Dynamics and Architectures of Innovation Systems

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ABSTRACT

Innovation processes are multifaceted. Different studies usually focus on different facets of innovations without being integrated into a complete innovation system. In this thesis, system dynamics and system architecture approaches are adopted to integrate different studies in innovations and to develop a more holistic view of innovation systems.

Three key elements, knowledge diversity, spatial proximity, and strategic relatedness, are found to be fundamental to innovations after analyzing and comparing different studies. However, these three factors derived from resource-based view and knowledge-based view do not seem sufficient to explain the evolutionary behaviors of innovations. Therefore, another two factors, mutation mechanisms and dynamic capabilities, are proposed to supplement the original three factors in the analysis of innovation systems.

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Chapter 1 Introduction

1.1 The Process of Technical Innovations

In the resource-based view of the firm (Wernerfelt, 1984), it is suggested that a firm's competitive advantages derive from the possession of specific resources, competences, or capabilities. Those that can lead to competitive advantages, by definition, must be scarce, valuable, and durable (Barney, 1991), and be appropriable by the firm. The primary task of the firm is to maximize the value generation through the optimal deployment of its idiosyncratic bundle of resources and at the same time develop new resource base for the future. However, in an efficient market, these rent-yielding resources or capabilities must originate within the firm for them to be valuable and appropriable. Since all the tangible resources are available in the market and are not appropriable by the firm, it follows that the competitive advantages of the firm must originate from the intangible firm-specific knowledge with which the firm can add values to tangible input factors or create values by the applications of these tangible factors. Based on this perspective, a knowledge-based theory of the firm is being developed.

Nowadays, in this fast changing "information age," intangible knowledge is playing an even more important role in technological innovation that continually re-shapes the world. How does knowledge affect the technological innovation? Utterback (1971) proposed a model for the process of technological innovation within the firm (Figure 1-1). In his model, the technological innovation process includes three phases: idea generation, problem solving, and implementation, possibly followed by diffusion. In each of the three phases, information from technical or environments flows through the boundary to the firm to facilitate the synthesis of knowledge that is necessary for the technological innovation. The information, no matter technical or environmental, involved in this process can be classified knowledge as long as the information is regarded as "justified true belief." Within the boundary of the firm, different types of knowledge also flow between different phases of technological innovation process. In this model, the whole technological innovation process is comprised of different knowledge-processing activities. It implies that in many modern firms where technological innovation has become the key element of competitive advantages, not only the componential knowledge itself but also the knowledge of

knowledge-processing (procedural knowledge) from a system level will both affect the performances of technological innovation and hence the performances of the firm.

Utterback's model has provided us some ideas about the role of knowledge in the technological innovation process. In this thesis I will expand his model to tentatively set up a conceptual generalized model to reify the dynamics of technological innovation under different knowledge conditions. Since knowledge will be the key objective of our analysis in this thesis, it's important to clarify the following characteristics of knowledge to lay the foundation for the subsequent discussions.

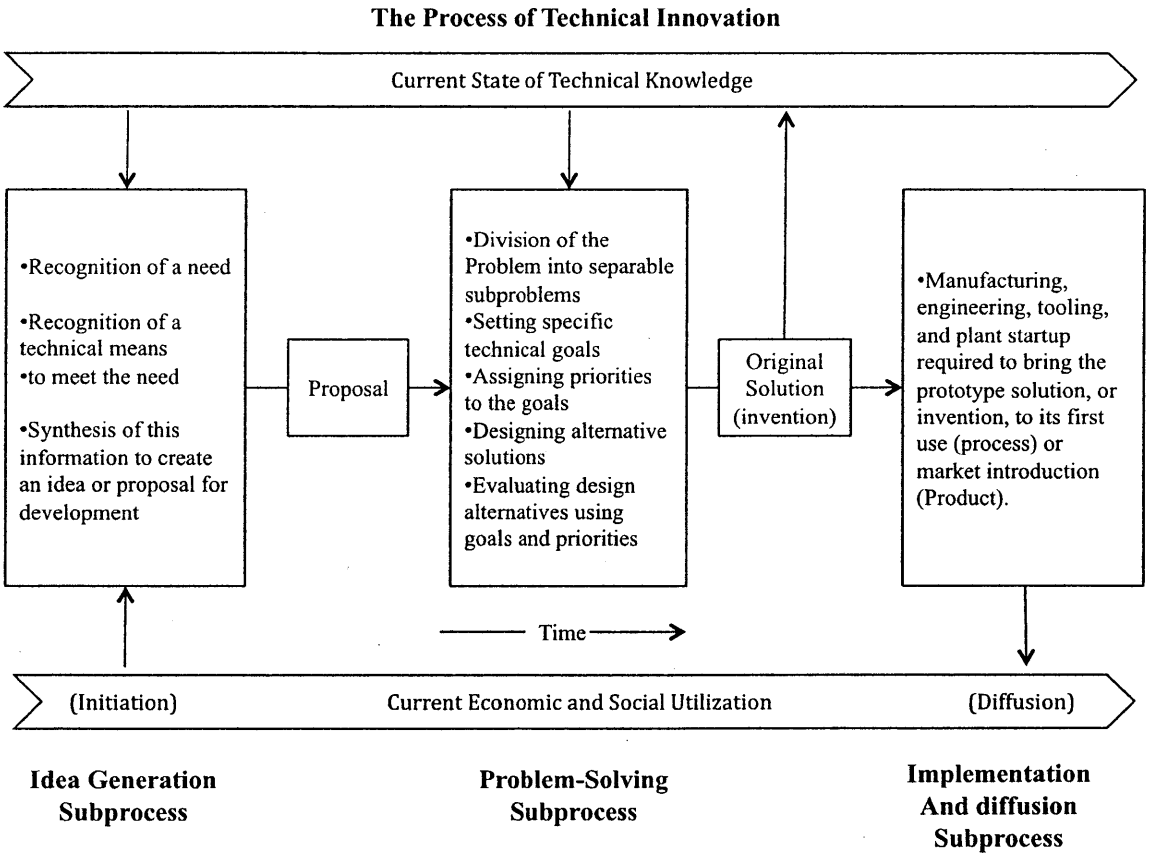


Figure 1-1 Process of technological innovation within the firm (Source: Utterback 1971)

1.2 The Definition of knowledge

The concept of knowledge has intrigued many great thinkers without the emergence of any clear consensus. Knowledge should be built around some perceptive reality. Unfortunately, different epistemology may have its own cognition about the relation between knowledge and reality. As a consequence, the intent of knowledge may vary under different assumptions and conditions. To a realist, it is assumed that reality exists and is knowable. To an empiricist, it is assumed that our knowledge corresponds to reality. To a rationalist, it is assumed that reality's structure is logical. "All the traditional epistemology naturally emphasizes the absolute, static and nonhuman nature of knowledge, typically expressed in propositional forms in formal logic" (Nonaka 1994). However, all these positions neglect the essence of Kantian critique that our knowledge is constructed based on our sensory experiences and impressions and therefore cannot tell us about a reality beyond these impressions. In this sense, knowledge is subjective interpretation of individuals' experiences and impressions about a reality. The formation of knowledge about a reality is a subjective process involving justification of individuals' perception about that reality. Therefore, it is generally accepted that knowledge can be defined as "justified true belief." This definition, "sees knowledge as a dynamic human process of justifying personal beliefs as part of an aspiration for the truth." (Nonaka 1994) I will also use this definition in this thesis.

1.3 Dimensions of Knowledge

Knowledge is a multifaceted concept. It can be categorized differently from different angles and hence no single taxonomy is sufficient to describe the concept of knowledge completely and precisely. The most common taxonomy is to classify knowledge into "explicit knowledge" and "tacit knowledge" proposed by Polanyi (1966). Explicit knowledge refers to knowledge that is transmittable in formal, systematical language. On the other hand, tacit knowledge is not codifiable and hence is not communicable. As will be discussed in later sections, tacit knowledge can only be learned through observation, imitation and practicing. Henderson and Clark (1990) note that for a product consisting of multiple components, the knowledge about the components is not sufficient to describe the total knowledge embodied by the product. In addition to component knowledge, architectural knowledge that defines the spatial and temporal connections of different components is also an integral part of the knowledge represented by the product. In

Anderson's ACT Model (1983), knowledge is divided into declarative knowledge (actual knowledge) and procedural knowledge (methodological knowledge) which is used in such activities as remembering how to ride a bicycle or play piano. Declarative knowledge consists of a statement that provides state description. On the other hand, procedural knowledge consists of a statement that describes a process. To some extent, declarative knowledge is very similar to Henderson and Clark's (1990) component knowledge and procedural knowledge is very similar to what they called architectural knowledge. Under some circumstances, declarative knowledge is analogous to explicit knowledge and procedural knowledge is analogous to tacit knowledge. Instead of trying to categorize knowledge, Rogers (1983) and Winter (1987) circumvented the taxonomy and developed five dimensions to characterize a firm's knowledge: Codifiability, Teachability, Complexity, System Dependence, and Product Observability. Codifiability captures the degree to which knowledge can be encoded and documented. The higher the codifiability, the more explicit the knowledge. Teachability, on the other hand, captures the extent to which workers can be trained in school or on the job. It emphasizes the training of personal skills. Complexity reflects the inherent variations when people try to integrate different knowledge to form capabilities. System dependence captures the degree to which the transfer or creation of knowledge is dependent on other systemic knowledge. For example, sometimes the creation of new knowledge depends on the knowledge of experienced experts in the organization or on some other specific capabilities of the organization. This kind of new knowledge is thought to be of high system dependence. The last dimension is Product Observability. This dimension captures the degree to which knowledge embedded in the product is observable and therefore imitable to capable competitors. These dimensions of knowledge are closely linked to different dimensions of innovation, which are profitability, communicability, observability, complexity, and compatibility, proposed by Rogers (1983) as innovation is usually an outcome of knowledge activities.

In addition to Rogers (1983) and Winter's (1987) effort to characterize the properties of knowledge itself in five dimensions, consolidating different insights from the literature on the analysis and management of knowledge, Grant (1996) concluded the following characteristics as pertinent to the utilization of knowledge within the firm to create value: transferability, capacity

for aggregation, appropriability, specialization in knowledge acquisition and the knowledge requirements of production.

Transferability

Transferability of a firm's resources and capabilities is regarded as a critical determinant to sustain competitive advantages in the resource-based view of the firm. Knowledge, being recognized as an important resource of the firm, must be transferable not only across the firm boundary but also within the firm. However, the transferability and the mechanisms for knowledge transfer between different entities, space and time are dependent on the properties of the knowledge in question. Explicit knowledge that can be codified can be revealed and transferred by communications in different forms such as reports, videos, programs and etc. On the other hand, implicit knowledge that cannot be codified can only be acquired or transferred through its application and practice.

Capacity for aggregation

For the knowledge to create values, it's imperative that the new knowledge assimilated by the recipient be added to and combined with the existing knowledge. Recipients' ability to assimilate new knowledge can be analyzed in terms of recipients' absorptive capacity proposed by Cohen and Levinthal's (1990). The efficiency of knowledge aggregation depends greatly on the commonality between new and existing knowledge. I will talk about the concepts of absorptive capacity and common knowledge in detail in later sections.

Appropriability

Appropriability refers to the ability for the owner of a resource to receive the return that is equal to the values created by the resource. If the owner of a resource cannot appropriate the values created by the resource, the resource cannot contribute to the competitive advantage of its owner. In general, except for patents or copyrights where the knowledge owners are protected legally, explicit knowledge is inappropriable by means of market transactions. On the other hand, implicit knowledge, which cannot be translated directly and can only create values through its applications by its owners, is much more appropriable.

Specialization in knowledge acquisition

Herbert Simon's principle of bounded rationality points out that humans' rationality is limited by their ability to formulate complex issues and to process (receiving, storing, retrieving, transmitting) information. This principle reflects the basic limitation of knowledge production by human beings and therefore specialization in particular areas of knowledge is a necessary condition for human beings to produce knowledge efficiently.

The knowledge requirement of production and innovation

Production involves the transformation of inputs to outputs. Innovation involves the transformation of input knowledge to output products (and sometimes knowledge). The values created from such transformations are all dependent on knowledge. Other resources such as labor, land, machine and etc. are simply the embodiment of knowledge.

1.4 The Architecture of Innovation Processes

To conceptualize the model of innovation, we first need to understand the origin of innovation. In Utterback's model of technical innovation, the innovator first needs to recognize the needs and then identify the technical means to meet the needs. Utterback does not mention whether the needs are internal needs or external needs. We presume that the needs can either come from inside the organization or outside the organization. After the needs are recognized, the innovators are then able to search the technical path, either from inside the organization or outside the organization, based the knowledge stock of the organization to develop solutions that can satisfy the needs. In Utterback's model, the technical innovations are triggered by the needs inside or outside the organization. If the knowledge stock of the organization is not sufficient to develop a satisfactory solution, the organization must seek to satisfy the needs by acquiring or assimilating knowledge that is not inherent in the organization.

This model implies that the companies' intent to adopt external knowledge is induced by internal or external factors. However, before this intent can be induced, the organization must be aware of these factors first. These factors, no matter internal or external factors, are consequences of the interactions between the organization and the environment. Knowledge about the context in which the organization is operated must be transferred to the organization continually before any

actions are taken. Namely, transfer of external knowledge to the organization is a continual process regardless of what internal or external actions the organization decides to take to overcome the challenges facing them. Therefore, we contend that the innovation must start from the absorption of external knowledge. This external knowledge will then trigger the transformation of current knowledge stock to solutions or stimulate the assimilation of external new knowledge that is necessary for the development of solutions. As Cockburn, Henderson, and Stern (2000) noted, an organization's ability to identify and respond to environmental cues may shape the developmental paths and the timing of deployment of organizational capabilities.

The external knowledge about the need for innovation diffuses into the organization through the interfaces. However, certain instruments must exist before the knowledge diffusion process can be triggered and progress. The first instrument is the "absorptive capacity." There are different definitions for absorptive capacity. The most common one would be Cohen and Levinthal's definition. In their definition, absorptive capacity is "the ability to value, assimilate, and apply new knowledge." The ability of an organization's interface processes to identify valuable external knowledge and to diffuse it into the organization can be considered part of the organization's absorptive capacity. After the external knowledge is transferred to the organization by the interface processes, the organization also needs the absorptive capacity to assimilate the external knowledge and to apply it to commercial ends. However, for the innovation to occur, the organization also needs knowledge processing capacities that can transform external knowledge into new knowledge. These interface processing capacities and knowledge processing capacities must be built on some infrastructures that can facilitate organizations' searching, collecting and transferring of knowledge in different knowledge environments. Since knowledge originates from and is stored in individuals or other organizations, the most important function for these infrastructures is to connect people or organizations with different knowledge base. Therefore, internal social networks and external social networks can be considered the key infrastructures in the innovation system. With time the spillover of new solutions or new knowledge developed by the innovation process from the organization to the industrial context outside the organization boundary will change the knowledge environment of the industry and induce the coevolutionary effects (Van den Bosch, Volberda and de Boer 1999).

Consolidating the discussions above, it is concluded that five key elements, which are knowledge processing capacities, absorptive capacity, internal networks, external networks and interface processing capacities, are necessary to form a working innovation system. The innovation system will co-evolve with the knowledge environment in which the system resides. Figure 1-2 illustrates the high-level architecture for the innovation system. In this thesis, I will discuss these key elements in details in subsequent chapters based on different frameworks and studies. I will also talk about some important issues such as effects of spatial proximity and tie strengths to solidify my discussions. At last, I will extract some common key elements from these studies on different facets of innovation using system dynamics and system architecture approaches and propose a high-level framework to analyze the innovation system.

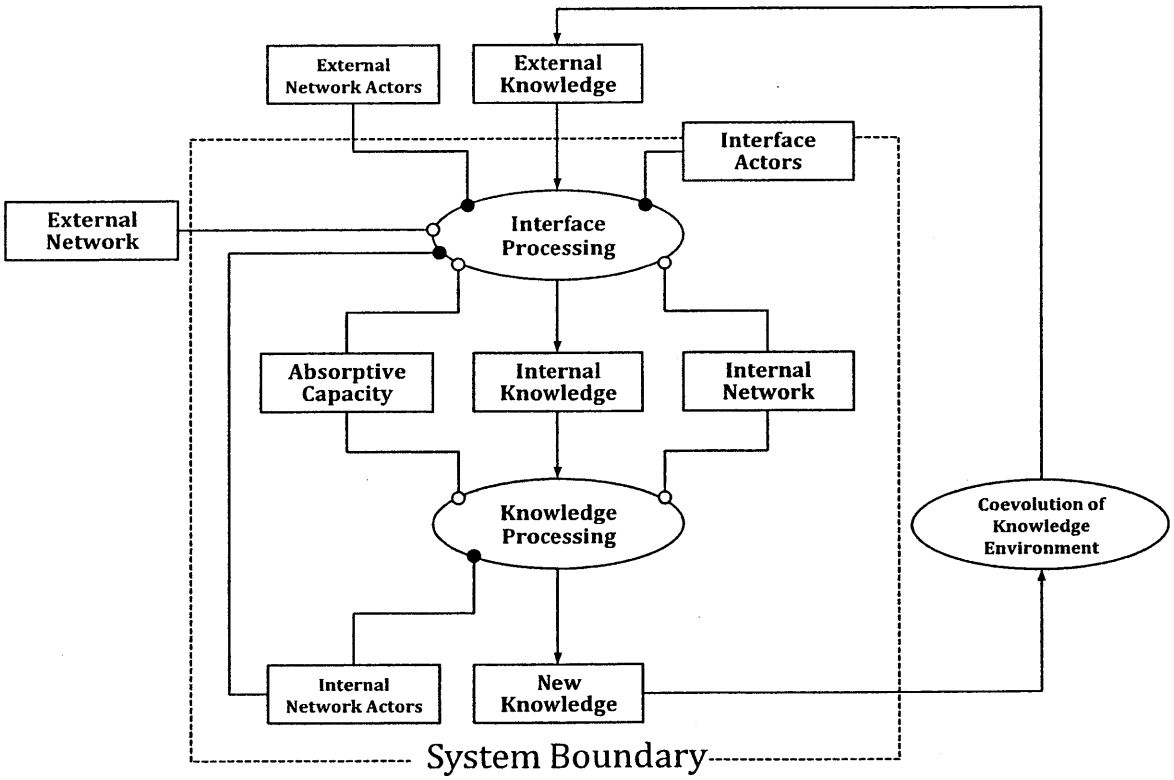


Figure 1-2 High-level architecture for the innovation system

Chapter 2 Knowledge Creation Processes

The resource-based view perceives the firm as a unique combination of idiosyncratic resources and capabilities and the firm's primary task is to maximize the values of these resources and capabilities by optimally deploying existing resources and capabilities while developing the firm's resource base for the future. In modern industries, knowledge can be regarded as a firm's most idiosyncratic resource with which competitive advantages can be built. However, according to the resource-based view, if knowledge belongs to part of a firm's resources, a firm should not only optimize the deployment and the application of knowledge to maintain its current competitive advantage, but also develop and expand its knowledge base to secure its future competitive position. There are different ways to develop and expand a firm's knowledge base. A firm may choose to acquire or transfer new knowledge from external knowledge sources to become part of the firm's idiosyncratic resources. Unfortunately, except for patents and copyrights where knowledge owners are protected by legally established property rights, knowledge is in general inappropriable by means of market transactions. Tacit knowledge, which makes knowledge "idiosyncratic" resource, is especially inappropriable. Namely, the knowledge acquired or transferred from external knowledge sources can seldom become a firm's idiosyncratic resource and a firm can not rely merely on this kind of acquired or transferred knowledge to sustain its competitive advantage over time. In this sense, in addition to knowledge acquisition or transfer, knowledge creation possesses the central role of a firm's capabilities nowadays. In this chapter, I will talk about different knowledge processes that can facilitate and promote knowledge creation.

2.1 Enabling Conditions

Individuals in the organization are the basic units of knowledge creation. Organizational knowledge stems from the enlargement, conceptualization and crystallization of individuals' knowledge in the organization. Individuals continually commit themselves to recreating the world according to their own perspectives. Commitment is one of the most important components for promoting knowledge creation within the organization. Three factors can induce individual's commitment in the organization setting: intention, autonomy, and fluctuation.

Intention is related to how individuals "form their approach to the world and try to make sense of their own environment" (Nonaka 1994). Different intentions may confer different meanings on the same information. Namely, intention forms the foundation based on which individuals can judge the values of information or knowledge perceived or created. As knowledge is generally defined as "justified true belief," intention plays an important role in qualifying knowledge created in the organization. "The intentionality of the mind not only creates the possibility of meaning, but also limits its form" (Searle 1983, p. 166). Different intentions of individuals may enrich the body of knowledge in the organization and further foster diversity of knowledge that is very important in the knowledge creation process. However, diversified knowledge that is not sharable or communicable cannot stimulate the creation of knowledge. By allowing individuals to act autonomously, the organization may increase the possibility of introducing creative metaphors that can enhance the sharing and communication of individuals' diversified tacit knowledge. Namely, autonomy can shape a favorable environment for individuals to absorb knowledge freely. In addition, individual autonomy also widens the possibility that individuals will motivate themselves to form new knowledge. Even though intention is internal to individuals, knowledge creation at individual level involves continual interactions with the environment. Fluctuations in environment will change the patterns of interactions between individuals and their environment and consequently change individuals' intentions. When individuals change their intentions, they will change their approaches to search, transfer or create knowledge that can take account of ambiguity, redundancy, noise or randomness from the organization and its environment. Environmental fluctuation often triggers "breakdown" in human perception which interrupts individuals' habitual comfortable "state-of-being." When breakdown occurs, individuals start to question the values of habits and routine tools, and are given opportunities to reconsider their fundamental thinking and perspectives (I will use the term "Introspection" to describe this process in the system architecture).

The intention, autonomy, and fluctuation discussed above are factors that can promote knowledge creation at individual level. Although organizational knowledge creation is initiated by individual knowledge creation, the factors above are not sufficient to secure the knowledge creation at organization level. For effective creation of organizational knowledge, different

enabling conditions are necessary. At individual level, environmental fluctuations can induce individual commitment. At organization level, environmental fluctuations can generate "creative chaos" which triggers the process of organizational knowledge creation. When the organization faces an issue that cannot be resolved by existing knowledge, it will try to create new knowledge by making use of the fluctuation itself. Creative chaos occurs naturally when the organization faces a real crisis. It can also be generated intentionally to evoke a "sense of crisis" among organization members by proposing challenging goals. This creative chaos can increase the tension within the organization and focus organization members' attention on delivering new solutions. What Zahra and George (2002) call "activation triggers" to some degree is very similar to "creative chaos" in the sense that both "creative chaos" and "activation triggers" can stimulate organizations' sense of urgency to assimilate or create new knowledge to deal with the crisis that cannot be resolved by existing knowledge. According to the discussions above, I set up a causal loop diagram below (Figure 2-1).

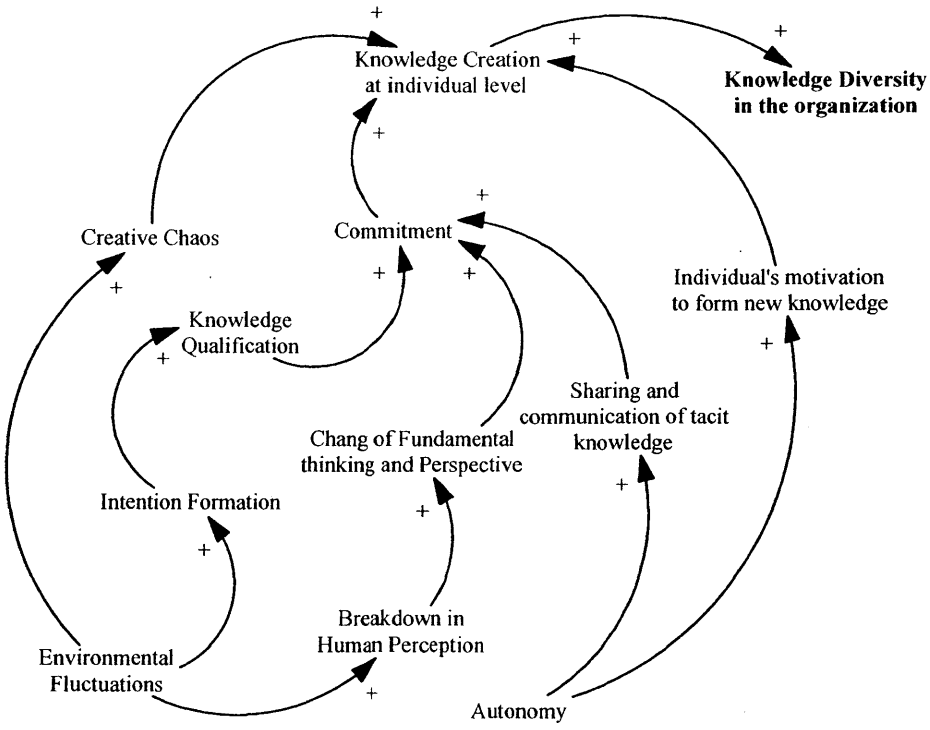


Figure 2-1 Causal loop diagram for knowledge creation at individual level

In the organizational knowledge creation process, once a common implicit perspective is formed, the team members need to articulate the perspective through continuous dialogs that can facilitate the conversion of tacit "field-specific" perspectives into explicit concepts by activating externalization at individual level. As Nonaka concluded, "The participants in the dialog can engage in the mutual co-development of ideas." Dialogs can also enable participants to "formulate messages that are tightly linked to the immediate knowledge and perspectives of the individual participants, because it affords the participants moment-to-moment information on each other's understanding" (Krauss and Fussell 1991, p. 175). As proposed by Madhavan and Grover, dialog, the most common form of dynamic interaction between team members, is determined by trust, information redundancy, and rich personal interaction.

