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ANALYSIS OF RESOURCE-SHARING DECISIONS IN DYADIC COLLABORATIVE KNOWELDGE CREATION: A GAME-THEORETIC APPROACH

BY

SAVITHA KADIYALA NAMUDURI

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree
of
Doctor of Philosophy
in the Robinson College of Business
of
Georgia State University

GEORGIA STATE UNIVERSITY
ROBINSON COLLEGE OF BUSINESS
2006

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ACCEPTANCE

This dissertation was prepared under the direction of the Savitha Kadiyala Namuduri's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor in Philosophy in Business Administration in the Robinson College of Business of Georgia State University.

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"*A journey of a thousand miles begins with a single step.*"
Lao-tzu (604 BC - 531 BC), *The Way of Lao-tzu*

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ABSTRACT

ANALYSIS OF RESOURCE-SHARING DECISIONS IN DYADIC COLLABORATIVE KNOWELDGE CREATION – A GAME THEORETIC APPROACH

By

SAVITHA KADIYALA NAMUDURI

Defended December 19th, 2005

Committee Chair: Dr. Subhashish (Sub) Samaddar

Major Department: Managerial Sciences

Knowledge is an asset that can give an organization competitive edge. However, knowledge creation is an expensive activity. One of the reasons organizations form knowledge creation collaborations is to share resources that are needed to create knowledge.

This dissertation models the dyadic collaborations as games between the partners and arrives at resource-sharing schemes for them. Specifically, the collaborations are modeled as two games- Stackelberg Leader-Follower game and Partnership game. The types of collaborations are distinguished based on the nature of the marginal return functions with respect to knowledge creation investments for each of the collaborating organizations.

Three essays are presented and discussed. In Essay 1, collaborations between organizations characterized by decreasing marginal returns with respect to investments are modeled as a partnership game. In Essay 2, collaborations between organizations characterized by increasing marginal returns with respect to investments are modeled as a Stackelberg Leader-Follower game. In Essay 3, collaborations where the leader organization is characterized by decreasing marginal returns with respect to investment and the follower organization is characterized by increasing marginal returns with respect to investments are studied. The solutions for the game in terms of the participation rate, knowledge creation investments, and the system gain are presented for each essay. The results are analyzed and the observations are stated as propositions. The propositions provide guidelines for collaborating organizations to arrive at a resource-sharing scheme. Additionally, the results suggest conditions under which the potential partners collaborate specifically with respect to the participation rate and the system gain. The results of Essays 2 and 3 provide conditions for participation rate. The results of Essay 3 provide the conditions of expected system gain under which the follower organization will collaborate with a potential leader organization. The results have implications for several stages of the alliance management process such as partner selection, gauging the behavior of potential and current partners, and renegotiation of alliance terms.

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Chapter 1 INTRODUCTION

1.1 Knowledge, Knowledge Creation and Collaborative Relationships

Knowledge is increasingly being recognized as the most important competitive asset for organizations (Webber, 1993). The knowledge-based view of the firm (Grant, 1996; Kogut & Zander, 1992) endorses the importance of creating, managing and using knowledge for an organization's competitive advantage. One of the most difficult tasks facing the field of knowledge management today is the definition of knowledge itself. Although attempts have been made to agree on a comprehensive definition, the inherent nature of the concept of knowledge probably makes it difficult for researchers to arrive at a plausible definition. For instance Grant (1996) remarks that:

> *"Developing knowledge-based theory of the firm raises the issue: What is knowledge? Since this question has intrigued some of the world's greatest thinkers from Plato to Popper without the emergence of a clear consensus, that is not an arena in which I choose to compete. In terms of defining knowledge, all I offer beyond the simple tautology of 'that which is known' is recognition that there are many types of knowledge relevant to the firm."* pp.110.

A definition of knowledge that originates from traditional Greek epistemology is that knowledge is a "justified, true belief" (Nonaka, 1994). This definition calls for a belief that a certain tenet is true and unless such belief is justified, there is no knowledge.

