process is a dynamic process, occurring in multiple cycles. Past research has suggested that the adoption process takes place (with some variations) through the steps of obtaining an initial awareness of a technology, investigating or gathering information about it, evaluating its merits and potential uses, using the innovation on a trial basis, making the decision to continue or discontinue use, implementing the innovation, and possibly re-diffusing it to other units (Ettlie, 1976; Pelz, 1985; Pelz, 1983; Rice and Rogers, 1980; Rogers, 1983). Specific types of knowledge are transferred during those stages, with the knowledge gained in one phase forming the foundation for further knowledge transfer work (Hall and Johnson, 1970). The final proposition forms a closed loop in the technology transfer process framework and captures its dynamic nature.

P7: The greater the scope of technology transferred between firms, the smaller the resulting differences in knowledge architectures that will exist between them.

Differences in knowledge architectures represent relative deficits in knowledge between firms, and as knowledge is transferred between them, that deficit decreases. This is not to imply that through technology transfer, all collaborating firms will become replicas of each other. Indeed, a firm may chose to discontinue specific technology transfer efforts with a partner after only general knowledge has been transferred, perhaps because that information has revealed that adoption is unnecessary or that the cost of adoption is too great. The propositions and their relationship with one another in the technology transfer process are shown in Figure 1.

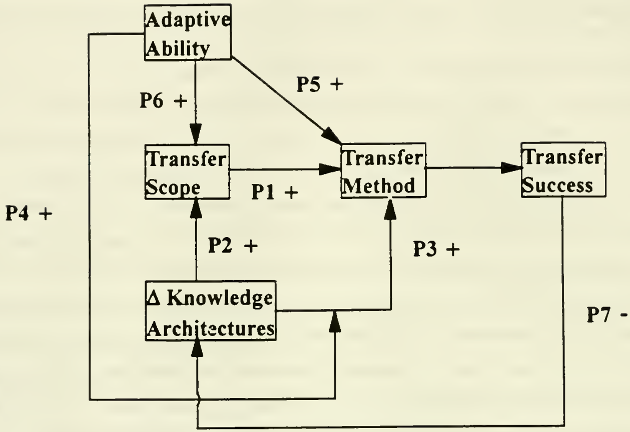

Figure 1. Relationships Between Transfer Scope, Transfer Method, Knowledge Architectures, and Organizational Adaptive Ability in the Technology Transfer Process.

The literature reviewed at the beginning of this paper discussed three distinct areas of technology transfer research, on how transfer methodology, and organizational and technological attributes each affect the success of technology transfer efforts. The point was made that little or no previous effort to integrate them into a unified explanation of the technology transfer process. The framework presented here attempts to remedy that problem. Transfer methodology is addressed as a separate category in the framework. Technology attributes are addressed by transfer scope. Knowledge architecture and organizational adaptive ability capture the attributes of the organizations involved in the transfer. Finaliy, the proposed relationships between the categories create a framework that demonstrates possible relationships between the areas of prior research.

SUMMARY

An organizational knowledge asset-based framework of technology transfer has been proposed. The framework depicts the organization as bundles of embodied knowledge which include technology, procedures, organizational structure, and hierarchical relationships. Firms are different from one another because they have chosen or evolved different combinations of embodied knowledge to accomplish their strategic goals within their given competitive environments. Technology transfer is the transfer of embodied knowledge assets from one organization to another. Four concepts, Transfer Scope, Transfer Method, Knowledge Architectures, and Organizational Adaptive Ability, describe important elements of the transfer process. Successful technology transfer involves the use of proper transfer methods, given the scope of the technology being transferred, working within the constraints of an organization's existing knowledge architectures and its adaptive ability.

The knowledge asset-based view of technology transfer not only describes the transfer process, but also informs several issues involved in the strategic management of technology. First, a firm's "uncopyable" assets are thought to be the source of its competitive advantage vis-à-vis other firms. The "uncopyableness" of a technology may stem from at least two sources. The scope of the transfer may be large from differences between firms in technological, or "non-technological" areas such as organizational culture or practices, or the transfer may require the use of intensive transfer methods. While little can be done about the impact of excessive scope, a firm can use more intensive transfer methods through a close partnership with another firm, such as a joint venture. The use of partnerships to transfer uncopyable assets can itself be troublesome, since partners with different adaptive abilities may benefit from a collaborative effort differently. A more adaptive partner may be able to transfer a greater scope of technologies, using more intensive transfer methods than its less adaptive partner. Finally, the knowledge asset-based framework suggests that an organization's adaptive ability may also have an important role in an organization's capacity to absorb new technologies from the environment. Investment in the active development of those technologies has traditionally been seen as primary source of an organization's ability to absorb new technologies.

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