The first factor that can assist the process of knowledge creation through interpersonal interaction is the degree of information redundancy. Information redundancy means the sharing of information over or above the minimum amount that is required to finish a team member's job. The redundancy of information can help team members explore another person's area and allow the formation of common perspectives and concepts. Without redundancy of information within the team, the creative dialogs cannot be realized. Information redundancy can facilitate the sharing of different meanings of knowledge or information underlying different team members' perspectives and promote the serendipitous interactions of ideas. Furthermore, the existence of redundant information also allows the organization members to circumvent the official communication channels embedded in the organization structure and promotes the effective informal interchange between hierarchy and nonhierarchy in the problem solving or knowledge creation process. In this sense, redundant information can release individuals' tacit knowledge and expand organizations' knowledge pool. Redundant information can also increase the communication probability among members of different levels in the organization and hence increase the possibility of knowledge creation. This perspective also corresponds to Meyers and Wilemon's (1989) finding that informal networks were much more significant than formal channels in transferring learning. Therefore, it is reasonable to assume that information redundancy is positively related to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge. However, the strength of this correlation depends much on the sense making of redundant information. Research in developmental

psychology suggests that a person's ability to make sense of new information depends on the breadth of categories into which prior knowledge is organized, the differentiation of those categories and the linkages across them (Bower and Hilgard 1981). Namely, knowledge diversity can strengthen a person's ability to make sense of redundant information. On the other hand, information redundancy will increase the amount of information to be processed. Since the sources and the contents of redundant information could be diversified, according to Ashby's law of requisite variety, it is important for the organization to foster larger or same degree of diversity in order to process the redundant information. In this sense, knowledge diversity of individuals in the organization is of fundamental importance to the creation of organizational knowledge. Therefore, Nonaka regarded requisite variety as one of the principles of organizing knowledge creating activities. Aside from the effects on the conversion of embedded knowledge to embodied knowledge, information redundancy also plays a key role in the formation of trust in the organization. Trust has been identified not only an integral element of the performance of small teams but also of many contemporary organizational arrangements such as strategic alliances or JIT(Just In Time) systems. As pointed by Zand (1981), information sharing is closely associated with trust. Nonaka also notes that mutual trust among team members can be promoted through information redundancy. Information redundancy can eliminate cheating among organization members. It is observed that opportunism tends to occur less in organization settings than in market transactions because the sharing of redundant information among organization members can minimize the possibility of cheating and facilitate the establishment of mutual trust in the organization. Therefore, as Madhavan and Grover proposed, the aggregate level of trust in a team will be positively related to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

The third factor, richness of personal interaction, consists of direct (face-to-face), frequent and informal communication among team members. Richness of personal interaction can facilitate the formation of trust through increasing group cohesiveness. On the other hand, enabled by the formation of mutual trust, richness of personal interaction can also enhance knowledge creation indirectly through sharing of redundant information. In the previous section, we discuss the importance of redundant information in the formation of trust. However, the existence of redundant information is not sufficient to initialize the formation of trust in the organization. In

addition to redundant information itself, the organization needs to develop mechanisms to immobilize the redundant information. Personal interactions can promote the sharing of redundant information and immobilize the redundant information and consequently promote the formation of trust in the organization. Therefore, it is reasonable to infer that richness of personal interaction is positively related to the formation of trust. In addition, as Grant points out, 'integrative efficiency depends upon the effectiveness of this communication in eliciting appropriate responses from each organization member. This is a function of the frequency with which the particular pattern of coordinated activity is performed.' Richness of personal interaction also regards the contact frequency among team members. The more frequent this particular pattern of coordinated activity is performed, the more frequent the external knowledge is exposed to the group members and the more the tacit knowledge can be transferred and hence the more efficient and effective the knowledge creation process will be. The frequent interactions between team members on the other hand can also build strong ties between them and further facilitate the use and creation of knowledge within the team (Krackhardt 1992). As a result, richness of personal interaction is also positively related to the efficiency and effectiveness of knowledge creation.

Concluding from the discussions above, we can work out a causal loop diagram in Figure 2-2 to depict the interactions among different factors as well as their effects on the efficiency and effectiveness of knowledge conversion process. In this process, there are two exogenous factors, redundant information and richness of personal interaction respectively. Redundant information means the information over or above the minimum amount that is required to finish a team member's job. In a well-established team where team members know one another's knowledge base very well (team members know what other team members know and do not know), the amount of redundant information that can be shared is promoted by degree of knowledge diversity in the team and the knowledge diversity can further be enhanced by the knowledge creation. With these two additional correlations, several reinforcing loops (all the loops except the "Trust Loop" in Figure 2-2) can emerge. Richness of personal interaction by definition is the direct (face-to-face), frequent and informal interaction among team members and this feature is enhanced by spatial proximity. As a result, these two exogenous factors actually are representative of the impacts of knowledge diversity and spatial proximity respectively.

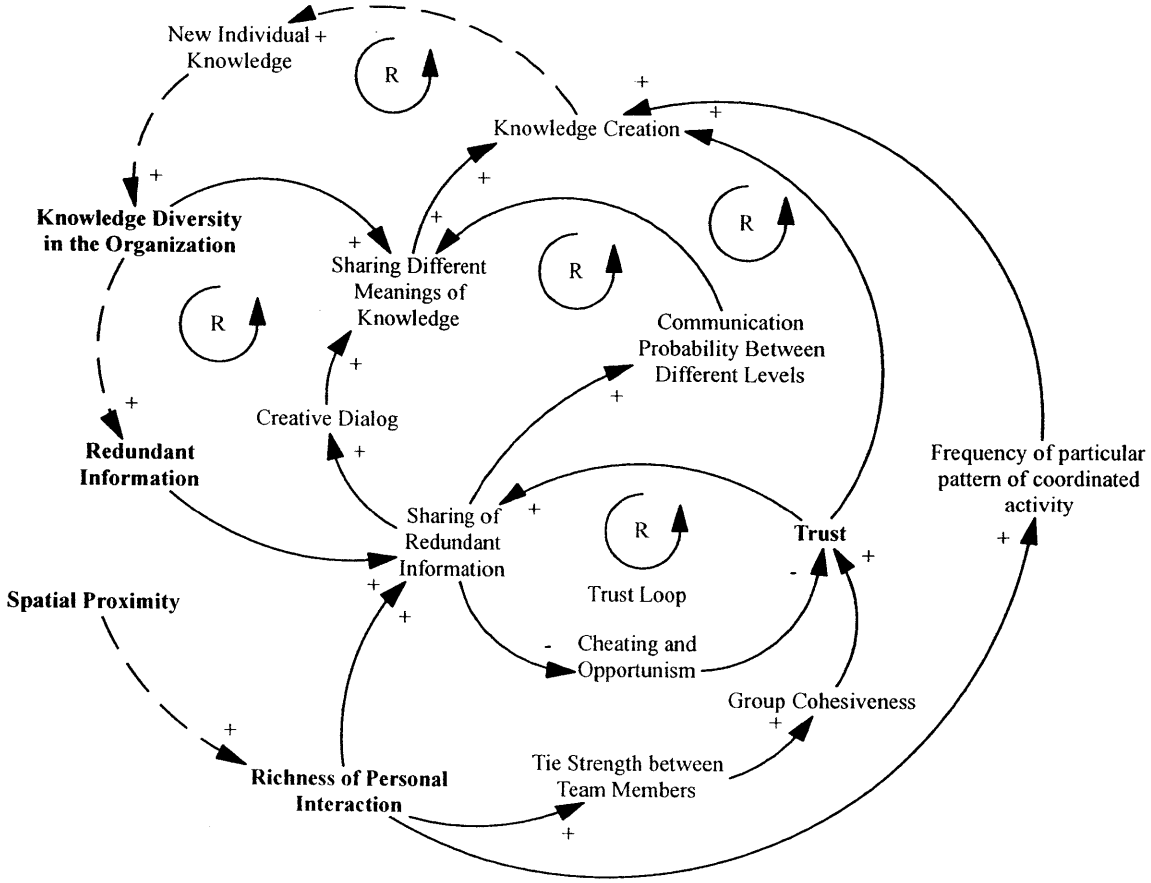


Figure 2-2 Effects of redundant information, Richness of Personal Interaction, and Trust

A case by Kiyonori can help us realize the importance of these factors in the innovation process. In 1970's, in order to compete with US in the computer and semiconductor industry, Japanese Ministry of International Trade and Industry (MITI) forced five competitive computer companies to set up a VLSI Technology Research Organization focusing on some basic common areas for computer and semiconductor industries. To accomplish its mission, the Association established a cooperative laboratory involving these five corporate participants. This laboratory initially faced the problem of how to manager researchers who were on loan from competitors. This project was proven to be successful and ever since the semiconductor industry in Japan started to catch up with that in US. In this case, Kiyonori attributed this great success mainly to the existence of the cooperative laboratory. The existence of the cooperative laboratory allowed the exchange of information and frequent interactions of personnel. High-level communication of personnel with

different specialties, careers and companies occurred and stimulated each other. However, these interactions or high-level communications are not inherent in the organization. They are triggered by some natural characteristics and designed mechanisms. In this cooperative laboratory, there are many conflicts because the forming companies all have their own agenda, interests, and priorities. As a result, confrontations are not uncommon in this cooperative laboratory. But confrontations are allowed although it takes much time. In the confrontation, the researchers do not disguise their hostility and selfish desires because their performances are evaluated by their parent companies but not the Association. This kind of communication may seem very non-conventional and is not based on trust at the first glance. However, this kind of richness of personal interaction, regardless of its intent behind, had contributed much to the sharing of knowledge. Another mechanism that enhanced the communication among different parties in the laboratory is the formalization of documentation and communication. Because this is a national project, many documents were needed. In order to finish these documents, frequent face-to-face communication or confrontation of the first line researchers was necessary. In addition, a formal internal meeting for the researchers to report and discuss their recent research results was held once or twice a month. Such formalized processes were indeed useful in clarifying and sharing the contents and joint efforts among different researchers. Aside from the natural or designed mechanisms above, "institutionalization" of the cooperative laboratory is a very important step to foster trust and further improve the knowledge sharing. Selznick distinguishes between organization and institution as follows:

"Organizations are technical instruments, designed as means to definite goals. They are judged on engineering premises; they are expandable. Institutions, whether conceived as groups or practices, may be partly engineered, but they have also a "natural" dimension. They are products of interaction and adaptation; they become the receptacles of group idealism; they are less readily expandable."

From Selznick's description about institution, it's not difficult to realize the role of trust in the process of institutionalization. To foster trust in the organization, in addition to the formalized communications, many opportunities for off-the-job communication were also arranged. A number of extracurricular groups in sports and travel were organized by the researchers. The

drinking at night, usually at the executive office or the reception room of the Association also facilitated the off-the-job communication. These informal off-the-job communications provided opportunities for sharing redundant information which is indispensable for the formation of trust in the organization according to our model. Through such multiple and intense communication, the trust was finally formed in the organization. The organization eventually institutionalized and turned into a social unit instead of a convenient conglomeration. The knowledge processing in this cooperative laboratory became very efficient and effective and led to the success of the project.

2.2 Spiral of Knowledge

Anderson's ACT model (Anderson 1983) categorizes knowledge into declarative knowledge (actual knowledge) and procedural knowledge (methodological knowledge). ACT model hypothesizes that for human's cognitive skills to be developed, declarative knowledge must be transformed into procedural knowledge first. Meanwhile, ACT model also hypothesizes that the transformation procedure occurs unidirectionally from declarative knowledge to procedural knowledge. However, Nonaka (1994) argues that the transformation should be bidirectional and proposes his "Four Modes of Knowledge Conversion." In lieu of Anderson's declarative knowledge and procedural knowledge, Nonaka uses explicit knowledge and tacit knowledge in his model. In this model, it is assumed that knowledge is created through four different modes of conversion between explicit and tacit knowledge (Figure 2-3): (1)Socialization mode: from tacit knowledge to tacit knowledge, (2)Combination mode: from explicit knowledge to explicit knowledge, (3)Internalization mode: from explicit knowledge to tacit knowledge, (4)Externalization mode: from tacit knowledge to explicit knowledge.

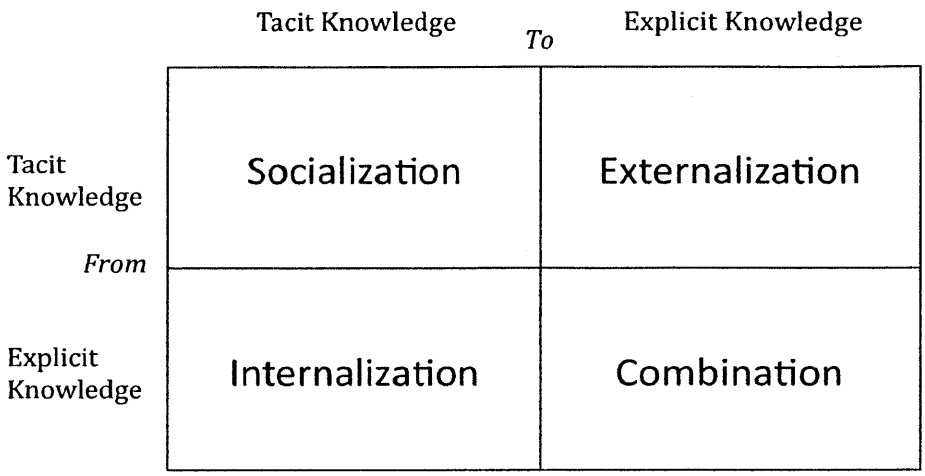


Figure 2-3 Modes of knowledge conversion (Source: Nonaka 1994)

The socialization mode involves the conversion of tacit knowledge to tacit knowledge through the interaction between individuals. This kind of conversion can be achieved without language or other forms of "knowledge carriers." For example, apprentices can learn craftsmanship from their mentors by observation, imitation and practice in lack of knowledge carriers. On-the-job training is also another type of socialization mode of knowledge conversion. The key to this mode is the existence of shared experience. Without some form of shared experience, the acquisition of tacit knowledge may not happen. The combination mode involves the conversion of explicit knowledge to explicit knowledge using social processes. Through social processes, individuals can exchange and combine different bodies of explicit knowledge and create new knowledge. Conferencing, co-authoring and etc. all belong to this mode of knowledge conversion. The third type and fourth type of knowledge conversion involve both explicit and tacit knowledge at the same time. Externalization mode relates to the conversion of individuals' tacit knowledge to explicit knowledge. Internalization mode relates to the conversion of explicit knowledge to individuals' tacit knowledge. This internalization mode is similar to what is traditionally referred to as "learning." Metaphor plays an important role in the externalization process while action is an inseparable part of the internalization process.

At the fundamental level, it is individuals that create knowledge. An organization cannot create knowledge without individuals. Therefore, organizational knowledge creation should be

understood in terms of a process that "organizationally amplifies the knowledge created by individuals, and crystallizes it as a part of the knowledge network of organization" (Nonaka 1994). Individual knowledge can be created by the four modes independently while organizational knowledge, originated from individual knowledge, is created through the dynamic interactions between different modes of knowledge conversion. These interactions, i.e. shifts between different modes, are induced by different triggers and take place in a certain order to form a continual cycle. In an organization, because of common interests, needs or strategic relatedness, participants in the organization usually form self-organizing teams to eliminate uncertainties collectively when pursuing their goals. The formation of a self-organizing team provides a field of interaction between different individuals. As discussed in the previous section, this field of interaction can enrich personal interactions and enhance the formation of mutual trust that facilitates the sharing of members' experiences and perspectives with which tacit knowledge of different individuals can be "socialized." In addition to socialization mode of knowledge conversion, externalization mode is also triggered by successive rounds of dialogues between team members. In the dialogue, sophisticated metaphors are used to communicate the hidden tacit knowledge which is otherwise hard to articulate. Through the externalization mode of knowledge conversion, new concepts are formed in the team and hence we can regard externalization mode as the dominant mode for the conceptualization step in the formation of organizational knowledge. The necessary creative dialogues in this mode are realized only when information redundancy exists within the team. The information redundancy, according to the discussions in the previous section, will promote the mutual trust in the team. After the externalization process, team members can then share and grasp the concepts and perspectives of one another and form common meanings. These common meanings are then combined with existing and external knowledge to make the meanings more concrete and sharable. This combination mode is triggered by coordination mechanism between the team members and other parts of the organization as well as the "documentation" of knowledge. Through iterative trial-and-error processes, concepts are articulated and developed until a more concrete form eventually emerges. This "experimentation" mechanism triggers the internalization mode through a process of "learning by doing," which allows the participants in the field to translate the explicit knowledge gradually into different aspects of tacit knowledge according to their own "intentions." In this process the organization can test the reality and applicability of knowledge

created by the self-organizing team and crystallize the knowledge into some concrete form such as products or systems. It should be noted that individuals' new tacit knowledge internalized in this stage may trigger another round of knowledge creation spiral, which usually results in refinement of the current concept or even re-creation of a brand new concept fundamentally. Through the interactions between the four modes of knowledge conversion, tacit knowledge of individuals can be mobilized and amplified to become part of organizational knowledge. This dynamic "entangling" of different modes of knowledge conversion is referred to as "spiral" model of knowledge creation as illustrated in Figure 2-4. This process of interactions between tacit knowledge and explicit knowledge tend to become larger and faster as more and more actors in the organization are involved. As a result, the creation of organizational knowledge can be regarded as an upward spiral process starting from individual knowledge up to collective knowledge, and then to organizational knowledge. If inter-organizational actors are involved in the process, the spiral may even move up to inter-organizational level.

As the creation of organizational knowledge is a continual spiral with no end, an organization needs to converge this spiral process at some point to condense the concepts created in the process to a body of knowledge so that it can be shared across the organization boundary for further knowledge creation. As knowledge is typically defined as "justified true belief," this convergence must be based on the justification or truthfulness of the concepts. Justification is a screening mechanism that determines the true value of the knowledge created to the organization. Justification also determines the extent to which the concepts created in the process are condensed to knowledge and therefore the "quality" of created knowledge. This justification mechanism also involves criteria or "standards" for judging truthfulness. In the knowledge-creation organization, it is top or middle-level managers' responsibility to develop and determine the standard which must be evaluated in terms of its consistency with higher order value systems. The justification standard to some degree is embedded in the cognitive dimension of social capital (refer to discussions about social capitals in chapter 4), which described by Tsai (1998), "is embodied in attributes like a shared code or a shared paradigm that facilitates a common understanding of collective goals and proper ways of acting in a social system." In this sense, Nonaka's conclusion that the justification mechanism must be developed and determined by top

or middle-level managers is in accordance with my perspective that the cognitive dimension of social capital can only be fostered deliberately by the management elaborated in chapter 6.

Furthermore, we should also pay attention to the temporal effects on team performances. Because the whole process involves conversion between explicit and tacit knowledge, team experiences play another key role in the process. As more and more common knowledge is accumulated with team experiences, team members can share and communicate their explicit as well as tacit knowledge in different steps of the spiral more effectively and efficiently, and therefore enhance the knowledge creation performance of the team. However, Katz (1982) observes that team longevity and familiarity among team members eventually become detrimental to team performances. Guzzo and Dickson (1996) also note that lack of change in team members can contribute to sluggish team performances. Familiarity among team members can induce ignorance or miscoding of familiar situations that may signal new opportunities for innovation. As a result, the redundant information shared by the team members may decrease as team members become more and more familiar with one another. These phenomena observed in contemporary research about team performances may be a reflection of an old saying "Familiarity breeds contempt." In this sense, Madhavan and Grover's proposed that past team experiences will have a curvilinear (inverted-U) relationship with a team's performances. The familiarity that results in ignorance and miscoding stems from high degree of knowledge commonality, which is shaped by the externalization process in the creation of organizational knowledge. The common knowledge will then change the base of "Existing Knowledge" recognized in the subsequent combination process.

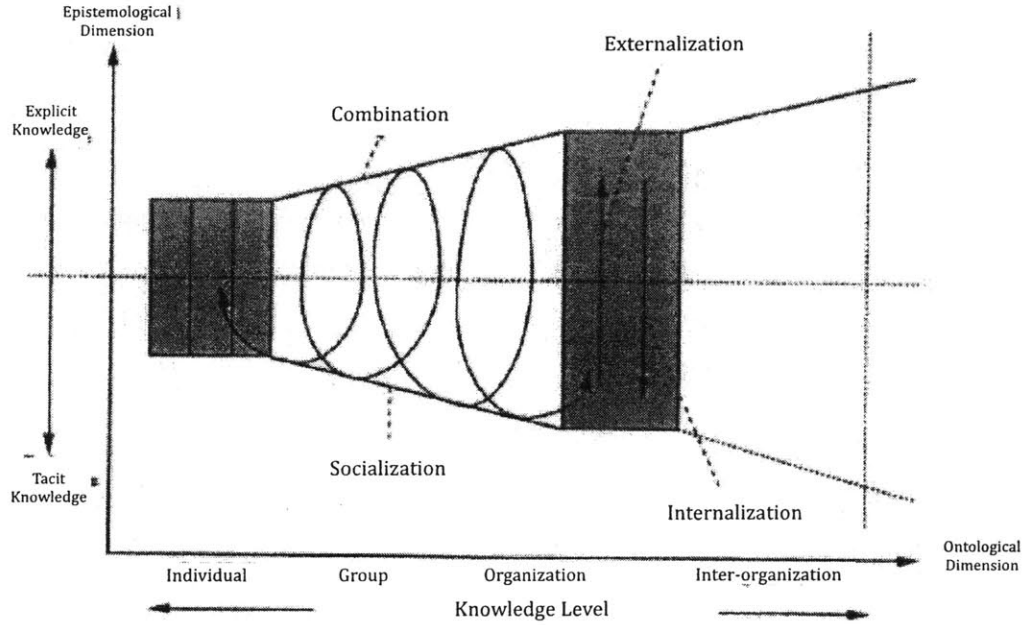


Figure 2-4 Spiral of organizational knowledge creation (Source: Nonaka 1994)

The new concepts realized through the spiral process represent the emergence of the organization's knowledge network. After the new concepts are crystallized and justified in the organization, they are integrated into the organization's knowledge base which is expressed in form of a whole network of organizational knowledge. The creation of organizational knowledge initiated by the individuals in the organization is an endless spiral with many interfaces with the environment that serves as a continual source of stimulation to knowledge creation within the organization. For example, new product development process, as described by Madhavan and Grover (1998) can be considered a process to transform embedded knowledge (tacit knowledge of individuals in the organization) to embodied knowledge (new products or services). The embodied knowledge in form of products then interacts with customers' or other market participants' tacit knowledge through their bodily actions such as purchasing, adapting, using or criticizing. Through these interactions customers' or other market participants' tacit knowledge can be mobilized and fed back to the organization to trigger a new cycle of organizational knowledge creation. What von Hippel called "Democratizing Innovation" (2005) can be considered a process that systematically integrates customers' or other market participants' tacit knowledge into the organization's spiral of knowledge creation. The total process of organizational knowledge creation is summarized in Figure 2-5 below.

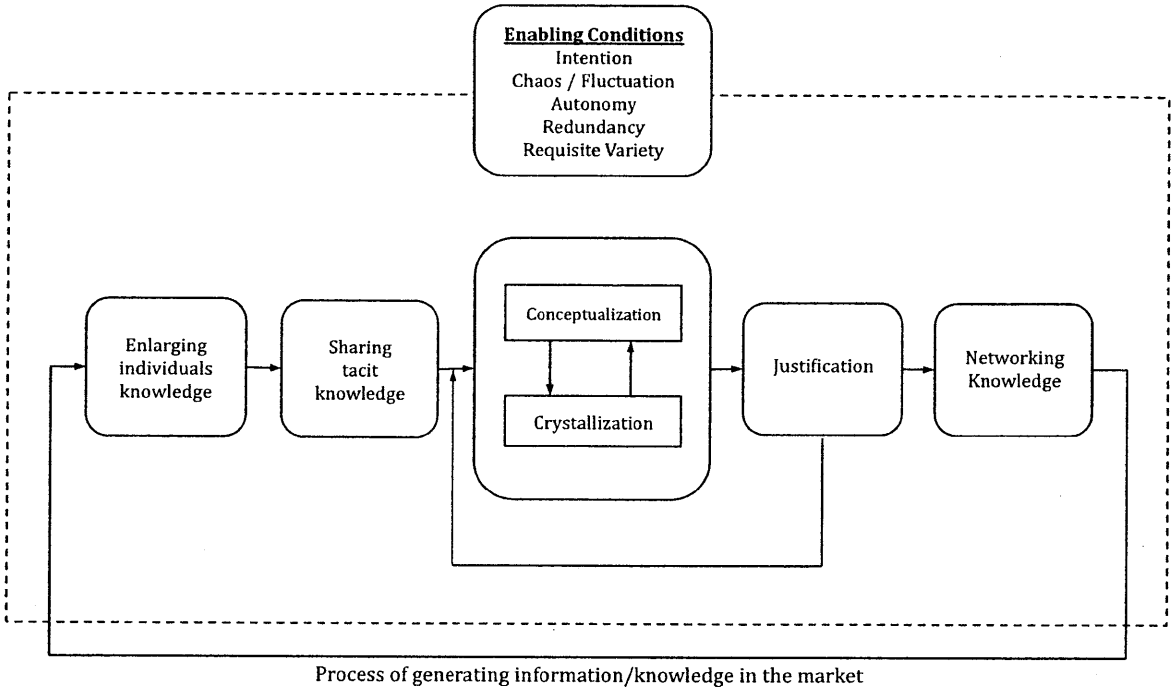


Figure 2-5 Organizational knowledge creation process (Source: Nonaka 1994)

Consolidating all the discussions above, I organize a system architecture for the knowledge processing in Figure 2-6 below. According to the discussions above, RPI (Richness of Personal Interaction), Trust and Redundant Information are the enabling factors for the dialog within the team. Since dialog is the most important form of knowledge socialization process, these three factors are closely related to the socialization process. Redundant information is the operand of the socialization process. This process can convert the redundant information to common perspective or concepts within the team. Richness of Personal Interaction and Trust can be considered the instruments for the process and the self-organizing team is the major operator of this process. The common perspectives or concepts formed in the socialization process then go through the externalization process, combination process and internalization process to become internalized concepts of each team member of the self-organizing team. These internalized concepts are then justified by the team members according to different intentions and high order values of the organization and become different individual tacit knowledge. Therefore, in the "Justification/Qualification" function, "Internalized Concepts" are the input operands and "Individual Knowledge" is the output operand. "Intention" and "High Order Values" play the

roles as instruments in this process. The new individual knowledge formed after the justification process will become the new source of redundant information and trigger another round of knowledge creation loop. The internalized concepts created by the self-organizing team are continually tested by different functional or divisional departments and crystallized into knowledge of concrete forms such as products or systems. During the "Concept Testing" process some instrumental skills, which belong to a part of tacit knowledge, will be exploited. In this sense, "Individual Knowledge" can be regarded as an instrument to the "Concept Testing" process. "Knowledge of Concrete Forms" crystallized in this process will become an instrument to mobilize market participants' tacit knowledge. The mobilized market participants' tacit knowledge will then be integrated with team members' individual knowledge and trigger a new round of creation of organizational knowledge. In this architecture, the three factors that can induce individuals' commitment to create knowledge in the organization setting, which are intention, autonomy, and fluctuation, are the instruments of three different processes. "Intention" is the instrument of the "Justification/Qualification" process that transforms concepts into knowledge. "Fluctuation" is the instrument of the "Introspection" process that drives team members to reconsider their fundamental thinking and perspectives. This process will affect the creation of knowledge by changing the intentions of individuals. Therefore "Intention" can also be regarded as the operand of this process. According to previous discussions, "Autonomy" can increase the possibility of introducing creative metaphors that can enhance the sharing and communication of individuals' diversified tacit knowledge. It's appropriate to consider "Autonomy" the instrument of "Sharing and Communication" of tacit knowledge. This architecture eventually manifests the fact that the three most important processes composing knowledge creation at individual level are "Justification/Qualification," "Introspection" and "Sharing and Communication."

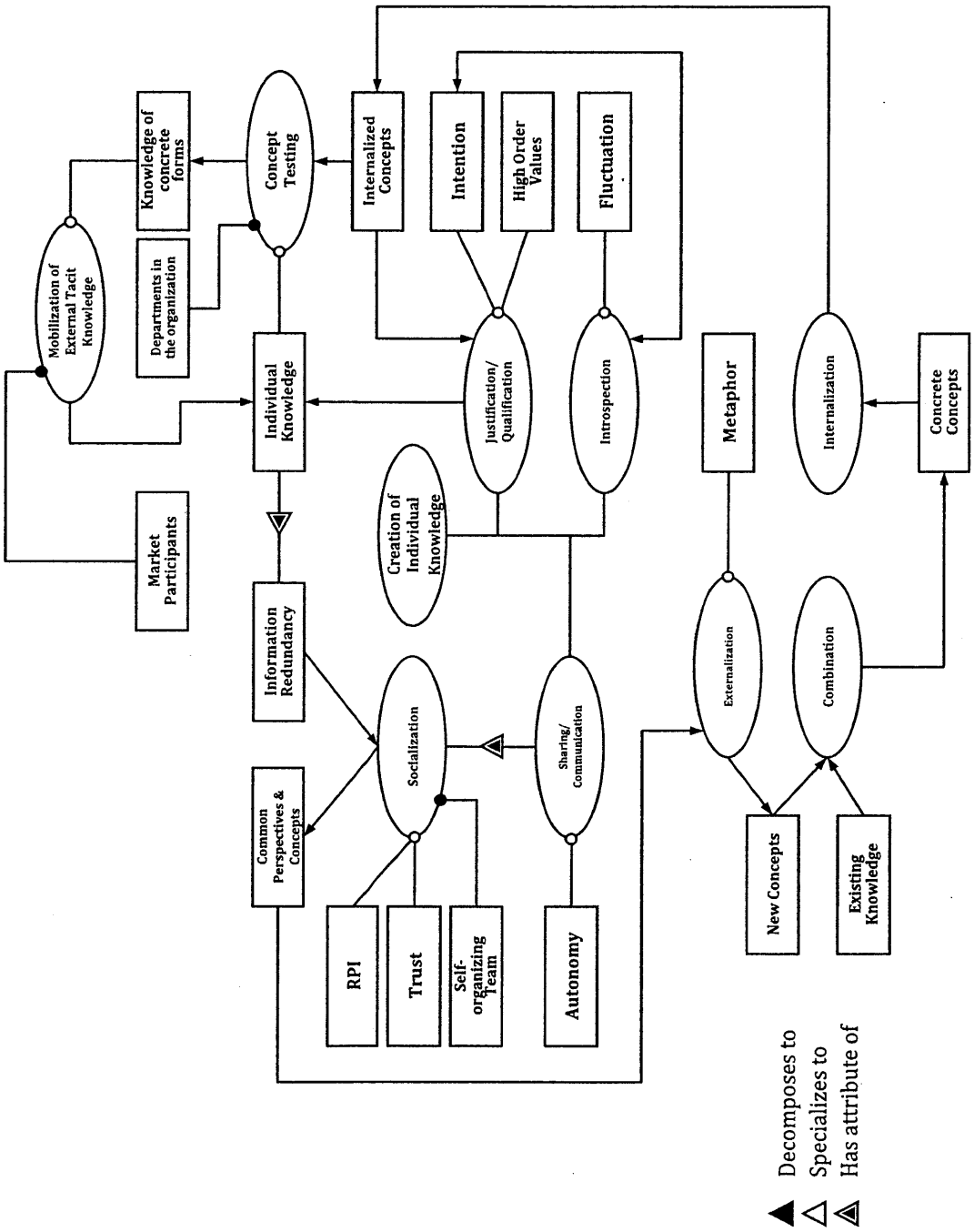


Figure 2-6 System Architecture for knowledge processing

According to the discussions above, I set up a causal loop diagram below (Figure 2-7). This diagram is a combination of different processes. The solid lines represent the correlations of different factors described in this section. In addition to the processes discussed in this section, we can combine this organizational knowledge creation process with the individual knowledge creation process discussed in the previous section. The factor "Formation of Tacit Knowledge" in this diagram is actually the same as "Knowledge Creation at Individual Level" in Figure 2-1 because the tacit knowledge can only be formed at individual level. Combining these two levels of knowledge creation processes, we can add the links between "Environmental Fluctuations" and "Formation of Intentions," and "Environmental Fluctuations" and "Formation of Tacit Knowledge" illustrated by dotted lines. Aside from intentions and environmental fluctuations, autonomy is another important factor affecting the knowledge creation at individual level. The degree of autonomy is enhanced by the formation of self-organizing team. Formation of self-organizing team is a process of establishing networks within the organization. I will discuss this network-formation process in a later chapter in which the correlation between network formation and other factors in addition to "Common Interests & Strategic Needs" will become manifest. The other correlation I would like to highlight is the correlation between "Environmental Fluctuations" and "High Order Values." Sometimes the cognitive dimension of social capital can change with external knowledge environment owing to coevolution effects (refer to chapter 4). Since the change of external knowledge environment represents a kind of environmental fluctuation and "High Order values" is part of cognitive dimension of social capital, it's reasonable to assume that there exists a positive correlation between "Environmental Fluctuations" and "High Order Values." The environmental fluctuations will affect the high order values of the organization and further influence the creation of organizational knowledge through justification and qualification of knowledge. In this model, there are three key exogenous factors, "Environmental Fluctuations," "High Order Values," and "Common Interests & Strategic Needs" respectively. All these three factors will influence the creation of organizational knowledge. Managers in the organization may not be able to influence the creation of organizational knowledge by controlling "Environmental Fluctuations" but they can try to do so by setting proper high order values and by maintaining an atmosphere that can manifest different interests and strategic needs of different participants in the organization to encourage the formation of self-organizing teams. The self-organizing teams also play an

important role in the development of organizations' knowledge diversity that can help organizations catch the signals of opportunities or threats from environmental fluctuations by promoting the sharing of redundant information as discussed in the previous section about requisite variety.

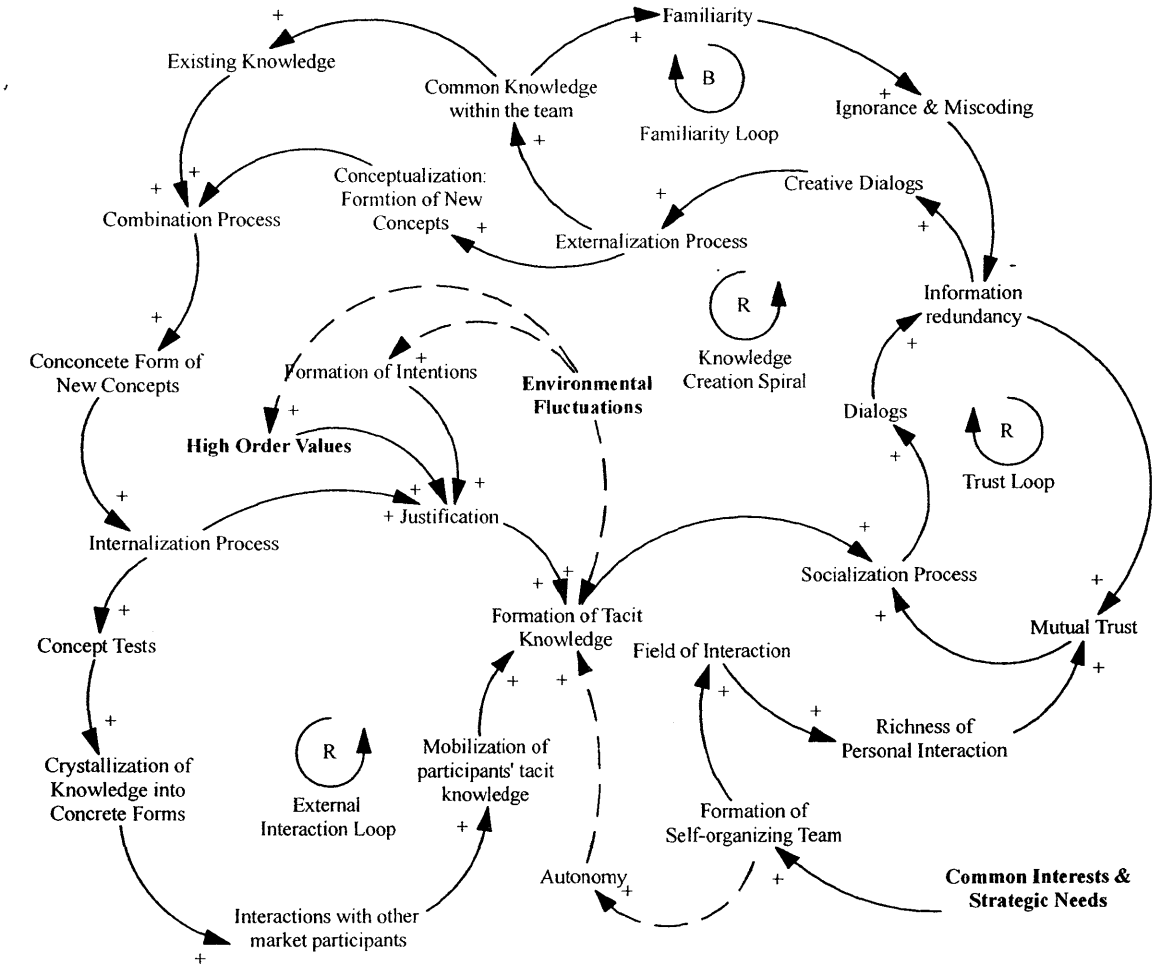


Figure 2-7 Dynamics of the knowledge creation process

Eisenhardt and Martin (2000) observed that over time firms' capabilities converge to an industry standard wherein competitor capabilities are similar in key attributes. This equifinality feature can well be derived from the system dynamics discussed in this section. As an industry becomes matured, the industrial environment also becomes stable with few environmental fluctuations and consequently the rate of knowledge creation tends to become slower according to Figure 2-7. However, ceteris paribus, the rate of knowledge diffusion among different industrial players is not affected by the environmental fluctuations. Eventually the rate of knowledge diffusion will exceed the rate of knowledge creation at industry level. As a result, the degree of knowledge commonality among players of the industry with a stable environment tends to equalize over time. The high degree of knowledge commonality will further enhance the absorptive capacity of different players in the industry and expedite the diffusion of knowledge. This reinforcing loop catalyzed by common knowledge is especially influential in stable environments where the innovations are usually incremental rather than radical. In a stable environment, the members of self-organizing teams in the organization usually share more common knowledge and hence the effects of "Familiarity Loop" balancing loop are usually stronger. This balancing loop will further decrease the average rate of knowledge creation in the industry and equalize industrial players' knowledge level. Consequently, knowledge creation activities tend to diminish at industry level and the knowledge level of industrial players tends to equalize over time in a stable environment. A simplified causal loop is illustrated in Figure 2-8 below to account for this phenomenon.

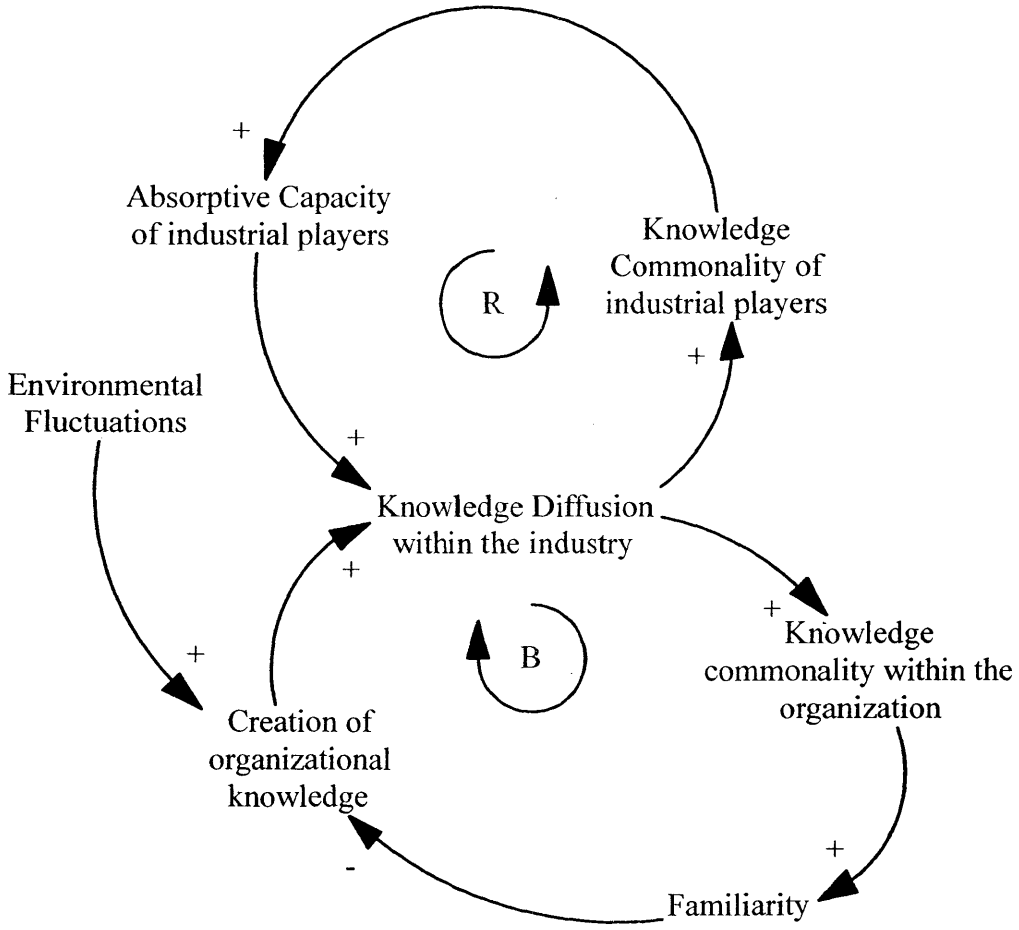


Figure 2-8 Equifinality of knowledge creation in a stable environment

Chapter 3 Absorptive Capacity

In our architecture of innovation processes, absorptive capacity serves as the instrument for both the diffusion process of external stimuli that raise the need for innovation in the organization, and the subsequent innovation process in response to the need. The ability to explore and exploit external knowledge is thus a critical component of innovation capabilities. The abilities to "recognize the value of new information, assimilate it, and apply it to commercial ends" collectively constitute what Cohen and Levinthal call "absorptive capacity." After Cohen and Levinthal published his new concept of "Absorptive Capacity" in knowledge management in 1990, researchers have implemented this new concept in their analysis in different fields including strategic management (Lane & Lubatkin, 1998), technology management (Schilling, 1998), international business (Kedia & Bhagat, 1998), new product development (Stock, Greis, and Fischer, 2001) and organizational economics (Glass & Saggi, 1998). According to Cohen and Levinthal, this absorptive capacity is largely a function of the level of common knowledge among team members in the organization. As Grant (1996) concluded, the level of common knowledge in the organization is one of the key factors that will affect the efficiency of knowledge integration. The level of common knowledge enables the required communication between individuals to benefit from pre-defined routines or processes or other un-defined socialization processes. No matter the transfer of explicit knowledge that relies on communication or the transfer of implicit knowledge that relies on practicing, common knowledge is an indispensable element. Common knowledge allows individuals to share and integrate the knowledge that is not in common. The level of common knowledge is usually formalized as the perception of the intensity of external stimuli including external knowledge. Grant (1996) concluded different types of common knowledge that played different roles in knowledge integration:

- Language
- Other forms of symbolic communication
- Commonality of specialized knowledge
- Shared meaning
- Recognition of individual knowledge domains

The key function of common knowledge in the organization is communication, which is the very first step for the knowledge sharing and acquisition. At the most basic level, effective communication within and across the boundaries of organizations is only possible when the knowledge to be communicated consists of language and symbols shared by different organizations. The higher level of common knowledge, the more effective the communication. However, if all the actors in the organization possess the same specialized language, they absolutely can communicate with one another very effectively, but on the other hand, they may also lose the ability to tap into the diverse external knowledge sources to sustain the development of knowledge diversity which is crucial to problem solving and knowledge creation. The coexistence of diverse knowledge in individual's mind can elicit learning and problem-solving that yields innovation (Simon, 1985). Utterback (1971) also noted that diversity in work setting "increases the probability of idea generation." The criticality of diversity of knowledge in the organization derives from the role of redundancy in the organization. To some managers, the connotations of unnecessity, duplication and waste of "redundancy" may sound unappealing. However, Nonaka (1994) notes that "redundancy" plays a key role in the knowledge creation at organization level. Redundant information can be an instrument in speeding up concept generation and a vehicle for problem resolution and knowledge creation processes that are not specified by the official organization structure. In addition, redundant information will also promote the formation of deep, mutual trust between the members of the organization, which Nonaka regarded it as the creator of knowledge. Without diversity of knowledge in the organization, sharing of redundant information will never happen. This perspective about knowledge diversity of group members can also be reflected from Lewin's (1951) field theory in social psychology that defines a "group" as "a dynamic whole based on interdependency rather on similarity." As Utterback (1971) observed that diversity in the work setting could stimulate the generation of new ideas, Clark and Fujimo (1987) also found that the links between different problem-solving cycles involving diversified roles and functions in an organization had strong influence on the speed of product development. Therefore, there is a trade-off between the commonality and diversity of knowledge in the organization. Excessive dominance of one over the other in an organization will be dysfunctional. Both knowledge commonality and diversity in the organization are important to innovation processes. It is not surprising that Lofstrom (2000) reports that knowledge complementarity, defined as the extent to which knowledge is common to

but meanwhile different from the knowledge of contacts in their information network, is positively related to a firm's learning.

However, to develop effective absorptive capacity, it's not enough to just expose people to common or diverse prior knowledge unless they make conscious efforts to internalize, to combine and to apply the knowledge. According to learning-set theory, high intensity of effort is necessary for people to learn from early problems and to transfer and apply the knowledge learned from early problems to later complex problems. Therefore, intensity of effort can determine the speed of knowledge conversion. As Kim (2002) concluded, intensity of effort is "represents the amount of emotional, intellectual, and physical energy that members of an organization invest in acquiring and converting knowledge." Of prior knowledge and intensity of effort, the intensity of effort or commitment is more important than the knowledge base as the former creates the latter but not vice versa according to Ulrich (1998). High intensity of effort played decisive role in Samsung's technological learning in semiconductors (Kim 1997). To close the technological gap between Korea and other leading companies in US and Japan, Samsung deliberately set some seemingly unreasonable goals for its technological learning progresses and mass-production plan of new technologies to intensify its internal efforts in learning and converting knowledge. This strategy drives Samsung to expedite its technological learning in early stages to initialize the rapid development of its own capabilities that in consequence enable its more complex technological learning and innovation processes in later stages. With intensity of effort as the catalyst, Samsung eventually catch up with its foreign rivals in DRAM technologies.

The development of absorptive capacity over time is path-dependent. Prior knowledge permits the exploration, assimilation and exploitation of new knowledge. The accumulation of absorptive capacity in one period will allow more efficient accumulation in the next. With the absorptive capacity developed in an area in one period, the organization is more ready to establish new absorptive capacity in the vicinity of that area in the next period owing to higher commonality of knowledge. The absorptive capacity also confers the organization the ability to better understand and evaluate the new knowledge development in related areas that signifies the changes in the knowledge environment it dwells in and thus affects the formation of expectations about the

eventual merits of developing new absorptive capacities in response to the changes. As a consequence, the current absorptive capacity will condition the incentives for the investment in subsequent absorptive capacity. Therefore, the development of absorptive capacity is domain-specific and path or history-dependent. Because of these domain-specific and path-dependent properties of absorptive capacity, a firm that does not develop its absorptive capacity in some initial period in a fast-changing field may be "lockout" from the subsequent development of absorptive capacity. This phenomenon can also be reflected by Ahuja and Lampert's (2001) observations about "competence traps." The first type of competence trap is "propinquity trap" reflecting organizations' tendency to explore new knowledge closest to its existing knowledge. This trap is exactly a reflection of domain-specific property of absorptive capacity. Another type of competence trap is familiarity trap resulting from an overemphasis on refining and improving existing knowledge, preventing the organization from exploring alternate knowledge sources. This trap from my perspective to some degree is a consequence of propinquity trap. If the organization cannot develop enough diversity of knowledge over time owing to the propinquity trap, it would be more and more difficult for the organization to detect the external stimuli that may evoke the need for innovation in the organization. Losing this perspective to external environments, the organization naturally becomes more inward-looking and focuses more on refining and improving existing knowledge rather than acquiring external knowledge. This trap reflects the path-dependent property of the absorptive capacity.

Despite the wide adoption of the construct of "Absorptive Capability," the definition of "Absorptive Capacity" remains diversified and ambiguous and varies depending on the focuses of different researches. In Cohen and Levinthal's original definition, absorptive capacity (ACAP) is the ability to value, assimilate, and apply new knowledge to commercial ends. Suggested by Cohen and Levinthal, the R&D intensity defined as R&D investment divided by sales can be considered an index for ACAP. However, in different papers, ACAP is conceptualized differently. Zahra and George (2002) have consolidated different definitions and concepts about ACAP and summarize them in a table (Table 3-1 below). Extending Cohen and Levinthal's concepts of absorptive capacity, Zahra and George also proposed a model for the development of competitive advantages (Figure 3-1 below). In their model, absorptive capacity can be divided into potential ACAP (PACAP) and realized ACAP (RACAP) which are complementary to each

other. PACAP captures Cohen and Levinthal's description of firms' ability to value and acquire external knowledge but does not necessarily lead to the exploitation of this knowledge. RACAP, on the other hand, reflects firms' capability to leverage and exploit the absorbed knowledge. In this model, the development of potential absorptive capacity (PACAP) is a response to activation triggers. Triggers are events that encourage or compel a firm to respond to specific internal or external stimuli (Walsh & Ungson, 1991; Winter, 2000). The triggers can either be internal or external. Internal triggers could be performance failures or events that may reshape company's strategies. External triggers could be the emergence of dominant design or disruptive technologies, or changes in government policies. All these internal or external triggers intensify a company's efforts to seek for external knowledge. PACAP and RACAP play separate but complementary roles in an organization. These two elements coexist in the organization all the time and execute their respective functions all together to improve an organization's performance.

In this thesis, I will follow Cohen and Levinthal's original definition for absorptive capacity. With absorptive capacity built in the organization, the organization can then be sensitive to cues for change from the environment such as customers, suppliers, alliances or even competitors. After the organization confirms its need for innovation and start to take actions to innovate, the absorptive capacity can enable the acquisition, conversion and application of knowledge in the innovation process. Therefore, the absorptive capacity can be regarded as the locomotive of the innovation process. From this definition, we can extract two important qualities of absorptive capacity. Its definition implies that the development of absorptive capacity in the organization requires a good mechanism to identify and assimilate valuable knowledge to the organization, which necessitates knowledge diversity in the organization. This capability to identify and assimilate valuable knowledge will eventually affect the "effectiveness" of the absorptive capacity. However, the identification and assimilation of new knowledge from external knowledge sources are originally initiated by individuals acting as "gatekeepers" or "boundary spanners" in the organization (refer to chapter 8). The organization needs to transform this knowledge at individual level to absorptive capacity at organization level with a different mechanism. The pace of this transformation process will influence the "efficiency" of absorptive capacity. The faster the transformation, the faster the absorptive capacity at organization level can be developed and start to create values. This mechanism should facilitate the diffusion of

knowledge in the organization and the collective creation of new knowledge about the application of assimilated knowledge to commercial ends. Nonaka's knowledge creation spiral model (refer to chapter 2) can well describe this process. To trigger this mechanism, communication and sharing of knowledge enabled by common knowledge among team members are indispensable. Therefore, it is concluded that knowledge diversity and knowledge commonality will both affect the quality of absorptive capacity. Their effects will be manifested in the causal loop diagram described in the subsequent section.

Past Conceptualization of ACAP

Definition	Dimensions	Illustrative Studies
The ability to value, assimilate, and apply new knowledge (Cohen & Levinthal, 1990)	Ability to value knowledge through past experience and investment Ability to assimilate • Based on knowledge characteristics • Based on organizational or alliance dyad characteristics Ability to apply • Based on technological opportunity (amount of external relevant knowledge) • Based on appropriability (ability to protect innovation)	Boynton, Zmud, & Jocobs (1994); Cohen & Levinthal (1989, 1990); Cockburn & Henderson (1998); Lane & Lubatkin (1998); Mowery, Oxley & Silverman (1996); Szulanski (1996)
A broad array of skills, reflecting the need to deal with the tacit components of transferred technology, as well as the frequent need to modify a foreign-sourced technology gor domestic applications (Mowery & Oxley, 1995)	Human capital: • Skill level of personnel • Tranind R&D personnel as percent of population • Trained engineering graduates • R&D spending	Glass & Saggi (1998); Keller (1996); Kim & Dahlman (1992); Mowery & Oxley (1995); Veugelers (1997)
ACAP requires learning capability and develops problem-solving skills; capacity to assimilate knowledge—for imitation and problem-solving skills to create new knowledge—for innovation (Kim, 1998)	Prior knowledge base; intensity of efforts	Kim (1995, 1997); Matusik & Heeley (2001); Van Wijk, Van den Bosch & Volberda (2001)

Table 3-1 Past conceptualization of absorptive capacity (Source: Zahra and George 2002)

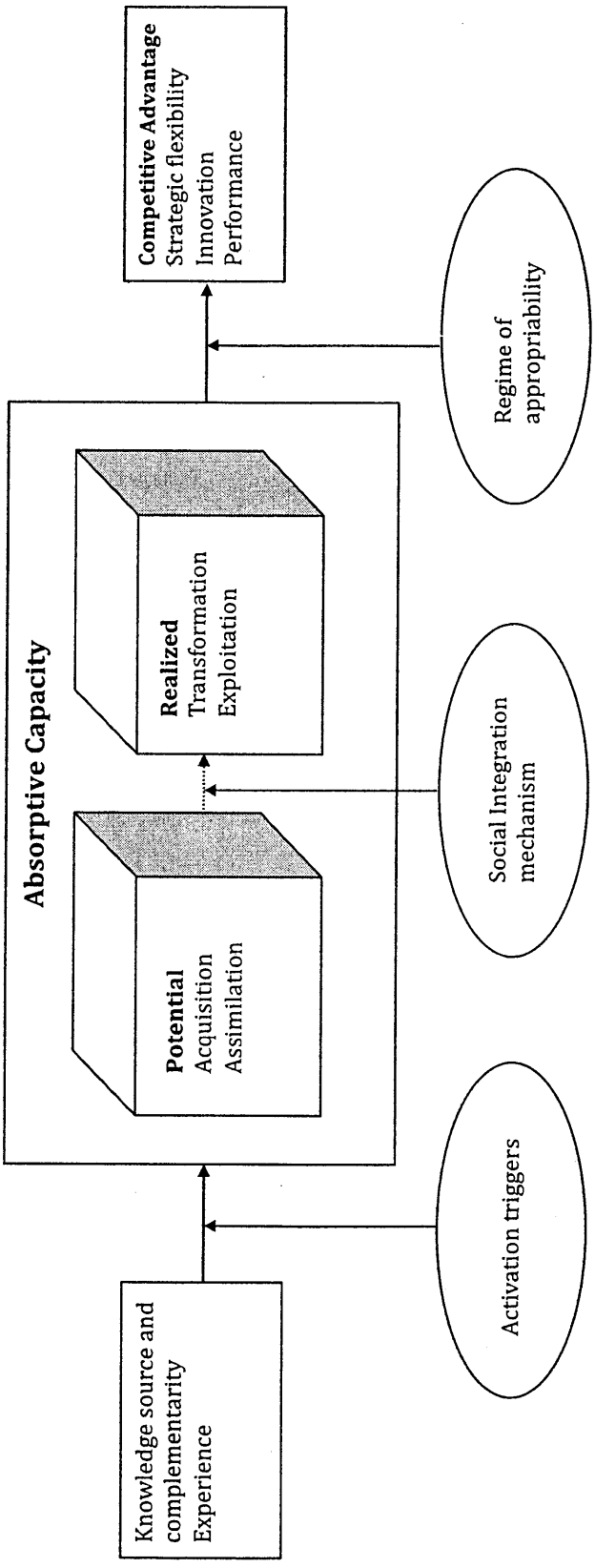


Figure 3-1 A model of absorptive capacity (Source: Zahra and George 2002)

The absorptive capacity is one of the instruments for the innovation process that acquires, assimilates, transforms and exploits knowledge. The descriptions about the absorptive capacity above suggest that common knowledge and intensity of effort are the two instruments for the development of absorptive capacity in the organization. Absorptive capacity (ACAP) is the operand of this process and it can be decomposed to Potential ACAP (PACAP) and Realized ACAP (RACAP). The duality of R&D role also deserves our attention. In the conventional perspective that focuses only on the knowledge spillover attribute of innovation, the negative spillover effects of R&D will eventually neutralize the benefits of R&D. However, Cohen and Levinthal introduce the concept of absorptive capacity and point out that R&D, which is a specialized form of absorptive capacity, can enhance organizations' ability to assimilate external knowledge spillover in the industry. Taking both the negative effect and positive effect of R&D investment into account, it is concluded that the total benefit to invest in R&D is still positive. Based on the discussions above, I propose a system architecture for the development and effects of absorptive capacity in Figure 3-2 below.

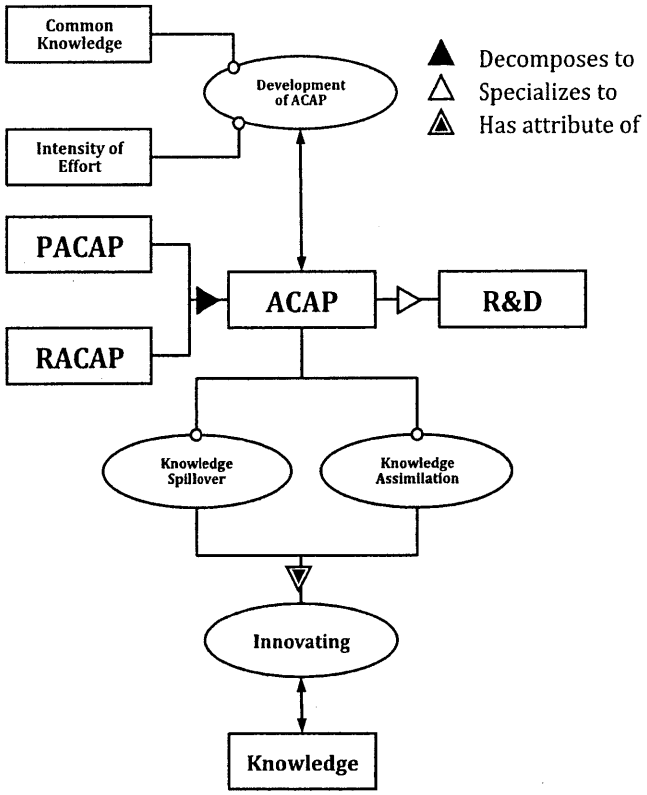


Figure 3-2 System architecture for absorptive capacity

Based on the discussions about factors that affect the development of absorptive capacity in previous sections, I set up a system dynamics causal loop diagram to describe the dynamic interactions between these factors in Figure 3-3 below. We can analyze the diagram from knowledge commonality first. Knowledge commonality in this diagram means the degree of overlap of team members' individual knowledge. Different team members may possess their own respective knowledge when a team is formed. Some of the knowledge is common to all team members and lays the foundation for communication and knowledge sharing among team members. Some is idiosyncratic to different team members and shape the knowledge diversity of the team. High level of common knowledge may enhance the knowledge diffusion among team members and promote the quality of the absorptive capacity in "efficiency" dimension. The improvement in this dimension of absorptive capacity will promote the assimilation of new knowledge through more efficient assimilation of external new knowledge (Efficiency Loop in the diagram) because of faster development of absorptive capacity. On the other hand, high level of knowledge commonality suggests low level of knowledge diversity in the organization. Low level of knowledge diversity will affect the "effectiveness" dimension of absorptive capacity and decrease new knowledge assimilation owing to deterioration of perceptivity to environmental cues (Effectiveness Loop in the diagram). The balancing efficiency loop and the reinforcing effectiveness loop counteract with each other and consequently lead to the "inertness" of new knowledge creation. Namely, because of the counteractions of these two loops, it's usually difficult to innovate without strong external driving forces. That's why environmental fluctuations are considered necessary conditions for innovation. It is worth noting that "New Knowledge" in this diagram represents the new knowledge assimilated by individuals, which has not been integrated into organizational knowledge at this stage. Therefore, different team members may form different knowledge according to diversified individual intentions. As a result, the new knowledge can contribute to the knowledge diversity of the organization (or decrease the knowledge commonality of the organization). The new knowledge will then be integrated into organizational knowledge during the development of absorptive capacity. The integration process is represented by the "Knowledge Integration Loop" in the diagram. The knowledge commonality among team members can enhance the communication in the organization and trigger the knowledge integration. The knowledge integration will then further increase the knowledge commonality in the organization as illustrated by the "Knowledge

Integration Loop" in the diagram. This reinforcing loop will create a momentum to increase knowledge commonality in the organization. The intensity of effort has positive effects on the creation of absorptive capacity. In this diagram I connect intensity of effort to "Communication Enhanced by Common Knowledge" and "Assimilation of New Knowledge." Without efforts in these two steps the whole process may not be initiated. This model also reflects Ulrich's (1998) perspective that intensity of effort is more important than common knowledge in the development of absorptive capacity as intensity of effort, unlike common knowledge, is an exogenous factor that provides the activation energy to initiate the whole process. After the process is triggered, common knowledge then takes over to provide necessary momentum to continue the process until an equilibrium state is achieved. Continual efforts are necessary to "excite" the organization out of its equilibrium state and continue to innovate. This necessary condition proposed by Cohen and Levinthal echoes my inference derived in another section that external driving forces are indispensable to keep the viability of innovation processes in the organization. However, Cohen and Levinthal did not mention the causes that drive the efforts in this process. The chapter about knowledge processing in this thesis has some discussions about these causes.

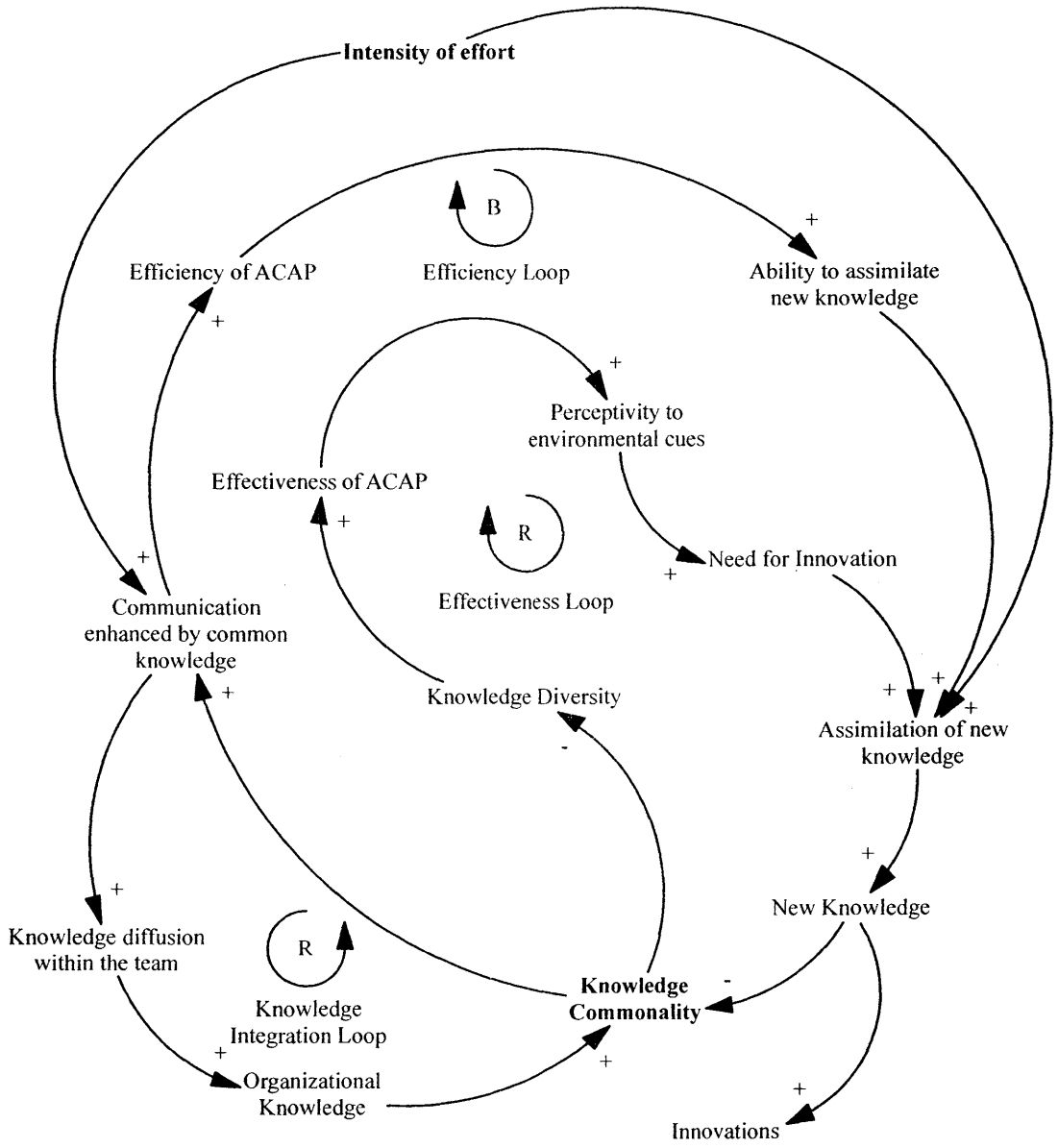


Figure 3-3 Dynamics between absorptive capacity and knowledge creation

Chapter 4 Intraorganizational Network

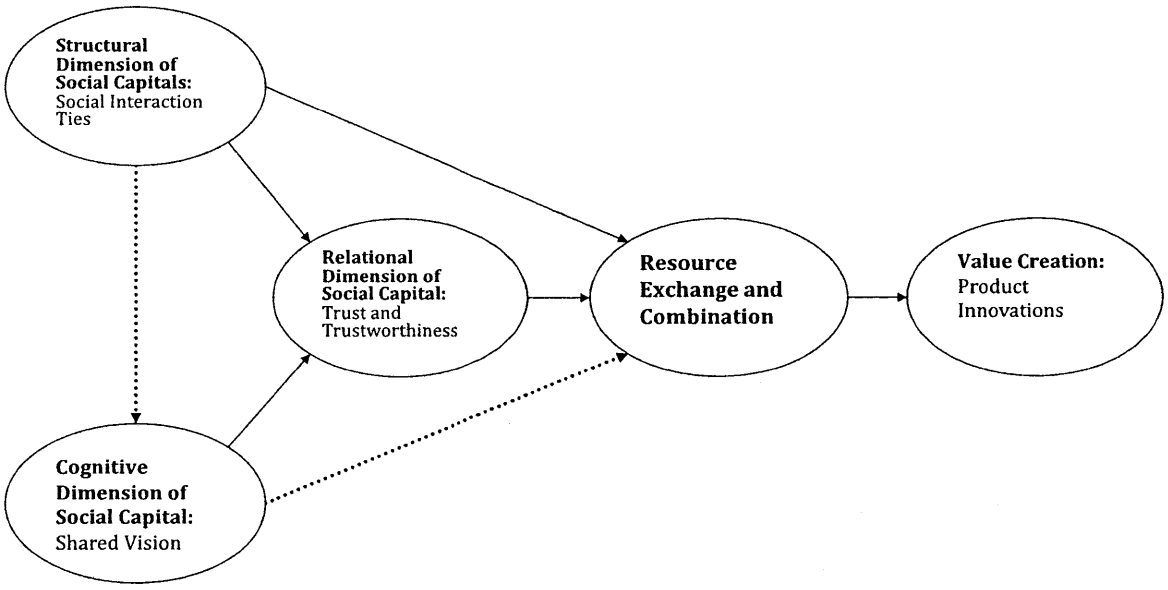
The transfer of knowledge involves both knowledge sources and knowledge recipients. When a unit in the organization needs specific resources or knowledge to resolve an issue, how can this unit search a proper internal or external source from which the unit can receive necessary resources or knowledge? Because usually the knowledge or information is quite "sticky" and ambiguous, how can the knowledge be transferred from the source to the recipient effectively after the source is identified? These questions are all related to the network in which the unit resides. The search and transfer of knowledge can only occur in the network formed in a shared social context. Intraorganizational (interunit) or interorganizational networks are the enabler of knowledge transfer. It is in these networks that the exchange of resources or knowledge can take place effectively and hence the competitive advantage can be developed (Hansen 1999).

Networks can be intraorganizational or interorganizational. Intraorganizational networks exist in large and complex multiunit organizations whose structure can be conceptualized as "a network arrangement consisting of a set of relational ties linking together dispersed organizational units" (Tasi 2000). Interunit resource or knowledge exchange can be an attractive alternative to market exchange as the communications that are crucial to exchange processes are facilitated by shared values, cultures or common organization languages. The development of social networks is path-dependent in the sense that prior networks may affect the development of future networks. The development of new linkages in the network is inevitably costly and risky in lack of sufficient and reliable information. After the formation of such linkages, it is also costly to maintain the relationship and the ties with other actors. As a result, once two actors have developed routines to manage the interface between them and form a stable linkage, they tend to rely exclusively on current routines and ignore the opportunities of forming new linkages with new actors. In exploring the role of coordination, Van de Ven and Walker (1984) also found that initial relationships between the actors significantly affected their subsequent development. In addition, the potential gains of relation-specific capital such as trust that must be developed over time can also create an inertial for the organization to focus on existing relationships rather than new ones. All these observations imply that the formation of linkages is a path-dependent process. Because of this path-dependency of network formation process, the capabilities and thus the innovation

outcomes of organizations following different paths in network formation may vary a lot. This may partially explain why competing companies exposed to similar market and resource conditions can perform so differently.

An effective and efficient intraorganizational network is not formed spontaneously. It must be fostered under some favorable conditions. Tsai (2000) examined the effects of two important factors, social capital and strategic relatedness, on the formation of intraorganizational networks. Like physical or human capitals, social capital can also enhance the productivity of an organization. As Tsai concludes from different papers, "Social capital represents the relational resources attainable by individual actors through networks of social relationship." Social capital can facilitate the formation of networks between actors in the organizational setting by providing a shared context for social interactions. Nahapiet and Ghoshal (1997) identified three dimensions of social capital: structural, relational and cognitive. The structural dimension of the social capital refers to the location of an actor's contract in a social structure of interactions. This structural location, like the spatial location, can provide actors the advantages in contacting and socializing external knowledge. A central position in a network structure means higher accessibility to other knowledge sources and hence provides more opportunities to establish linkages with other units. In addition, a unit in the central position of a network usually serves as a major channel of information for other units and hence is highly visible to other units in the organization. As a result, the central unit is also more attractive to other units to set up linkages. Therefore, the network centrality has become a focus in the discussion about the formation of interunit linkages and the creation of value in the firm. Relational dimension, on the other hand, refers to the assets that are rooted in these relationships such as trust and trustworthiness. Many uncertainties are involved in the formation of linkages. Trustworthiness can reduce these uncertainties by constraining opportunistic behaviors during the formation of linkages and by reducing the costs of finding an exchange partner. Without trustworthiness in the multiunit organization, the potential benefits of establishing strategic linkages with other units can never be fully achieved. It is trustworthiness among units that allows the exchange of idiosyncratic resources and knowledge and shapes the patterns of interunit networks. I will talk about the formation of trust in detail in a later section of this chapter. The third dimension of social capital, cognitive dimension, as described by Tsai (1998), "is embodied in attributes like a shared code

or a shared paradigm that facilitates a common understanding of collective goals and proper ways of acting in a social system." The shared value created collectively in the organization can coordinate common efforts of the individuals and facilitates the creation of values. Tsai and Ghoshal (1998) has set up a model to describe the relations between social capitals and value creation (Figure 4-1) based on empirical results. All these different dimensions of social capital may potentially contribute to the creation of values. However, the strength of the correlations between different dimensions is different according to the statistical analysis.



Solid lines indicated significant paths. Dashed lines indicate nonsignificant paths.

Figure 4-1 Relations between social capital and value creation (Source: Tsai and Ghoshal 1998)

The other important factor related to the formation of intraorganizational networks is strategic relatedness. With strategic relatedness among different units in the organization, the units can share internal resources that are not tradable through external market mechanisms and thus the organization can develop new competitive advantages accordingly. High degree of strategic relatedness among intraorganization units implies high degree of common prior knowledge which enhances communications and knowledge sharing among units. In addition, when units are strategically related, usually they share some common interests and therefore they have

higher incentive to exchange or share resources or knowledge through interunit linkages. Therefore, strategic relatedness among units is positively related to the rate of interunit linkage creation.

According to the discussions above, I set up a system dynamics causal loop diagram below (Figure 4-2). In this causal loop diagram I include only the significant paths and ignore the nonsignificant paths indicated in Figure 4-1 above. From the diagram, it seems that there is only one reinforcing loop that reinforces the relational dimension of social capital continually (Trust-Trustworthiness Loop). However, I would propose that there should exist another loop enabled by the link between value creation and the cognitive dimension of social capital. According to Grant's definition, the cognitive dimension of social capital consisting shared norms and values that can facilitate value creation in the organization can be considered a kind of common knowledge. This dimension of social capital is embedded in organizational cultures which are manifested by the values, norms and practices in the organization (Refer to the discussions about organizational cultures later in this thesis). The organizational cultures are usually the reflections of organizational tacit knowledge that is developed in response to environmental fluctuations to secure the prosperity or the survival of the firm. In modern industries especially knowledge-intensive industries, one of the most important environmental changes would be new external knowledge or innovations that may lead to disruption of a firm's competitive advantages. In this sense, the cognitive dimension of social capital to some degree is shaped by the knowledge environments. The problem is: how is the cognitive dimension of social capital shaped by the knowledge environments? According to Van den Bosch, Volberda and de Boer's model (1999), there are some coevolutionary effects between a firm's absorptive capacity and the external knowledge environment. These coevolutionary effects are illustrated in Figure 4-3 below. According to the model, different dimensions of knowledge absorption are required to survive different knowledge environments (stable vs turbulent) and a firm is likely to develop different organizational forms and combinative capabilities to increase its absorptive capacity in different knowledge environments. Different organizational forms and combinative capabilities including systems capabilities, coordination capabilities and socialization capabilities will then induce changes in practices, norms and values that lay the foundation of organization cultures (refer to discussions about organization cultures later in this thesis) comprising the cognitive dimension of

social capital. Based on the discussions above, I propose a new causal loop diagram (Figure 4-4) linking the value creation and the cognitive dimension of social capital. The linkage between value creation and the cognitive dimension of social capital then creates another reinforcing loop (Value creation-cognitive dimension loop). In Van den Bosch, Volberda and de Boer's model it is assumed that the organization will automatically perceive the need for higher absorptive capacity whenever there's any change in knowledge environment. From my perspective, this assumption is not so realistic as the sensitivity to environmental cues is rooted in an organization's knowledge diversity according to the discussions in the previous sections. The principle of requisite variety implies that the organization needs to possess larger or equal knowledge diversity than the knowledge environment it dwells in in order to process external knowledge effectively. Therefore, knowledge diversity in the organization plays a facilitating role to trigger the perception for need to increase absorptive capacity. Without sufficient knowledge diversity in the organization, the organization may ignore the signals of changes in knowledge environment and fail to adjust its organization forms and combinative capabilities to adapt itself to the changes. The system architecture for the formation of intraorganizational networks is also illustrated in Figure 4-5 below.

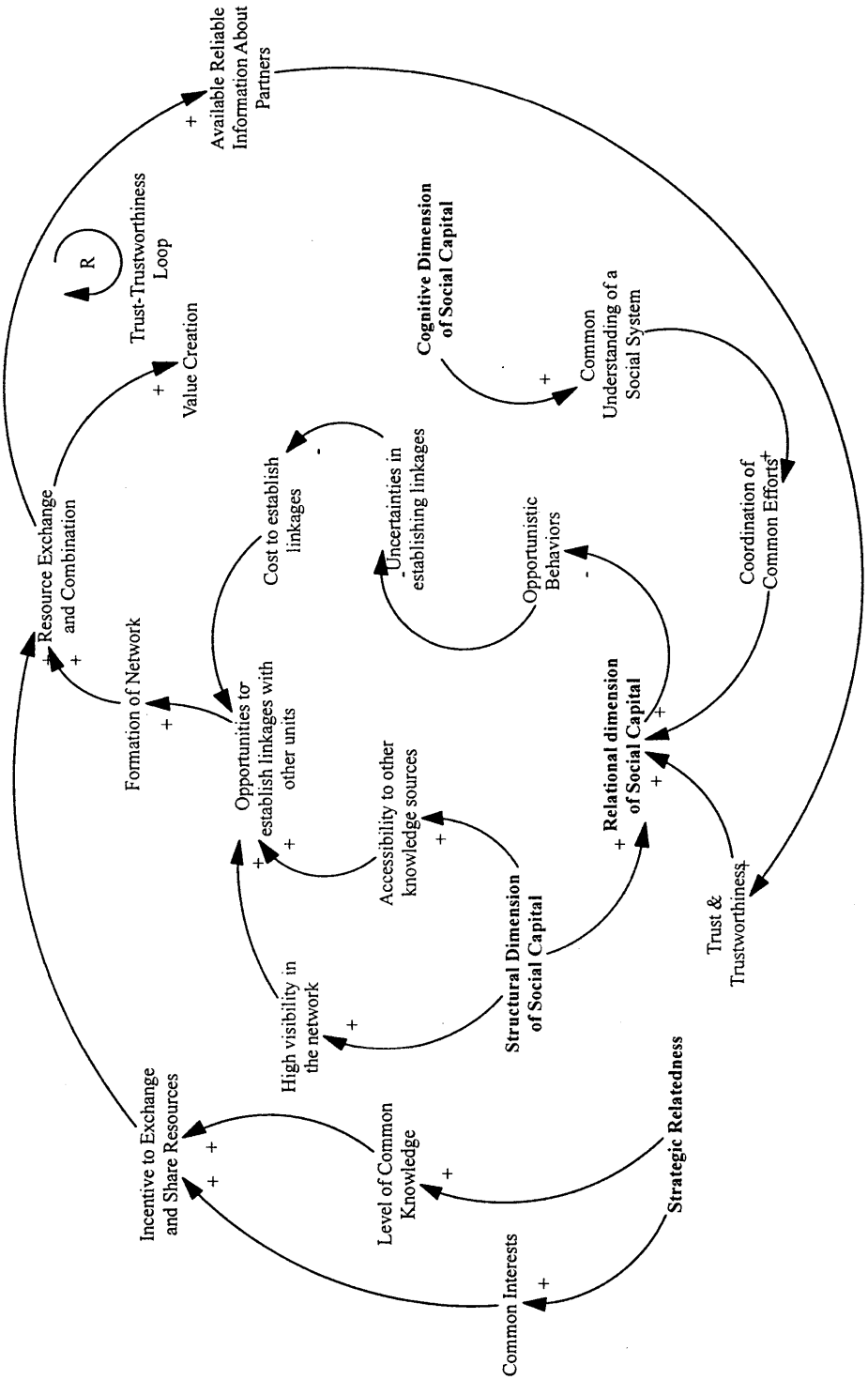


Figure 4-2 Formation of intraorganizational networks

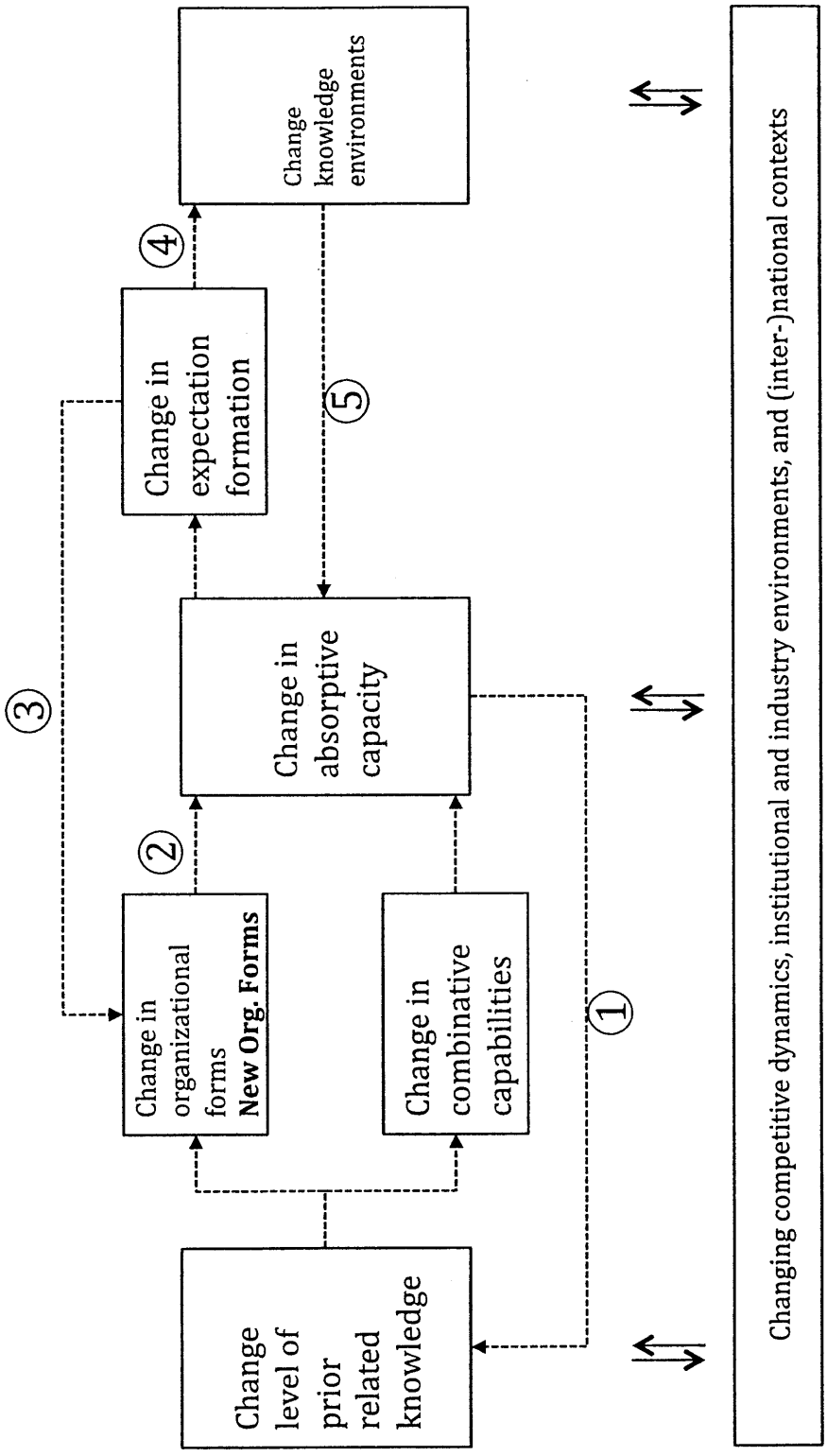


Figure 4-3 Coevolution of absorptive capacity and knowledge environment (Source: Van den Bosch, Volberda and de Boer 1999)

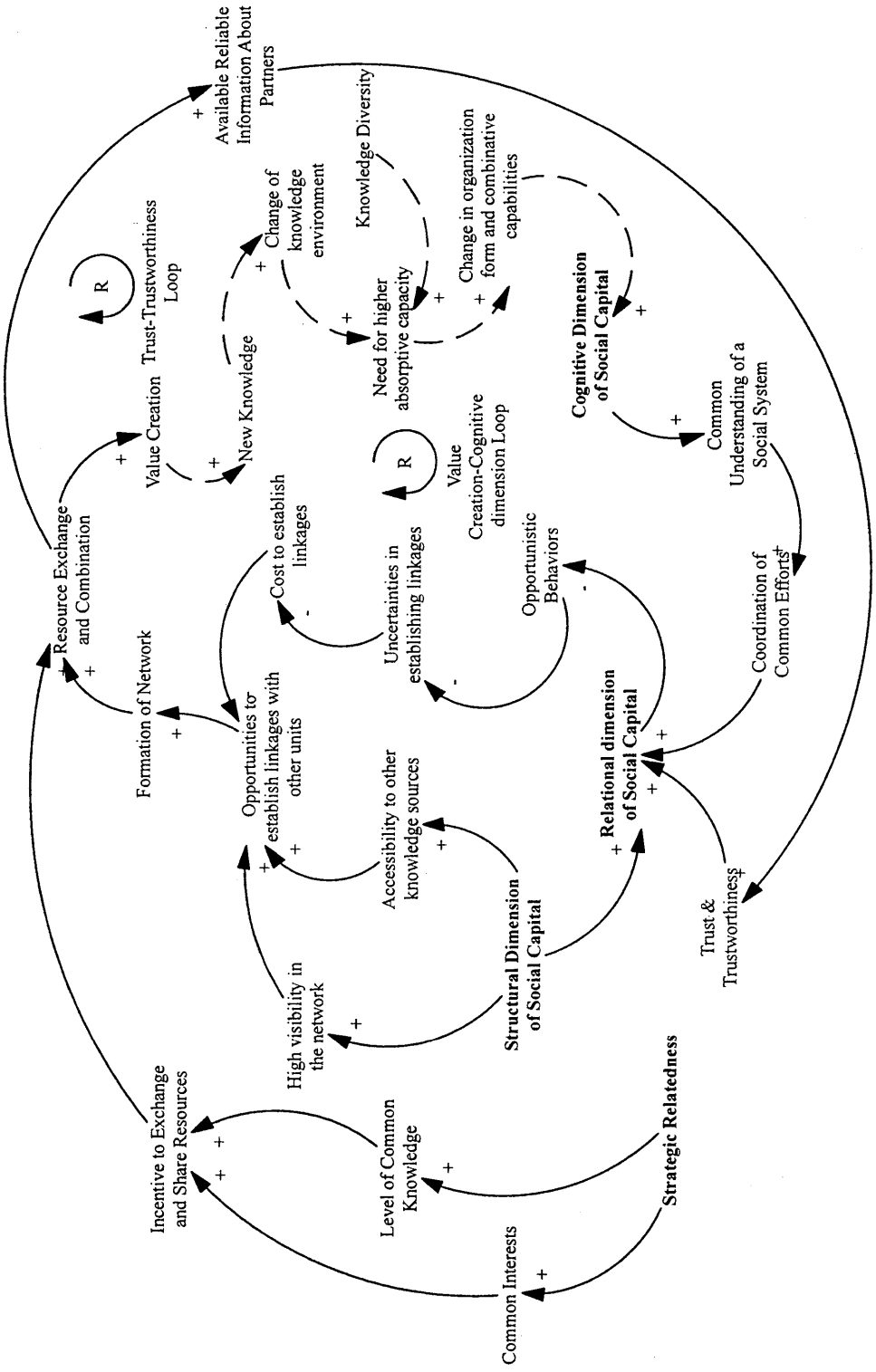


Figure 4-4 Coevolution of intraorganizational networks and their knowledge environment

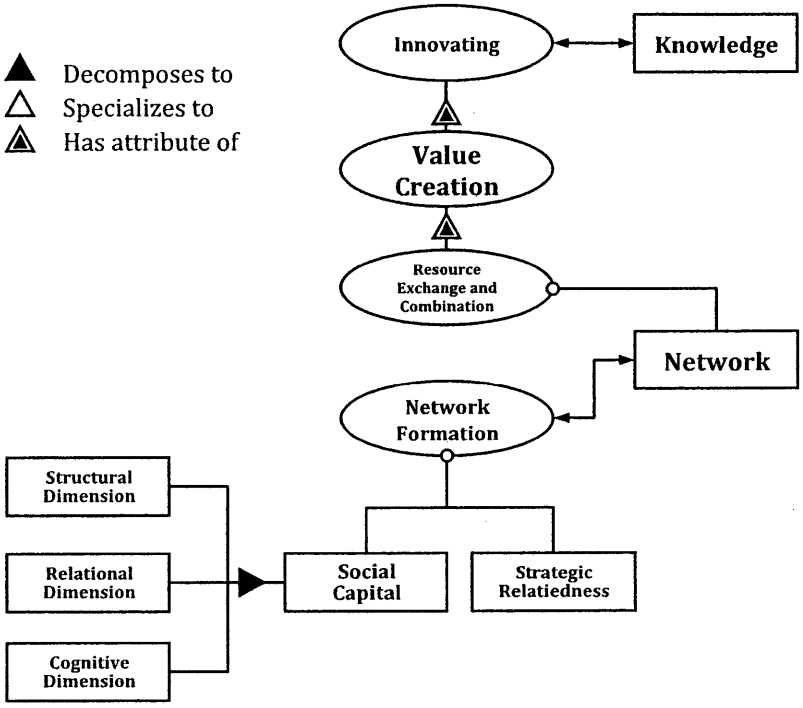


Figure 4-5 System Architecture for the formation of intraorganizational networks

Social capital plays a catalytic role in the formation of intraorganizational networks and hence the creation of values in the organization. Gold, Malhotra and Segars (2001) proposed three key infrastructures that can enable the maximization of social capital: technology, structure and culture. In modern firms, technology is combined with different routines, processes and rules in different levels and groups of a firm. The technology can integrate previously fragmented pieces or flows of knowledge and information to create new values. The technology can also eliminate the barriers of knowledge diffusion naturally exists between different group boundaries and knowledge boundaries. In the sales/marketing function, business intelligence technologies can help the firm generate knowledge about its competitions and its position in the economic environment it resides in. Data mining technologies such as CRM (Customer Relation

Management) can help marketing or R&D groups segment customers and identify their needs precisely to develop profitable products from the origin. Collaboration and distributed learning technologies can allow organization members scattered in different geographic locations or functions to collaborate more effectively and efficiently. Resource integration technologies such as ERP (Enterprise Resource Planning) can help the firm optimize the allocation of different resources across the firm and streamline the manufacturing processes. Other technologies such as CAM/CAD, computer simulation, DFM (Design For Manufacturing) and etc. can form boundary objects that can facilitate knowledge transfer and creation across different organization and knowledge boundaries. For example, in the designing of 777 passenger plane, with the support of an advanced CAD system as a common language, Boeing was able to integrate its knowledge of electronics and new materials with a wide range of different specialized knowledge from different specialists and suppliers. These technologies have a dual impact (Ernst and Kim, 2002). On the one hand, as described above, technologies can promote the value creation in the firm and allow the firm to operate dispersed firm-specific resources or capabilities more efficiently across national borders. Namely, technologies can equip the firm with mobility to create values in multi-national settings. This explains why international production rather than exports have become the main vehicle for international market share expansion. On the other hand, technologies also increase the need and new opportunities for globalization. Because the development of these technologies is risky and expensive, the firm needs to seek sales expansion to share these costs and increase the benefits of technology infrastructures. Unfortunately, only very few national markets are large enough to amortize these expenses. As a result, firms are incentivized to expand outside their national markets to seek for new opportunities that can balance the costs of technology infrastructures.

The second infrastructure to maximize social capital in the organization is the organization structure. Organization structures can be regarded as the embodiment of organizations' knowledge management mechanisms. Organization structures are usually designed to optimize critical knowledge processes which are key to the prosperity of the organization. However, the optimization of knowledge creation within a functional group may usually suboptimize the knowledge creation within the whole firm. Taken to a larger level, the optimization of knowledge creation in a firm may usually suboptimize the knowledge creation across different

organizations on the value chain. For example, the functional organization is most effective in a relatively stable environment when dominant competitive issues and goals stress functional expertise, efficiency and quality. However, functional structure is unable to respond to environmental changes that require coordination between departments. In the functional organization, because members in each functional group have very limited view of the overall goals of the whole organization, the decisions made by different functional groups may be locally optimized at the expense of firm-wide goals. On the contrary, divisional organization may respond to environmental changes swiftly owing to better coordination of different functions within the division. However, in-depth competence and technical specialization may be weakened in this structure since employees identify themselves with divisions rather than functional specialties. As a result, the organization structure can influence the richness in personal interactions as well as patterns of information sharing and consequently influence the knowledge absorption in its efficiency, scope and flexibility (Grant 1996). Van den Bosch, Volberda and de Boer (1999) have reached some conclusions in the influences of three basic organization forms (functional, divisional, matrix) on the three dimensions (efficiency, scope, flexibility) of knowledge absorption. Their influences are summarized in Table 4-1 below. The ideal organizational structure must be able to support the dominant knowledge activities that contribute majorly to the prosperity or even the survival of the firm. In addition, the organizational structure should also provide the organization the sensitivity to receive signals of external changes and the flexibility to respond to these external changes to sustain its competitive advantages. In their systems-based approach, Sanchez and Mahoney (1996) suggest that a modular organization design combined with modular product design can reduce the costs of coordination and adaptation and, thereby increase strategic flexibility. Nonaka (1994) also propose a hypertext organization that can enable efficient knowledge creation within the organization.

Dimensions of Knowledge Absorption	Organization Forms		
	Functional Form	Divisional Form	Matrix Form
Efficiency of Absorption	H	L	L
Scope of Absorption	L	L	H
Flexibility of Absorption	L	H	H
Impact on Absorptive Capacity	Negative	Moderate	Positive

H: high; L: low

*Assumption: Both scope and flexibility of knowledge absorption have a positive influence on the level of absorptive capacity, while efficiency has a negative impact.

Table 4-1 Three basic organization forms, dimensions of knowledge absorption and absorptive capacity (Source: Van den Bosch, Volberda and de Boer 1999)

The third infrastructure to maximize social capital in the organization is culture, which is perhaps the most significant hurdle to effective knowledge management in the organization. Culture is not only intangible and illusive but it can also be observed at multiple organizational levels. Culture is reflected in values, norms and practices. Values are often difficult to articulate and even more difficult to change. Norms are generally derived from values but they are more observable and easier to identify. Practices are the most visible symbols and manifestations of a culture. Although values, norms and practices reflect different level of observability of an organization's culture, these three aspects are fundamentally interrelated. Values are manifested in norms and in turn shape the practices. Sometimes, managers deliberately change practices and norms in an attempt to re-shape values over time. Organizational culture or other shared behavioral norms can also be regarded as a form of common knowledge. Organizational cultures can influence knowledge management in four aspects (De Long & Fahey, 2000). First, culture, especially subcultures, shapes assumptions about what knowledge is and which knowledge is worth managing. Second, culture defines the relationships between individual and organizational knowledge and determines who is expected to control specific knowledge as well as who must share it. Third, culture creates the context for social interaction that determines how knowledge will be used in particular situations. Fourth, culture shapes the processes by which new knowledge is created, legitimated, and distributed in organization. Cultures have also been identified as important constraints on international technology transfer. According to Hofstede (1980), national cultures can be mapped into a four dimensional framework of (a) weak versus

strong uncertainty avoidance, (b) individualism versus collectivism, (c) small versus large power distance and (d) masculinity versus femininity. Kedia and Bhagat (1988) proposed a conceptual model (Figure 4-6) highlighting the moderating role of societal culture-based differences in the international technology transfer setting. It was concluded that the effectiveness of technology transfer across nations depends on cultural compatibility between technology source and recipient nations. Societal cultural variations are especially important relative to organizational cultures and strategic management processes when transferring technology from industrialized nations to developing nations. Their conclusions are summarized in Table 4-2 below.

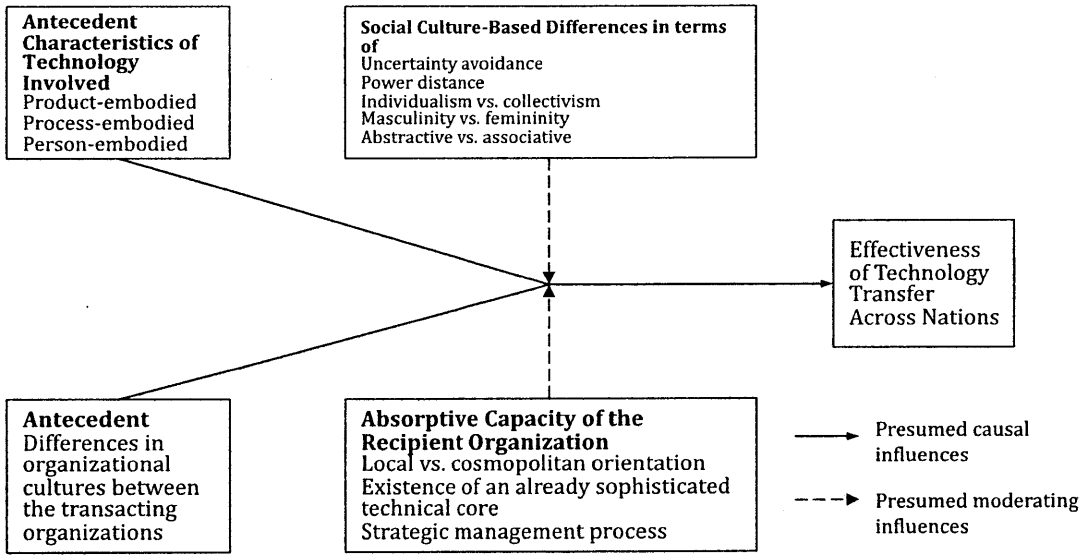


Figure 4-6 A conceptual model for understanding cultural constraints on technology transfers across nations (Source: Kedia and Bhagat 1988)

	From Industrialized to other Industrialized Nations (e.g. U.S. to West Germany)	From Industrialized to Moderately Industrialized Nations (e.g. U.S. to South Korea)	From Industrialized to Developing Nations (e.g. West Germany to India)
Social Culture	Least Important	Moderately Important	Most important
Organizational Culture	Moderately Important	Moderately Important	Moderately Important
Strategic Management Processes	Most important	Moderately Important	Least Important

Table 4-2 An examination of the relative importance of cultural variation and strategic management processes as determinants of the successful transfer of technology across nations (Source: Kedia and Bhagat 1988)

According to the discussions above, I set up a system dynamics causal loop in Figure 4-7 below. This figure highlights the dual effects of technology on market expansion and the coevolution of social capital with the knowledge environment. All the connections in solid lines indicate the correlations of different factors discussed above. Although in this section I do not talk about the correlations between value creation and organization structure, however, in the previous section we learn that value creation may change the knowledge environment and stimulate the need for different absorptive capacity. In order to develop necessary absorptive capacity, the organization needs to change its structure to maximize the knowledge absorption in the new knowledge environment (Refer to the causal loop diagram in Figure 4-4). This correlation is indicated by the dotted line connecting "value creation," "Change of Knowledge Environment," "Need for higher absorptive capacity" and "Change of Organization Structure." According to the discussions in the previous section, change of organization structure will also change the cognitive dimension of social capital, which can be regarded as a subset of organization cultures. This correlation is highlighted by the dotted line connecting "Chang of Organization Structure" and "Change of Organizational Culture" in the causal loop diagram. In this causal loop diagram, if "Change of Organizational Cultures" can enhance "Social Capital", both "Culture Loop" and "Market Expansion Loop" in the diagram will become reinforcing loops that generate the momentum for continual value creation in the system. On the contrary, if the change of organizational structures should introduce negative impacts to social capitals, these two loops will turn to balancing loops that can limit value creation in the system. Therefore, it's very important to secure that the change in organizational structures always introduces positive effects to the cognitive dimension

of social capital. Any subtle changes in this dimension through change of organizational structures may lead to huge deviations in innovation performances. Even under the most optimistic scenario that both loops are reinforcing loops, the development of knowledge diversity in the system will become another limiting factor for the value creation in the system. Any factors that can affect knowledge diversity in the organization will also affect knowledge creation through the effects of these two loops indirectly in addition to other direct effects. As a result, the behavior of the system is regulated mainly by knowledge diversity and organizational cultures in this setting. According to the discussion above, I also set up a system architecture in Figure 4-8. In this architecture, technology, structure and culture are the instruments of the social capital development process. According to De Long & Fahey, the organizational cultures can influence knowledge management in four ways. Therefore, the culture can be considered the instrument of these four processes. The operands of "Defining individual/organization relationships" process and "Creating Context for social interactions" process are "individual/organization relationships" and "Social interaction Contexts" respectively. These two operands, according to the definitions discussed in the previous section, can be regarded as the attributes of the cognitive dimension of the social capital. The operand of the other two processes, knowledge, can change the knowledge environment and influence the organization structure according to previous discussions, and should be considered the instrument of the change of knowledge environments. This architecture can then be connected with other architectures through "Social Capital," "Knowledge" and "Innovating" components.

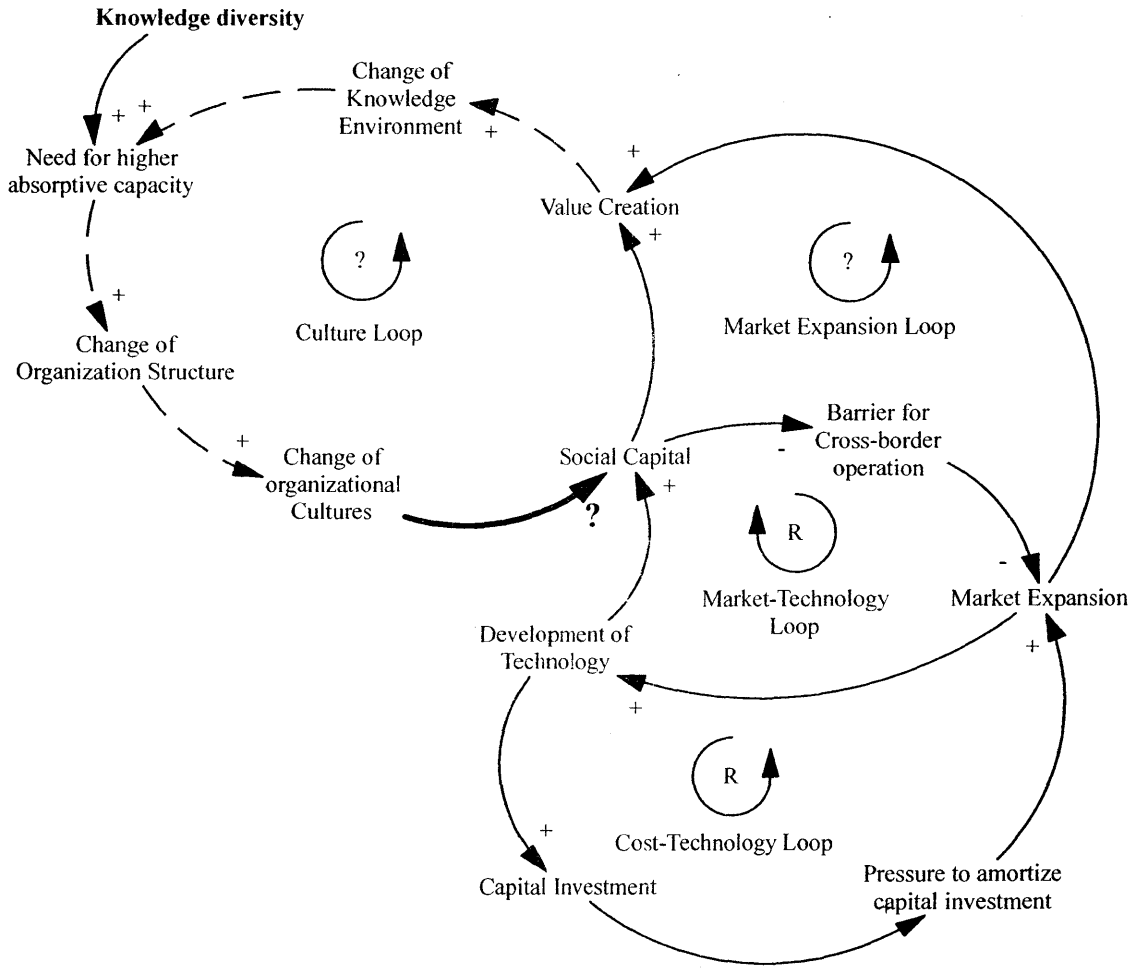


Figure 4-7 Dual effects of technology and coevolution of social capital with the knowledge environment

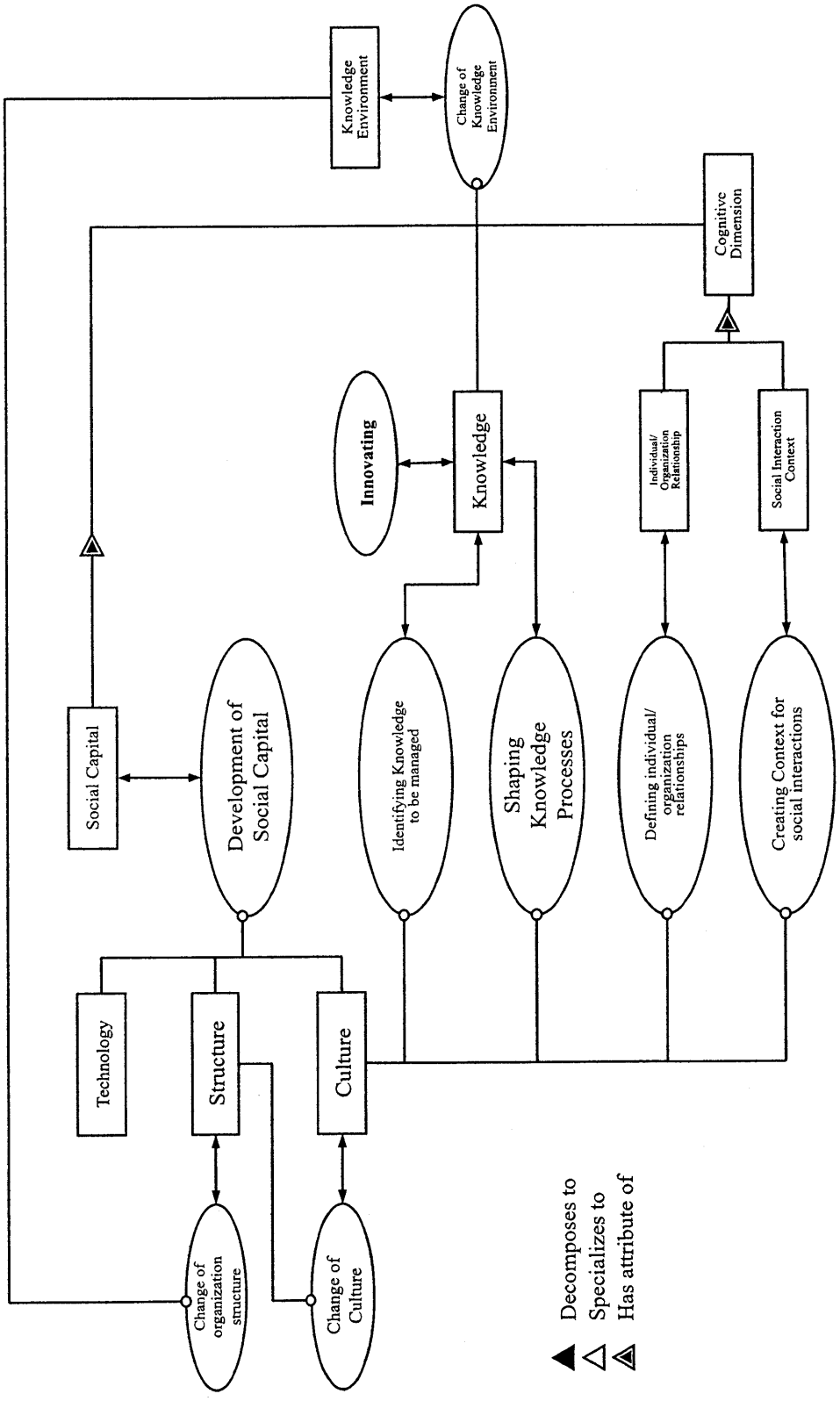


Figure 4-8 System Architecture for the development of social capital

Chapter 5 Interorganizational Network

In previous sections, we talked about the formation of intraorganizational networks. The formation of interorganizational networks to some extent is quite similar to the formation of intraorganizational networks. Gulati and Gargiulo (1999) proposed a model for the formation of interorganizational networks based on paper reviews and their own field investigations. Their model is demonstrated in Figure 5-1 below. Strategic interdependence is the most common explanation for the formation of interorganizational ties such as alliances. The strategic interdependence here is very similar to the strategic needs we discuss in the formation of intraorganizational networks. Oliver (1990) presented six broad categories of environmental contingencies that may stimulate the formation of such interorganziational ties. Of the six categories, necessity prompts mandatory ties to meet legal or regulatory requirements. Other types- asymmetry, reciprocity, efficiency, stability and legitimacy- lead to voluntary cooperative ties to address specific needs resulting from their external interdependence. The higher the interdependence, the more the organizations are incentivized to share their resources and capabilities through alliances. The higher the interdependence between two organizations, the more probable they will form the interorganizational alliances. Strategic interdependence may be necessary conditions for forming an alliance with other organizations. However, it's not sufficient to explain the choice of alliance partners in the interorganizational network. Similar to the formation of intraorganizational networks, many costs and uncertainties are involved in the formation of interorganizational networks. To reduce the uncertainties and the costs associated with building alliances, organizations rely on the information from existing interorganizational networks for the choice of alliance partners. Namely, the formation of interorganizational ties is shaped by different mechanisms of existing networks. Gulati and Gargiulo refer to these mechanisms as relational, structural and positional embeddedness.

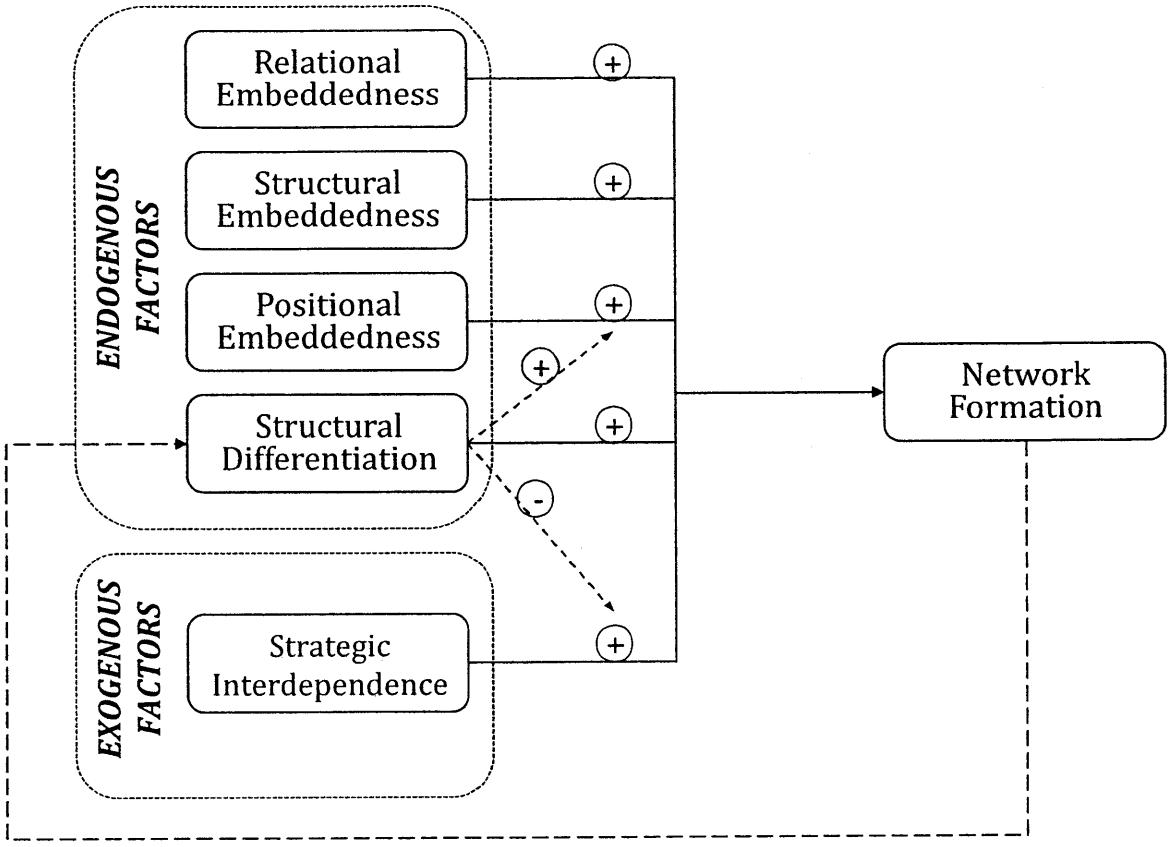


Figure 5-1 The endogenous dynamic of interorganizational networks (Source: Gulati and Gargiulo 1999)

Relational embeddedness highlights the effect of cohesive ties between organizations on the subsequent cooperation between them. Cohesiveness can amplify trust and reduce uncertainties between organizations. As a consequence, it's more probable for two organizations with previous direct alliances to form new alliances between them. Therefore, relational embeddedness is positively related to the formation of interorganizational networks. Structural embeddedness captures the impacts of structures of relations around actors in the network on their tendencies to enter alliance relations with one another. The relational embeddedness highlights the effects of direct ties between two organizations while the structural embeddedness emphasizes the effects of indirect common ties of the two organizations. The sharing of common ties between two organizations implies that both organizations are considered suitable partners of a common organization and may also indicate that both organizations can cooperate with partners of the same type. These commonalities all signal high degree of matchedness between two focal

organizations as alliance partners. In addition, common third-party ties can create a reputational lock-in. Any bad behavior of the focal organizations may be reported to the common third-party organizations and be delivered to their potential partners. Hence, structural embeddedness is positively related to the formation of interorganizational networks. The third mechanism, positional embeddedness, reflects the effects of network positions of organizations on their choices of new cooperative ties. This positional embeddedness in the interorganizational network is similar to the structural dimension of social capital in the formation of intraorganizational networks. The position of an organization in an emerging network can influence its ability to access fine-grained information and its visibility in the network. The centrality of an organization in the network allows the organization to access more information about potential partners that may facilitate its decision about the choice of partners. On the other hand, the central position of an organization in a network also signals its willingness, experiences, and ability to ally with other partners. This kind of signals is especially important in uncertain environments. As a result, organizations with central positions in the network are also more attractive to potential partners. Therefore, positional embeddedness is positively related to the formation of interorganizational networks.

The formation of interorganizational networks is a path-dependent and dynamic process. The network structure resulting from these mechanisms will drive the progressive structural differentiation of the interorganizational networks and re-shape related mechanisms. Gulati and Gargiulo define structural differentiation as "an emergent systemic property that captures the extent to which actors (organizations) come to occupy an identifiable set of network positions, each of them characterized by a distinctive relational profile." The higher the structural differentiation of an emerging network, the easier the organization to differentiate itself from other organizations in terms of relational profiles. In a network where all the organizations have similar relational profiles, decision makers can get very limited knowledge about potential new partners. On the opposite extreme, when the organizations in a network all have truly unique relational profiles, this network is equally uninformative to the decision makers. Therefore, it's reasonable to infer that the information available to the actors in the network increases with structural differentiation to some critical level and then decrease as the structural differentiation continue to grow with the accumulation of new ties. From actors' perspective, the additional

information provided by new ties will decrease the systemic uncertainties faced by the actors, which then affects the subsequent necessity and propensity to form new ties. Studies of mature social networks also suggest that the structural differentiation of most real systems does not demonstrate a continuous increase with time. Instead, actors in mature structures typically possess stable and similar network profiles. Therefore, it is assumed that the correlation between structural differentiation and interorganizational network formation is positive (non-negative). Since interorganizational networks are closely related to knowledge diffusion and capability formation (Ernst and Kim 2002), stagnation of structural differentiation tends to slow down or even cease capability differentiation. In addition, the effects of interdependence on partnership formation between organizations decrease with the level of structural differentiation of the interorganizational network. In early stages when the network is relatively undifferentiated and hence the knowledge about potential alliance partners from the network is very limited, different organizations can still cooperate with one another driven by the exogenous interdependence of their interests even in lack of related knowledge about one another. However, as the interorganizational network becomes more and more differentiated, actors are able to obtain more information about potential partners from this network channel and consequently the effects of interdependence will diminish.

According to the discussions above, I set up a causal loop diagram below (Figure 5-2). In addition to the dynamics in previous discussions, I introduce "Innovations" and "Spillover Effects" as mediating factors to link "Knowledge from the network" and "Structure Maturity". If firms can extract more knowledge from the network, it's reasonable to expect that the average innovation level of firms will also increase. However, owing to spillover effects, the knowledge or innovations invented in the network will diffuse to different actors through the network over time and eventually the differentiations between different competitors tend to diminish. This result echoes Eisenhardt and Martin's (2000) observation that over time firms' capabilities converge to an industry standard wherein competitor capabilities are similar in key attributes. The increasing "indifferentiations" between competitors usually reflect the increasing maturity of the industry in which the network resides in. The maturity of the industry will further decrease the structural differentiation of actors in the network. These new connections are highlighted in the dotted lines in the diagram. In this diagram there are several reinforcing loops and several

balancing loops intersecting the "Formation of Alliance Network." In the beginning of an organization when initial "Structural Differentiation" is relatively negligible, the formation of alliance networks is mainly driven by "Strategic Interdependence." The network formation driven by strategic interdependence will then further contribute to the "Structural Differentiation" and trigger different reinforcing loops that can promote the formation of alliance network. On the other hand, another balancing loop connecting "Structural Differentiation," "Knowledge about potential partners," "Network formation driven by strategic interdependence" and "Formation of Alliance Network" indicates that the importance of strategic interdependence to the formation of alliance network will decay as the structural differentiation becomes more obvious. However, the connections between "knowledge from the network" and "Structural Differentiation" through "Spillover Effects" and "Structure Maturity" introduce other balancing loops counteracting the reinforcing loops triggered by "Structural Differentiation" mentioned above. As a result, the dynamics of Figure 5-2 suggests that further formation of network alliances and differentiation of network structures will slow down and eventually become stagnant as the industry becomes mature. This result derived from the system dynamics model also corresponds to the general conclusions from studies of mature social network. In the previous discussions, "Strategic Interdependence" and "Positional Embeddedness" seem to be the two independent exogenous factors that shape the initial conditions for the network formation process. However, I would argue that the primitive positional embeddedness of an organization should originate from its strategic interdependence. The initial strategic interdependence of an organization stemming from its purposes or intentions will pre-determine its primitive positional embeddedness in the beginning of an organization. The strategic interdependence and the primitive positional embeddedness will then initiate the subsequent path-dependent development of alliance networks. Therefore I connect "Strategic Interdependence" and "Positional Embeddedness" with a dotted line to highlight this positive effect of "Strategic Interdependence" on "Positional Embeddedness." This conclusion also conforms to another inference that strategic relatedness is the origin of interunit communication derived from different evidences and different perspectives in the next section about "Effects of Physical Distances On Networks." The system architecture of the formation of interorganizational networks is illustrated in Figure 5-3 below. This architecture is very similar to that of intraorganizational networks and is linked with other structures through "innovating" process.

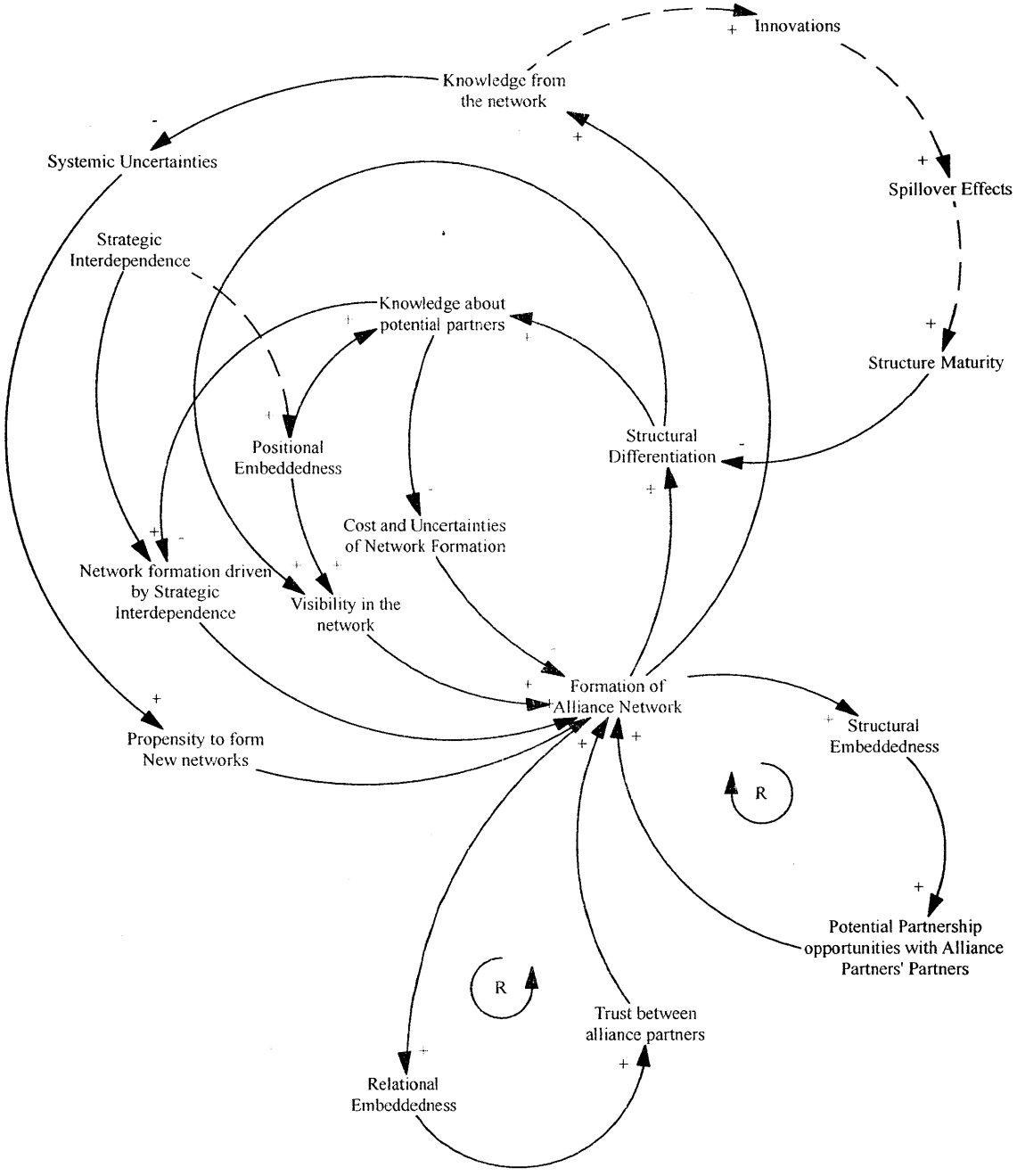


Figure 5-2 Dynamics of intrerorganziational network formation

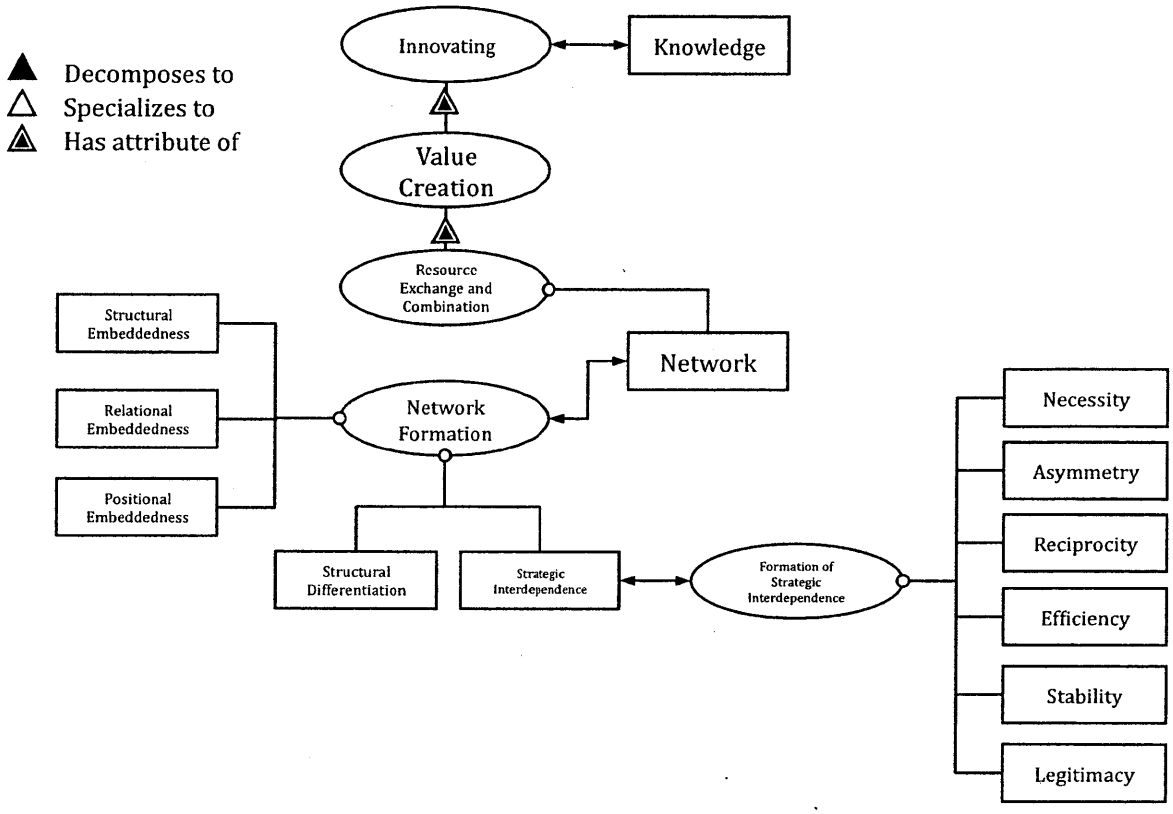


Figure 5-3 System architecture for interorganizational network formation

Chapter 6 Effects of Spatial Proximity On Networks

Not only intangible factors such as social capital or strategic relatedness will affect the performances of interunit networks or the formation of interunit linkages, physical distances may also introduce similar effects. In a series of researches about the communication patterns in organizations from different countries and industries, Allen (1997) found a universal phenomenon that the communication probability in the organization declines to an asymptotic level as distances between actors increase despite the differences in cultures or industries in which the organization dwells in. Same patterns can also be observed for both intra-departmental and inter-departmental communications. The only difference is that the communication probability of actors within the department is higher than that between departments at the same physical distance because of stronger ties between actors within the same department (Figure 6-1 and Figure 6-2). This finding also implies that tie strength or strategic relatedness is positively related to the communication probability and therefore to the formation of linkages.

In an unpublished study, Varghese George examined the "departmental effect" and found that the communication probability in a department is inversely proportional to the size of the department (Figure 6-3). Members of smaller groups are often organized in the same silo of specialty and arranged in proximate spaces. Because of high commonality of knowledge of members and spatial proximity, members in smaller groups tend to communicate more and be more cohesive. The higher the communication probability and cohesiveness, the more probable the members share the "redundant information" which is crucial for the formation of "trust" in the organization. The formation of trust can further enrich the relational dimension of social capital and enhance the sharing of valuable strategic resources or knowledge. Extending this concept, it's reasonable to assume that knowledge commonality and spatial proximity are both positively related to the formation of social capital in its relational dimension. In many cases the spatial proximity does play an important role in knowledge sharing and transferring. In the case of the development of VLSI technologies in Japan by Kiyonori (1983) indicates that the cooperative laboratory gathering the experts from different companies in the same location was of decisive importance to the exchange and integration of different knowledge originally spread in dispersed companies. It is also believed that JPL's decision to put all the suppliers in the same

building with the mission team in the mission-to-Mars is a critical determinant to the success of issue resolution and solution development.

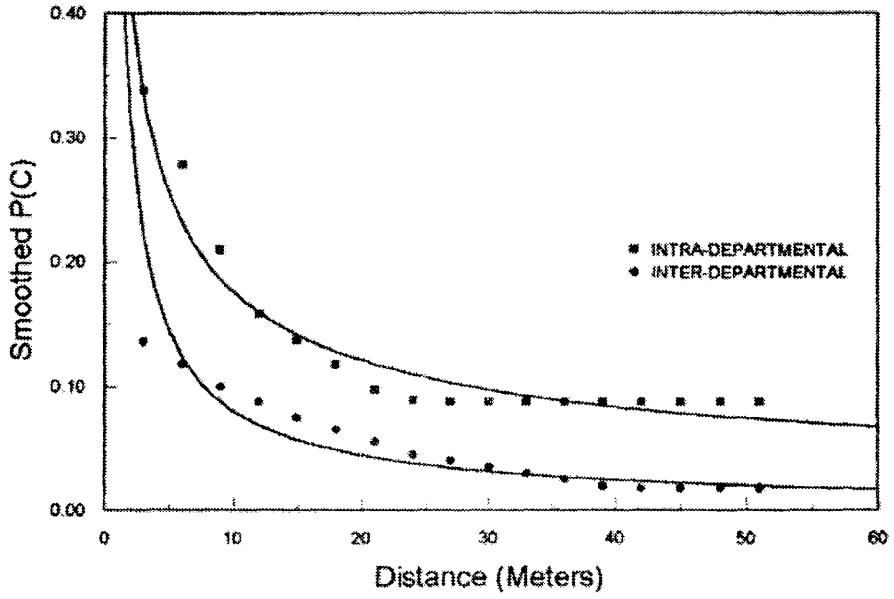


Figure 6-1 The effect of sharing or not sharing a department (Data taken from a single organization) (Source: Allen 1997)

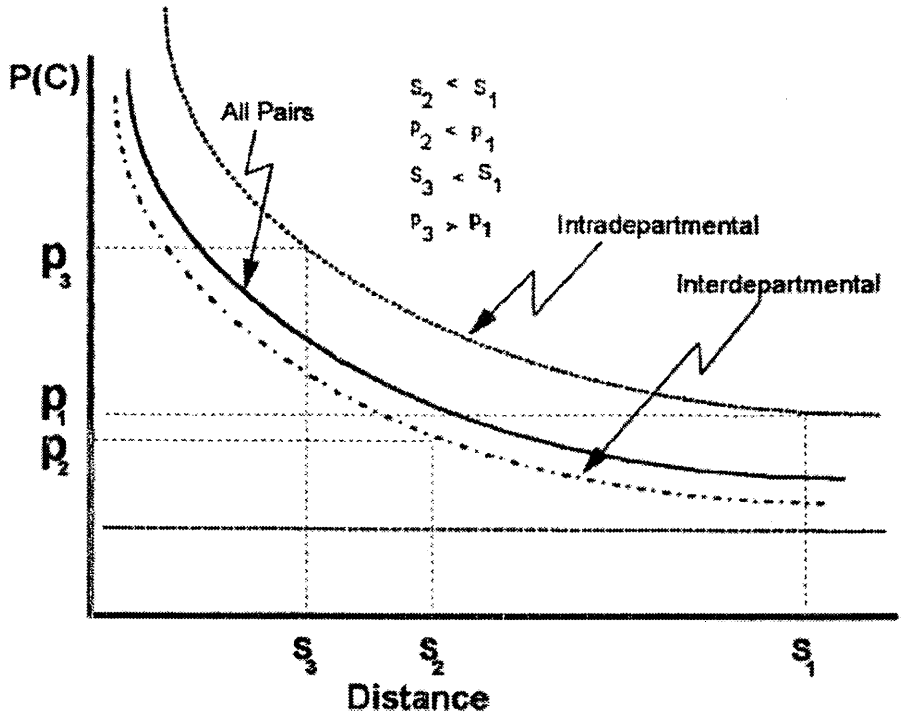


Figure 6-2 Combining the effects of organizational and physical separation or proximity (Source: Allen 1997)

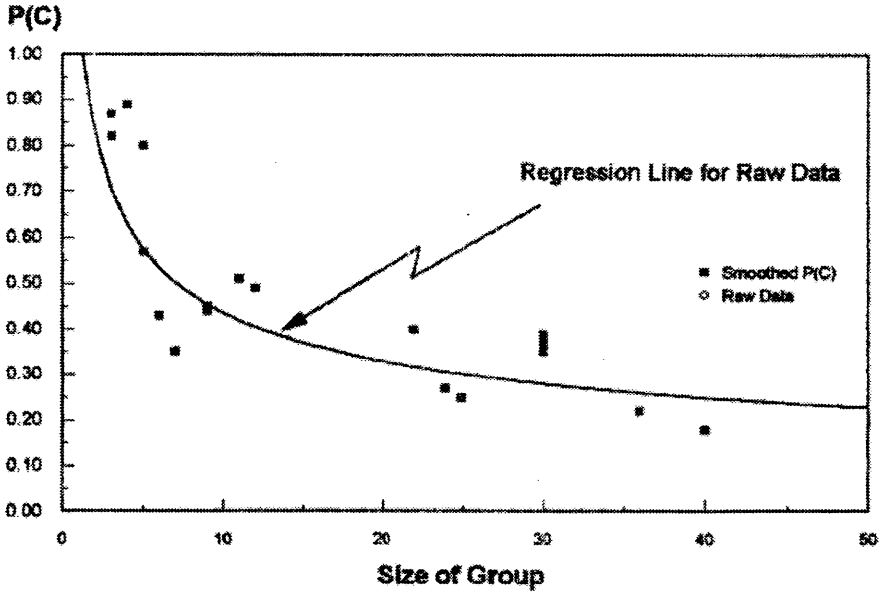


Figure 6-3 Probability of regular technical communication as a function of departmental size (Source: Allen 1997)

Some people may doubt that the effect of spatial proximity on face-to-face communication probability may decay with the population of new communication technologies such as telecommunication or e-mail. This inference at the first glance may seem reasonable. However, the empirical data demonstrate different results. In Allen's study, we do not see the decay of face-to-face communication as we expected in the presence of modern communication technologies. According to this study, people actually call or e-mail to the same group of people with whom they communicate face-to-face. The more often we communicate with people face-to face, the more often we communicate with them by telephones or e-mails. If we correlate the probability of face-to-face communication with the probability of telephone communication, we can see a nearly perfect correlation with correlation coefficient of 1 (Figure 6-4 by Allen and Hauptman, 1989). This may result from the limitation of "bandwidth" by communicating with these telecommunication technologies. It's difficult to communicate complex information or knowledge effectively through phones or e-mails. Face-to-face communication is still indispensable in the communication of complex knowledge. These results imply that the need for communication between units, which reflects their strategic relatedness, is the origin of interunit linkages. Different units in the organization communicate with one another because of strategic needs even in lack of favorable social capital. These needs for communicating with other units then shape the structural dimension of social capital in the organization gradually. Through the communication processes, the trustworthiness of different units is established and the trustworthiness then further shape the intraorganizational network and affect the strength of ties between units. The trustworthiness of units in the organization then fosters the "trust" attribute of the organization, which together with trustworthiness composes the most important aspects of the relational dimension of social capital. The enrichment of the relational dimension of social capital will further strengthen the current network. This also explains why the formation of networks is path-dependent. However, because the formation of linkages driven by strategic needs of different units in the organization usually focuses on actors' local interests instead of the global interests of the whole organization, I would argue that the cognitive dimension of social capital, which is related to the organization-wide shared values, shared codes or shared paradigm, can not be formed through such "myopic" interactions among units in the organization. Therefore, the cognitive dimension of social capital, unlike the structural or relational dimensions, cannot evolve spontaneously through these processes. This cognitive dimension can

only be cultivated deliberately by the management as an exogenous factor. Therefore, it's reasonable to assume that the effect of structural dimension and relational dimension on the cognitive dimension of social capital is low. This perspective echoes the empirical results in Tsai's (2000) study showing that the structural dimension and the relational dimension of social capital as well as strategic relatedness of different units in the organization is positively related to the formation of intraorganizational linkages. Although Tsai did not talk about the correlation of the cognitive dimension with the formation of interunit linkages in his study in 2000, his another study with Goshal in 1998 indicating the weak correlation between structural dimension and cognitive dimension can support my perspective indirectly (Figure 4-1).

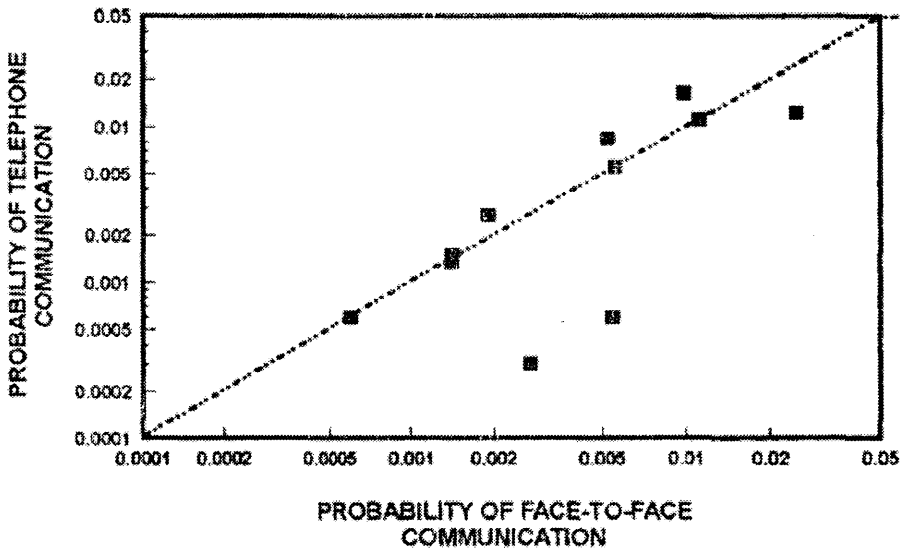


Figure 6-4 The relationship between telephone and face-to-face communication between locations (Source: Allen and Hauptman 1989)

According to the discussions above, I organize a causal loop diagram as shown in Figure 6-5 below. In this diagram, strategic relatedness is the direct driver for communication while spatial proximity and knowledge commonality are the facilitators for communication. The strategic relatedness may initiate the communication but without the other two factors the communication may not be sustainable enough to create values. We can combine this diagram with the diagram describing the formation of interunit networks (Figure 4-4) to form a more complete causal loop diagram (Figure 6-6). The new connections are illustrated in dotted line. In the new diagram, it

becomes clearer that the positive correlation between "Incentive to Exchange and Share Resources" and "Resource Exchange and Combination" is mediated by the "Communication Probability." Higher communication probability can then create more redundant information and form "Trust and Trustworthiness" that may enhance the relational dimension of social capital in the organization. From this combined diagram, we can realize that "Spatial Proximity," "Strategic Relatedness" and "Knowledge Diversity" are the only three exogenous factors managers can manipulate as managerial actions in the whole process. Any organization needs to maintain these three factors properly to secure the continual contributions of interunit networks to value creation and innovations in the organization.

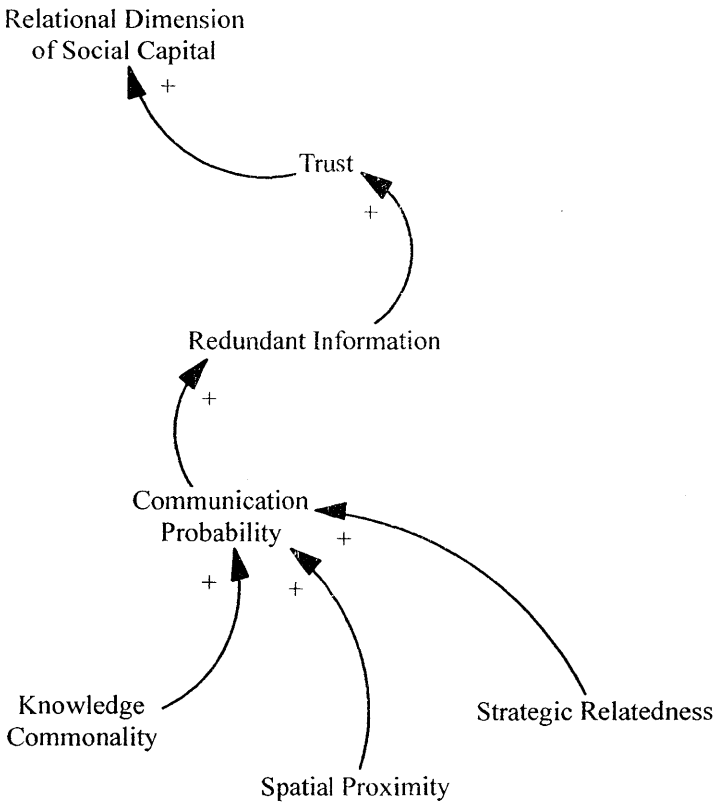


Figure 6-5 Knowledge commonality, spatial proximity, strategic relatedness and relational dimension of social capital

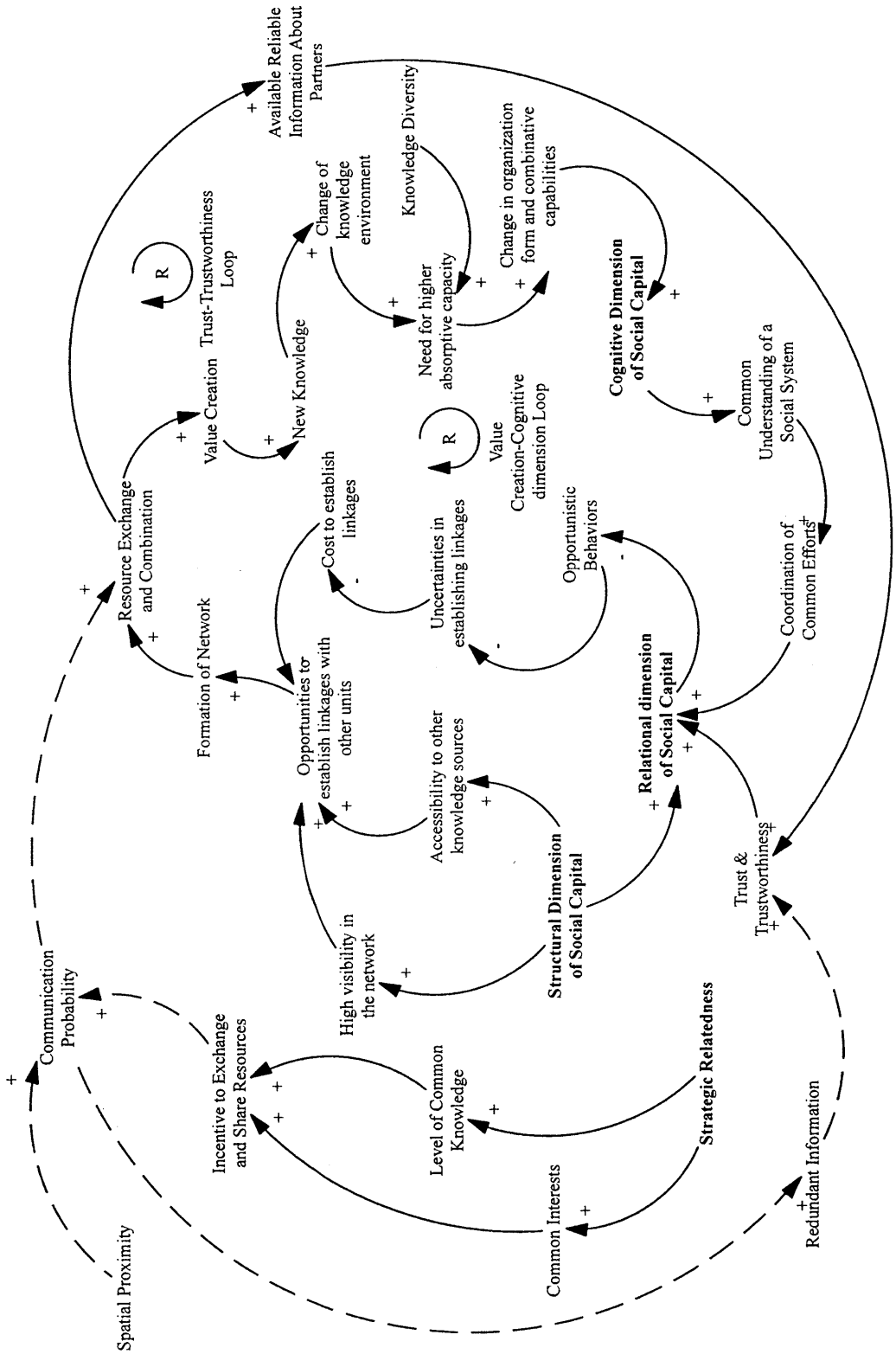


Figure 6-6 Effects of spatial proximity on the dynamics of intraorganizaional network formation

Spatial proximity plays an important role in innovation or knowledge activities such as technology transfer. As Von Hippel (1994) observes, sticky knowledge, high context and uncertain knowledge in his term, is best transmitted via face-to-face interaction and through frequent and repeated contact. Although nowadays different telecommunication technologies such as video conference can augment or simulate the effects of face-to-face interactions, they still cannot replace the effects of direct human interactions in the transmission of tacit knowledge which requires common experiences between knowledge transmitters and knowledge recipients. Feldman (1994) also points out that location can mitigate the inherent uncertainties of innovative activities. Spatial proximity can enhance firms' ability to exchange ideas and gain important initial knowledge to survive in the new field. Almeida and Kogut's (1997) study about patenting in semiconductor industry indicates that proximity and location clearly matter in exploiting knowledge spillover. Audretsch and Feldman (1996) found that the propensity of innovation activity to cluster geographically tends to be greater for industries where new knowledge plays more important roles in value creation. A lot of empirical evidences have demonstrated the decisive importance of spatial proximity to innovation activities.

Chapter 7 Knowledge Search And Transfer in The Network

During the formation of interunit networks, ties of different strength among different units in the organization are built simultaneously. In the previous discussions, strategic relatedness, social capital and spatial proximity are all important factors for the formation of intraorganizational networks. After the formation of networks, the ties between different actors in the network and the complexity of the knowledge to be transferred will eventually affect the performances of knowledge transfer and value creation in the network. Hansen (1999) discussed the role of ties in sharing knowledge among organization subunits in his study. Intuitively, people may believe that the stronger tie between a unit and other units in the organization network, the easier that specific unit can identify necessary knowledge and transfer the knowledge from other units in the network. However, our intuitions do not match the empirical results perfectly. According to the study, weak ties with other units are more advantageous when the targeted knowledge to be transferred is less complex. On the other hand, strong ties are more advantageous when the targeted knowledge is more complex. In a multiunit organization, when a specific operating unit is in need of obtaining new knowledge to cope with its issues, it first needs to search and identify proper knowledge sources and then transfers the useful knowledge from the sources. Existing relations that span different subunits usually serves as important channels for new knowledge. From this perspective, ties between subunits in the organization can be considered positive factors for the interunit knowledge searching process. During the knowledge searching process, it is found that weak tie- infrequent and distant relationships- is more advantageous than strong ties. Several reasons are proposed to explain this finding. The first reason is that weak ties may not provide as much redundant information as strong ties. Subunits with strong ties with one another usually imply that these subunits share high degree of common knowledge or experiences. This means that the knowledge among subunits with strong ties is usually redundant. Therefore, it's less likely to find new knowledge or other potential knowledge sources through the network with strong ties. On the contrary, it's more probably to find new useful knowledge sources through the network with weak ties because of less knowledge redundancy. In addition, the fact that it's more costly to develop strong ties than weak ties with other subunits implies that the costs to search new knowledge through networks with strong ties are also higher. Combining the knowledge redundancy factors and cost factors, it's reasonable to conclude that searching

new knowledge through networks with strong ties will be a much less cost-effective option than through networks with weak ties. Moreover, Weick (1976) also argued that subunits that are not tightly connected to other units are more adaptive because they are less constrained by the organization system. This argument originates from the conflicts between autonomy and social obligations of subunits in the organization. It is generally agreed that autonomy is positive for innovation processes. But innovation processes inherently need some new knowledge that resides outside the innovation unit. To access the new knowledge, the innovation unit needs to establish connections with other units inside or outside the organization. As the connectedness with other units becomes stronger, the risk of losing autonomy will also become higher because the innovation unit will need to confront more social obligations in the network in addition to formal procedures. As a consequence, ties with other subunits become constraints as ties grow stronger. The other concern with strong ties relates to "network inertia." Henderson and Clark (1990) found that product developers tend to rely on established communication channels in which they are strongly immersed. In the previous sections, from Allen's studies, it is concluded that higher communication probability stems from stronger ties between subunits. Therefore, Henderson and Clark's (1990) finding implies that innovation units with stronger ties are less likely to search new knowledge outside existing networks and establish new linkages with other actors than innovation units with weak ties. All the discussions above lead us to the conclusion that weak ties have comparative advantages over strong ties in knowledge searching in the network.

After the potential knowledge source in the network is identified through the knowledge searching process, the innovation unit needs to transfer and assimilate the knowledge from the source and integrate the new knowledge with existing knowledge to form innovative solutions. Under this circumstance, the innovation unit may have high motivation to transfer new knowledge from the source. However, the knowledge source may not have the incentive to transfer the knowledge because of the relative costs involving the transfer. Two types of issues are generally observed in this kind of knowledge transfer: willingness and ability to transfer. The knowledge source is unwilling to transfer the knowledge maybe because of an intraorganizational atmosphere of secrecy and competition. The transferability of the targeted knowledge can also limit the willingness of the knowledge source to transfer the knowledge. The

more complex the knowledge to be transferred, the lower its transferability. There are two dimensions for the complexity of knowledge. The main dimension is the "codifibility" of knowledge. Knowledge that cannot be articulated or documented easily is close to tacit knowledge which can only be transferred through experiences (Von Hippel 1988). Therefore, the transfer of tacit knowledge needs more communications and interactions between the knowledge source and recipient, which makes the transfer more difficult. On the contrary, it's much easier to pack and transfer codifiable knowledge through boundaries in form of "boundary objects." The other dimension of the complexity of knowledge is the interdependency of knowledge to be transferred (Teece 1986). If the targeted knowledge to be transferred is independent from other knowledge of the source, the innovation unit can transfer this type of knowledge relatively easily as a module. In contrast, if the targeted knowledge is interdependent on other knowledge of the source, the innovation unit may need to acquire some knowledge about the knowledge system in which the targeted knowledge is rooted before it can be transferred. Both dimensions of knowledge complexity intensify the need for strong ties between the knowledge source and knowledge recipient. As the knowledge to be transferred is less codifiable and more interdependent, more iterative two-way interactions and trial-and-error efforts are necessary in the knowledge transfer process. If the ties between the knowledge source and recipient are not strong, the knowledge source is unwilling to initiate the knowledge transfer process. As Granovetter (1982) noted, "strong ties have greater motivation to be of assistance and are typically more available." Moreover, units with strong ties usually share more common knowledge than those with weak ties. The high degree of knowledge commonality between knowledge sources and recipients can also facilitate the transfer of complex knowledge.

Considering both knowledge searching and knowledge transfer aspects, Hansen concluded that weak ties are beneficial in the knowledge searching phase while strong ties are beneficial in the knowledge transfer phase. The more complex the knowledge to be transferred, the more advantageous the strong ties will be and vice versa. The correlations between tie strength and knowledge type are demonstrated in Figure 7-1 below.

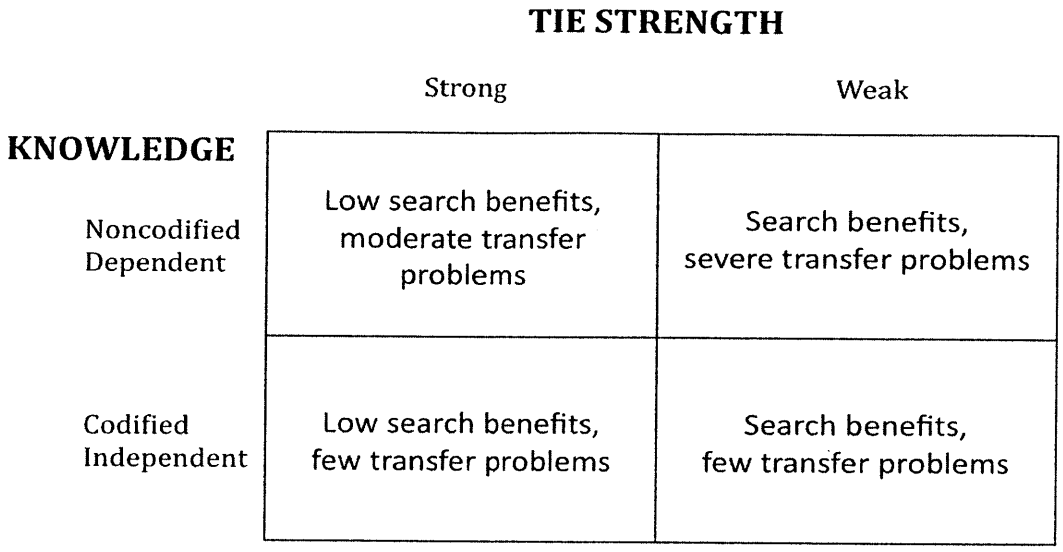


Figure 7-1 Search and transfer effects associated with four combinations of knowledge complexity and tie strength (Source: Hansen 1999)

Consolidating all the discussions about the effects of tie strength on innovation, I work out a causal loop diagram below (Figure 7-2). There is no apparent loop in this diagram and "Tie Strength" seems to be the most important exogenous factor in this process. However, since "Tie Strength" can be considered an attribute of the network and it is formed simultaneously and gradually as the network forms. "Tie Strength" should have some kind of correlations with factors involved in the formation of networks. Unfortunately, I cannot find any papers about the correlations between tie strength and network formation processes. According Hansen's (1999) original definition, weak tie is defined as "infrequent and distant relationships." This definition implies that tie strength is related to frequency and distance of relationships. According to Figure 6-6, "Communication Probability" and "Spatial Proximity" can reflect the "frequency" and "distance" aspects of relationships in the network. Therefore, it's appropriate to correlate "Tie Strength" in this diagram with "Communication Probability" and "Spatial Proximity." The higher the "Communication Probability" and the "Spatial Proximity" between actors in the network, the stronger the "Tie Strength" between them.

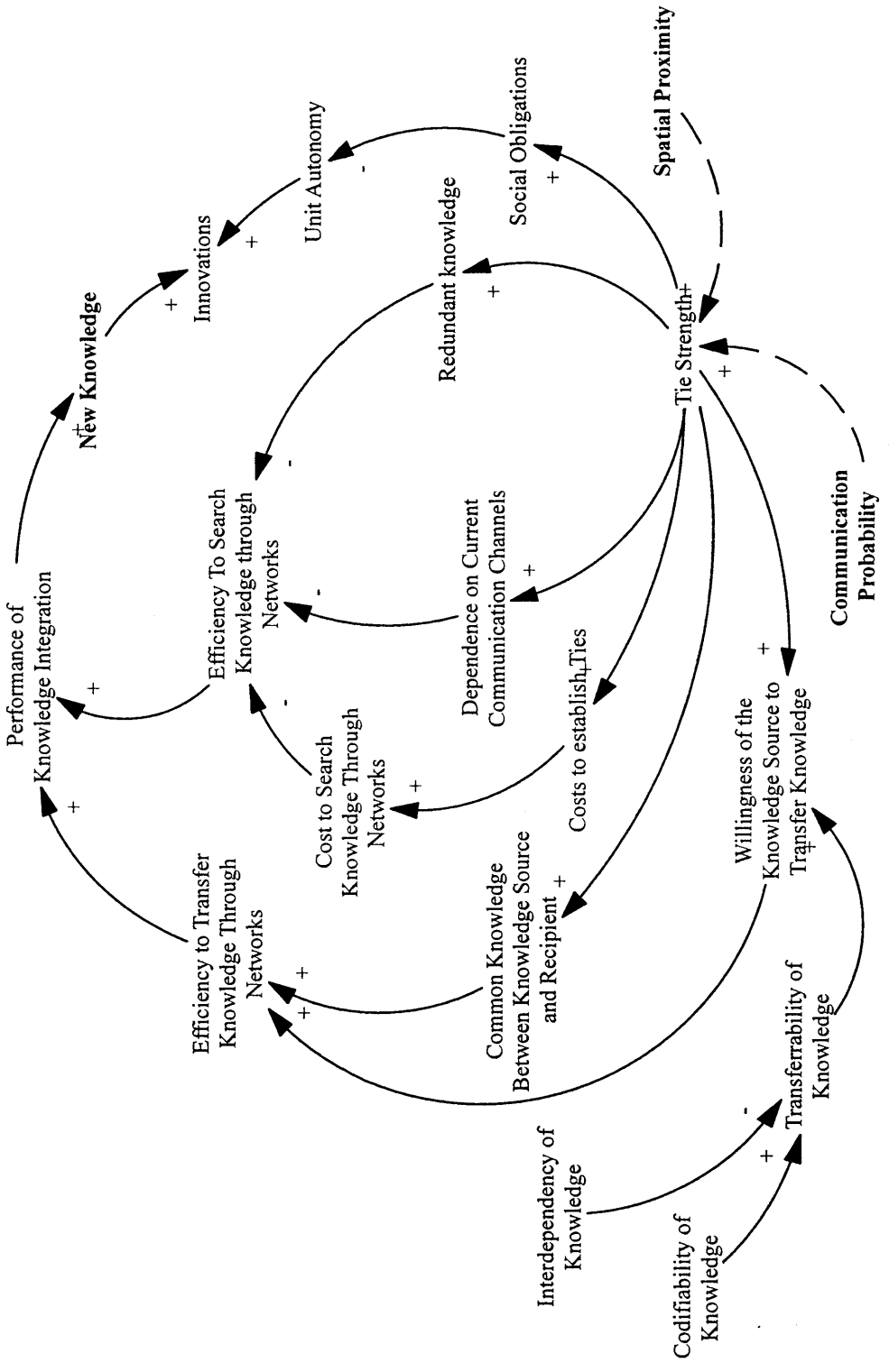


Figure 7-2 Dynamics of knowledge search and transfer in the network

Chapter 8 Interface Processing

8.1 Gatekeepers and Boundary Spanners

Cohen and Levinthal's observation that 'The firm's absorptive capacity depends on the individuals who stand at the interface of either the firm and the external environment or at the interface between subunits within the firm' implies that exchange of knowledge with external environment is a necessary step in the innovation process. This kind of knowledge exchange across organization boundaries involves an interactive learning process within formal or informal channels and is made possible by the role of knowledge gatekeepers or boundary-spanners in the organization. Knowledge gatekeepers or boundary-spanners refer to individuals who not only possess a portion of organizational knowledge but also other necessary knowledge to identify, search and assimilate external knowledge that is complementary to existing organizational knowledge. After assimilating new knowledge from external knowledge sources, knowledge gatekeepers need to transcode the knowledge to languages that are comprehensible to other organizational actors who do not have proper knowledge base to interact with external knowledge sources. In this sense, in addition to high level of absorptive capacity, knowledge gatekeepers also need to possess a network position that is well connected to external knowledge sources and internal knowledge recipients through a variety of formal or informal channels. With this kind of network position, the knowledge gatekeeper can bridge the internal knowledge recipients and external knowledge sources and vitalize the assimilated knowledge. Namely, the centrality of network position is another important qualification for a knowledge gatekeeper. Allen (1977) concludes that in general knowledge gatekeepers have the following features:

- They constitute a small community of individuals
- They are at the core of an information network
- They are overexposed to external sources of information
- Their linkages with external actors are mostly informal

Simon's principle of bounded rationality reflects the basic limitation of knowledge production by human beings and therefore specialization in particular areas of knowledge is a necessary condition for human beings to produce knowledge efficiently. Eventually, knowledge boundaries

can emerge as a result of this natural tendency for human beings to develop specialized knowledge. In an organization, distinctions between different functional groups such as sales/marketing, design, manufacturing and etc. are usually representative of boundaries of different types of knowledge. Many important organizational functions such as product development require the collaboration between different functional groups. Much of the research has highlighted the importance of integrating different types of specialized knowledge in the new product development process (Nonaka 1990, Clark and Fujimoto 1991). Demsetz (1991) also observes that efficiency in acquisition of knowledge requires that individuals specialize in specific areas of knowledge, while the application of knowledge to produce goods and services requires the bringing together of many areas of specialized knowledge. In addition, while some innovations are the result of the application of new knowledge, others result from the reconfiguration of existing knowledge to create "architectural innovations" (Henderson and Clark 1990, Henderson and Cockburn 1995). No matter how the external knowledge will contribute to the value creation processes of an organization, integration of different specialized knowledge in the organization is imperative. Because in an organization different functional groups usually reflects boundaries of different knowledge, gatekeepers or boundary-spanners in different functional groups may be helpful in transferring different types of knowledge across knowledge boundaries. However, as the transfer of knowledge across knowledge boundaries becomes routinized, the use of knowledge gatekeepers in transferring knowledge can be an extravagant and ineffective approach. In the organization, this purpose is usually served by different types of boundary objects instead of boundary-spanners.

8.2 Boundary Objects

The concept of boundary object, proposed by Star (1989), describes objects that are sharable and shared across different problem solving contexts. Carlile (2002) adapts Star's four categories of boundary objects to describe the objects and their use by individuals in the settings that he observes.

- Repositories: This kind of boundary objects serves as common reference point of data, measures or labels across functions as shared definitions or values used in joint problem solving activities. CAD/CAM databases, cost databases and parts libraries are all examples of this kind of boundary objects.

- Standardized forms and methods: This kind of boundary objects project the knowledge necessary for problem solving across different functional settings as mutually understood structure and language. They can manifest the measurables, potential consequences as well as their relations across different settings and therefore minimize possible problems in the cross-boundary knowledge transfer.
- Objects or models: They are simple or complex representations that can be observed and then used across different functional settings. They depict or demonstrate current or possible functions, operands, instruments, or other objects of the differences or dependencies identified at the boundary. Sketches, assembly drawings, prototypes, computer simulations and etc. all belong to this type of boundary objects.
- Maps of boundaries: They represent the dependencies and boundaries existing between different groups or functions at a more systemic level. Maps can help clarify the dependencies between different functional settings that share resources, deliverables, and deadlines. Gantt charts, process flows, computer simulations and etc. all belong to this type of boundary objects.

After understanding general properties of boundary objects, another important question we need to explore further would be the characteristics of effective boundary objects. Carlile (2002) identified three characteristics that may make boundary objects useful in joint problem solving at a given boundary. From my perspective, these three characteristics can be linked to Nonaka's knowledge creation model discussed in the later section. First, a boundary object establishes a shared syntax or language for individuals to represent their knowledge. This is the most fundamental requirement for a boundary object. For a routinized knowledge transfer across the boundary, it is crucial for actors in both sides of the boundary to express their knowledge in a mutual understandable form before the knowledge can be transferred across the boundary. This characteristic reflects the importance of "externalization" in the knowledge creation process. Second, an effective boundary object provides a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary. This characteristic captures the "internalization" part of the knowledge creation process. From the boundary object, individuals can internalize the knowledge about differences and dependencies of different bodies of knowledge across the boundary in their efforts to solve the problem collectively. This

internalized knowledge about differences and dependencies together with their existing knowledge then becomes the "seed" to crystallize new ideas or concepts in problem solving. Third, an effective boundary object should facilitate a process where individuals can jointly translate their knowledge. Individuals must be allowed to modify or manipulate the contents of boundary objects in order to transform the knowledge used at the boundary and to apply it properly in respective functional settings. This characteristic highlights the role of boundary objects in facilitating the "combination" step in the knowledge creation process. It's reasonable that boundary objects cannot capture the "socialization" part of knowledge creation process since socialization involves the direct transfer of tacit knowledge to tacit knowledge, in which no explicit knowledge is involved. The boundary object should provide a platform for the actors in both sides of the boundary to exchange necessary knowledge and combine the knowledge together to form new solutions.

I set up a system architecture for the interface as shown in Figure 8-1 below. The interface is decomposed to "Gatekeeper" and "Boundary Object." The gatekeeper is the operator for the transcoding process to turn external knowledge to internal knowledge with boundary objects as instruments. Both internal knowledge and external knowledge across the boundary can be necessary knowledge to form solutions in the joint problem solving process. The joint problem solving process is a specialized form of knowledge creation process. From this system architecture, the three sub-processes of the joint problem solving process can be mapped to three of the four sub-processes of knowledge creation process proposed by Nonaka (1994). The only sub-process that is not mapped is the "socialization" process which initiates the knowledge creation process in Nonaka's spiral model. Even for a routinized joint problem solving process, a field to socialize individuals' tacit knowledge is still necessary. However, as Ahuja and Lampert's (2001) "maturity trap" highlights, in the organization people tend to focus more on what can be measured and standardized and ignore what can not. As a result, the organization tends to develop a lot of routines or SOPs without fostering the indispensable socialization mechanisms that really trigger the whole knowledge creation process.

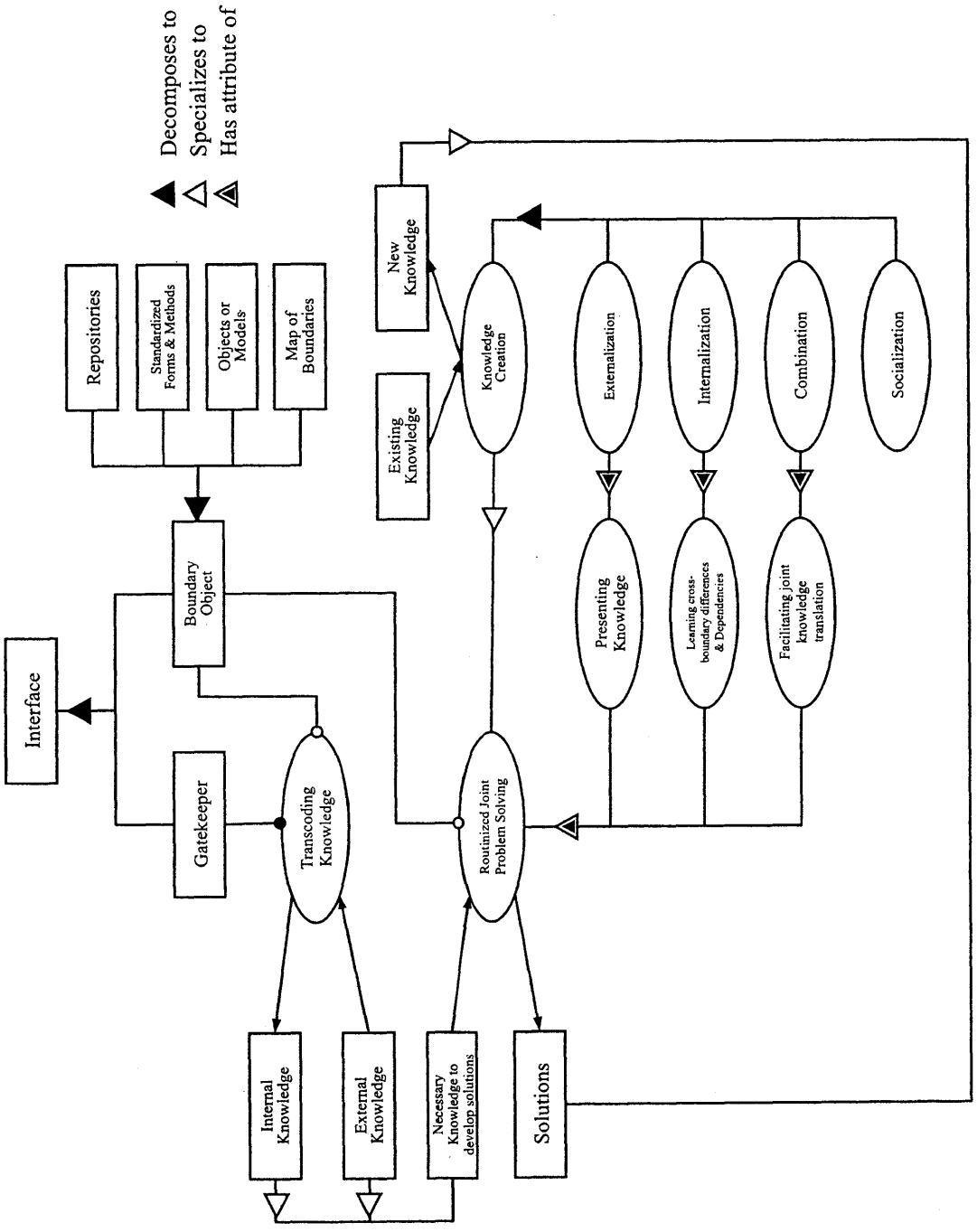


Figure 8-1 System Architecture for Interface Processing

Chapter 9 Conclusions and Discussions

9.1 Conclusions and Discussions

Innovation process is a complex and multifaceted process involving knowledge, organization, technology, psychology and etc. Different theories or frameworks usually articulate the innovation process from different facets. In this thesis, I try to analyze the innovation process with the conventional resource-based view and the developing knowledge-based view of the firm. After comparing and analyzing different frameworks about innovation processes with system architecture and system dynamics approaches, I summarize my conclusions with a high-level consolidated causal loop diagram and a system architecture illustrated in Figure 9-1 and Figure 9-2 below. I conclude that three exogenous factors in the dynamics of innovation processes, knowledge diversity, strategic relatedness and spatial proximity respectively, can be regarded as the most important external factors that drive the innovation process. Knowledge diversity in the beginning of organization formation means a unique combination of knowledge that help the organization survive the initial turbulent environment when the organization is formed. The knowledge in this setting includes the component knowledge and the architectural knowledge that can recombine different component knowledge in different environments. Therefore, this initial knowledge diversity can shape the "knowledge DNA" of the organization. This knowledge diversity also provides sources of variety in organization's knowledge base and forms the primitive absorptive capacity. In this process, we need to pay attention to the duality of the "knowledge diversity" concept in our analysis. In this framework, higher knowledge diversity suggests lower knowledge commonality among team members. Higher knowledge diversity is beneficial to the effectiveness dimension of absorptive capacity while knowledge commonality is beneficial to the efficiency dimension. These two dimensions exist in the organization at the same time and cannot be changed easily because the development of knowledge diversity (knowledge commonality) in an organization is path-dependent. According to law of requisite variety, higher variety in the organization can help the organization identify valuable external knowledge and hence promote the effectiveness dimension of absorptive capacity. However, higher knowledge diversity implies lower knowledge commonality which is important for knowledge transfer in the knowledge creation process. As a result, "Knowledge Diversity within

the organization" has a positive effect on "Effectiveness Dimension of ACAP" but has a negative effect on "Efficiency Dimension of ACAP" in Figure 9-1. In addition, because individuals in the organization need to combine different existing knowledge to form new knowledge in the knowledge creation process, it is inferred that knowledge diversity within the organization will have a positive correlation with knowledge creation. Although two dimensions of absorptive capacity co-exist in the organization, different dimensions may become dominant under different conditions. In a stable environment with few environmental fluctuations, the external knowledge sources are usually limited and shared by industrial participants. Therefore, an organization's ability to transform limited knowledge efficiently to valuable innovative outcomes is of decisive importance to an organization's competitive advantages. On the other hand, in a turbulent environment with constant environmental fluctuations, the external knowledge sources are very diversified and the values of different knowledge to the organization are usually opaque. Under this circumstance, an organization's ability to identify truly valuable knowledge effectively will distinguish the organization from its peers. Consequently in a stable environment the efficiency dimension may be dominant while in a turbulent environment the effectiveness dimension may become crucial in an innovative organization. The duality and path-dependency of the development of knowledge diversity within the organization highlight the difficulties for an organization to switch between different modes swiftly in different environments. Another two factors, "Spatial Proximity" and "Strategic Relatedness," are both positively related to the formation of networks, either internal networks or external networks. Strategic relatedness acts as the compass to search potential knowledge sources and facilitates the establishment of connections with these knowledge sources. Spatial proximity, on the other hand, is the most important enabling condition for knowledge transfer in our analysis. Spatial proximity with external knowledge sources can reduce the costs for searching and transferring external knowledge. Spatial proximity with actors in the organization can activate the socialization process and trigger subsequent knowledge creation mechanisms through externalization, combination and internalization. Both spatial proximity and strategic relatedness have positive effects on the effectiveness dimension of absorptive capacity through the effects of external networks and also has positive effects on the efficiency dimension of absorptive capacity through the effects of internal networks as illustrated in Figure 9-1. As new knowledge is created in the process, the knowledge environment in which the organization resides will also be changed. This

coevolution of knowledge environment will eventually change the structure of the organization in order to absorb the necessary external knowledge more efficiently. This change in organization structure will then affect the formation of networks in the new knowledge environment. As a result, it's appropriate to infer that "Knowledge Creation" has a positive correlation with "Formation of Networks" through the effects of "Change of Knowledge Environment" as shown in Figure 9-1. With the connections between "knowledge Creation" and "Formation of Networks" in the causal loop diagram in Figure 9-1, three reinforcing loops containing all the endogenous factors in the diagram may emerge. These reinforcing loops indicate that the inertia of the system is very strong and the whole system tends to move toward certain directions depending on the historical paths of innovations. The three exogenous factors, knowledge diversity, spatial proximity and strategic relatedness, are the only factors that can regulate the paths of innovations in such an innovation system. They are the leveraging points for managerial actions to improve the innovation system of an organization.

Figure 9-2 illustrates the high-level system architecture for innovation systems consolidated from different studies discussed in this thesis. The three key factors concluded in this thesis are embedded in "Network Formation" and "Development of ACAP" functions in the system. This system architecture shows how these three key factors correlate with one another through different processes, instruments, operands and operators in the system and how these factors may impact innovation performances through different paths. The studies in this thesis provide a systematic approach to decompose and analyze the problems about innovations into different levels. After identifying the direction for improvement from these Figure 9-1 and Figure 9-2 at the first level, one can then delve deeper into the architectures and dynamics developed in this thesis to identify the second level causes and third level causes. These second level and third level factors are usually correlated through different causal loops in different processes. In practice, an organization can start from the factor that reflects the most obvious issue first and then identify other potential factors in different levels with the causal loops or system architectures developed in this thesis. We can then analyze these causes of lowest level with other frameworks. For example, Michael Porter's diamond framework may be very useful in analyzing the conditions of knowledge diversity and strategic relatedness; Ghemawat's CAGE

(Cultural, Administrative, Geographic, Economy) distances may be useful in evaluating the effects of spatial proximity, network formation, organization structures and cultures.

These three factors can not only assess the innovation activities at firm level but also at industry cluster level. They can also be used in the analysis of innovation-related activities such as technology transfer. Almeida and Kogut's (1997) study about patenting in semiconductor industry indicates that proximity and location clearly matter in exploiting knowledge spillover. Audretsch and Feldman (1996) found that the propensity of innovation activity to cluster geographically tends to be greater for industries where new knowledge plays more important roles in value creation. Many empirical evidences have suggested that spatial proximity to external knowledge sources such as industry R&D, university laboratories and skilled labors is of decisive importance to innovation performances. Feldman and Audretsch's (1999) another study indicated that diversity across complementary economic activities sharing a common science base is more conductive to innovation than is specialization. This result implies that knowledge diversity and strategic relatedness are both important factors for innovations in an industry cluster.

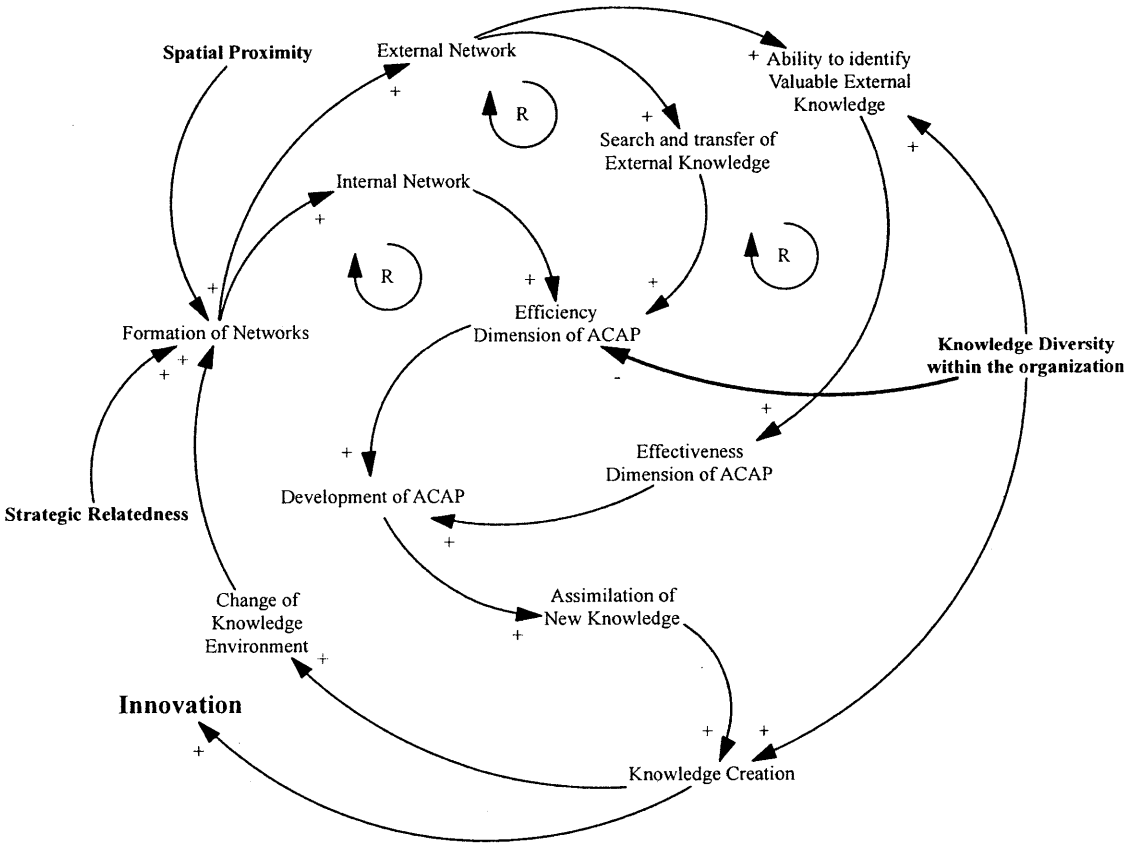


Figure 9-1 High-level consolidated dynamics for the innovation process

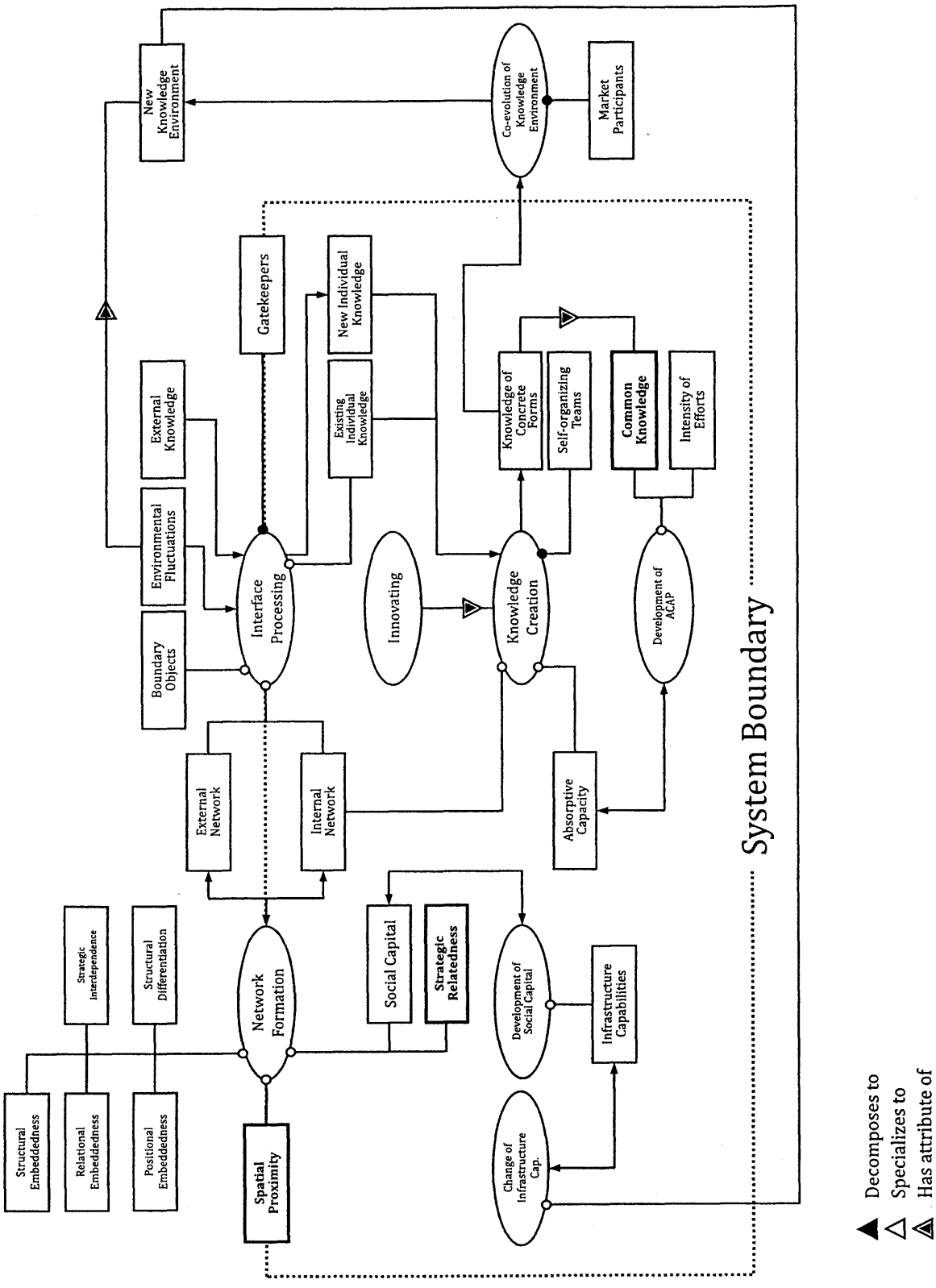


Figure 9-2 High-level consolidated system architecture for the innovation process

9.2 Directions for Future Researches

The three factors, knowledge diversity, spatial proximity and strategic relatedness, may help us evaluate the likeliness for innovations to occur under certain circumstances. However, from my perspective, they are not sufficient to help us gain an insight into how an organization can sustain its innovation performances in changing environments. As I highlight in earlier sections, the knowledge environment in which an organization resides continues to co-evolve with the innovations by the participants in the environment. Sometimes the disruptive technologies emerging from other fields may bring unexpected radical changes to the pre-defined knowledge environment. For an organization to sustain its innovation performances over time, capabilities that can drive the organization to adapt itself to the relentless environmental fluctuations swiftly is indispensable in addition to the three factors. From this perspective, an organization's innovation system must be equipped with the capabilities to evolve with the environment. To develop the evolutionary view of the innovation system, maybe it's a reasonable first step to compare these three factors (knowledge diversity, spatial proximity, and strategic relatedness) with the enabling factors in the evolution theory, which are reproduction, variation and selection respectively. Knowledge diversity is like the variation factor in the evolution theory. Through recombination of internal knowledge and external knowledge, the knowledge diversity as well as the absorptive capacity may also evolve with environmental changes. Another factor, strategic relatedness, can capture the spirit of "selection" mechanism in the evolution theory. In the conventional evolution theory, different species with different genes are selected by the environment passively and only the species that can survive the environment are retained. In this process the species are steady relative to environment changes and the environment is regarded as an independent variable from "species." However, in the evolution of organizational knowledge, not only the knowledge environment can select the organization but the organization can also select its knowledge environment. The last factor, spatial proximity, highlights the necessary condition for the "reproduction" mechanism to occur in the evolution theory. In the evolution theory, reproduction means the recombination of genes through different mechanisms such as mating. In the evolution of organizational knowledge, similar mating mechanism occurs when external knowledge combines with existing knowledge to form new knowledge in the knowledge creation spiral. For this kind of knowledge recombination to occur, "spatial proximity"

plays a crucial role. Without spatial proximity, it would be difficult to "reproduce" knowledge in the organization.

These three factors derived from this thesis seem to be able to connect the innovation process with the evolution process at the first glance. However, these three factors are still not sufficient to lay the foundation for the evolutionary view of innovation systems and can only depict the evolution of innovations under relatively steady environments. This kind of evolution as we discussed before can only handle slow and incremental but not fast and drastic environmental changes. In the natural world, mutation is one of the most important mechanisms to protect the species from extinction in drastic environmental fluctuations. In the business world, a mechanism to access and assess mutations systematically in the organization is as important especially in the "stable" environment. Unfortunately, this kind of mutation mechanism is not manifested in this model. "Mutation" in this setting means any idea or knowledge that obviously deviates from the normal knowledge base or developing path of a firm. In a turbulent environment where the knowledge base of the firm is developed faster in response to higher environmental fluctuations and where the future path of the firm is not so clear, usually firms tend to demonstrate higher perceptivity and acceptance to "mutations" in the organization. In a stable environment where the developing path of a firm is relatively stable and clear, usually firms are less perceptive and tolerant to "mutations." In addition, firms in a stable environment usually possess less knowledge diversity that is usually developed in response to environmental fluctuations. As the "mutations" usually come from the creativity or serendipity fostered by the culture and knowledge diversity within an organization, less knowledge diversity in an organization usually suggests lower probability of "mutation." An organization with fewer mutations will be more susceptible to environmental fluctuations and less likely to survive in the emergence of disruptive technologies. On the other hand, "mutations" in the organization may also mean new opportunities to re-shape competition frontiers. Many killer applications or disruptive technologies are products of "mutations" in the organization. Therefore, the research about mechanisms to foster and retain valuable "mutations" in the organization would be important to complement the findings in this thesis.

Aside from the three factors and mutations, another issue that is equally important would be how fast can an organization change in response to environmental fluctuations. In a stable environment where the pace of change is slow, what is important is to identify the direction of change. However, in a turbulent environment where changes are frequent and fast, the dynamic capabilities to respond to environment changes swiftly will become crucial and firms that cannot change themselves fast enough will be obsoleted. According to Teece et al (1997), dynamic capabilities can be defined as "the firm's ability to integrate, build, reconfigure internal and external competencies to address rapidly changing environments." As Eisenhardt and Martin (2000) stated, in high-velocity industries, "dynamic capabilities necessarily rely much less on existing knowledge and much more on rapidly creating situation-specific new knowledge." Dynamic capabilities are often characterized as unique and idiosyncratic processes that emerge from path-dependent histories of individual firms (Teece et al, 1997). In order to handle the rapid environmental fluctuations efficiently, effective dynamic capabilities in turbulent environments are usually simple (not complicated), experiential (not analytical), and iterative (not linear) comparing with those in stable environments. For example, when Intel faced strong challenges in technologies and prices in DRAM markets from its Asian competitors, it decided to give up its foundation in DRAM and transit to microprocessor markets rapidly based on one simple production rule, "margin-per-wafer-start." Because of this dynamic capability, Intel could escape from the red sea DRAM market and create its own blue ocean microprocessor business that secured its long-term prosperity for decades. Therefore, future researches about "dynamic capabilities" are imperative in the development of the evolutionary view of innovation systems.

To evaluate the sustainability of an innovation process, we need to take "mutation mechanisms" and "dynamic capabilities" into consideration in addition to these three factors. The combination of these five factors will form a complete framework for us to analyze the dynamics of innovation from an evolutionary view. It's also another interesting topic to research the sequence of the formation of different factors and the conditions under which different factors become dominant. Because this framework is established on the foundation of resource-based and knowledge-based view of the firm in which knowledge is regarded as the most VRIN (Valuable, Rare, Inimitable, Nonsubstitutible) resource, spatial proximity to knowledge sources such as universities, key markets and etc. can be considered the starting point of the evolution cycle.

Firms close to these knowledge sources can gain key new knowledge to form valuable initial knowledge diversity and hence the absorptive capacity at lower costs. The absorptive capacity combining strategic relatedness can then form specific competition advantages in certain markets. When entering a new market or creating a new market, the dynamic capabilities would be developed based on the histories or paths of innovation activities of the firm. I would argue that the dynamic capabilities are usually developed prior to mutation mechanisms because dynamic capabilities are more important for firms to survive the initial turbulent environments when they are first established. As the market or the industry of the firm becomes mature and stable over time, the importance of dynamic capabilities will be replaced by the mutation mechanisms which can ignite the innovation activities that provide the firm the energy to escape from the gravity of perishing markets. In the process of escaping, the firm needs to set up new connections with key new knowledge sources. At this stage, the importance of spatial proximity will come into play again. As a result, firms need to experience this evolution cycle continually for them to survive. Different firms at different stages in the evolution cycle will need different capabilities. This evolution cycle involves destructions and re-constructions of different organization capabilities, which are not discussed in this thesis. They would be important topics for subsequent studies to extend the applicability of this framework. In this framework, I assume that every organization will make its best efforts to change itself to survive the environmental fluctuations and therefore I exclude subjective factors such as "intensity of efforts" from this framework. This may not be true for all organizations. It would be another interesting research topic to understand how organization members with different intentions react to environmental fluctuations and how their individual reactions affect the organization's response to external changes. To solidify the theory foundation of this framework and to provide more practical guides to its applications, it is necessary to delve deeper into "mutation mechanisms" and "dynamic capability" in subsequent studies.

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