Alternately, Davenport and Prusak (1998) give a working definition of knowledge as follows:

> *"Knowledge is a fluid mix of framed experience, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices and norms."* pp. 5.

This definition appears to encompass all the features of knowledge such as the structural features, functional features, and where it resides within an organization. One can also gather

that knowledge is complex, fluid and its worth is recognized to the extent that the knower puts it to use. Hence, for the purpose of this dissertation I use Davenport and Prusak's (1998) working definition of knowledge.

Another method by which we can arrive at a working definition of knowledge, is by distinguishing it from data and information (Zack, 1991). Data is a collection of objective facts about events. The next level in the hierarchy is information, which is data with sense. Information is believed to have impact on the judgment of the receiver with reference to a particular event. Knowledge is further up in this hierarchy, adding experience and context to information.

Organizations create knowledge in several ways. While some organizations acquire knowledge from external sources, others dedicate a segment of the organization in the form of research and development (R&D) divisions for the purpose of creating knowledge (Davenport et al., 1998). Allocating dedicated resources for knowledge creation has been especially successful in knowledge-intensive industries such as biotechnology, aviation, manufacturing, and semiconductors (Mowery, 1988). Knowledge creation is an expensive activity, which might be better achieved through collaboration (Hartley & Benington, 2000). Especially in the high technology industries, where the innovation cycle time is shorter than in traditional manufacturing, collaboration plays a major role in putting both of the participating organizations in a win-win situation (Fine, 1998; Mowery, Oxley, & Silverman, 1996). This growing trend, to form knowledge creation collaborations, especially among high technology organizations, has been emphasized in recent literature (Boddy, Macbeth, & Wagner, 2000; Gibson & Rogers, 1994; Hagedoorn & Shakenraad, 1994; Kogut, 1988). Additionally, literature in knowledge management emphasizes the notion that organizations might gain more from knowledge creation

if they collaborate. For instance, Nonaka (1994) argued that inter-organizational knowledge creation could be possible when the informal interactions between partners such as suppliers and customers, distributors and even competitors, are formalized by forming alliances. Literature is abundant with examples of several types of knowledge creating collaborations, ranging from the simplest dyadic R&D collaborations to elaborate consortia, such as SEMATEC, formed within the semi conductor industry. However, as with any collaboration, there is a concern about the success of knowledge creation alliances. More importantly, one of the specific concerns this dissertation addresses is with regard to how the resources, which are necessary for knowledge creation, are shared among the partners. In other words, this dissertation studies the resource participation decision-making process during inter-organizational knowledge creation, specifically one that leads to the development of a viable resource-sharing strategy between the collaborating partners. The collaborating partners could be organizations or strategic business units of large organizations. Nevertheless, the collaboration itself is considered as a unit for the purpose of this thesis. A detailed discussion on the unit of analysis for the study is presented in Section 3.2.

1.2 Theoretical Positioning and Motivation for the Study

Knowledge creation is expected to generate financial benefits (Forrest & Martin, 1990), and its transfer to the collaboration partner within the context of a long-term, trusting relationship can "create resources that lead to competitive advantage" (Lengnick-Hall, 1998). With the knowledge-based view of the organization (Grant, 1996; Spender, 1996) coming to the forefront, and the importance of information sharing in collaborations (Boddy et al., 2000), it is evident that the goal of such collaboration is to derive financial and strategic benefits from knowledge creation, including ownership of knowledge, which, would in turn, generate economic rents in the future (Mowery et al., 1996). Thus, ownership of knowledge, and its potential for financial and strategic benefits, has become a point of interest for collaborating organizations.

In concert with this line of thought, I shall define a knowledge creation collaboration relationship as one in which two organizations initiate and implement a knowledge creation endeavor together and share the expense, and eventually the benefits of knowledge creation, including the ownership of newly created knowledge, through mechanisms such as patents. Collaborations among organizations for the purpose of knowledge creation have been the focus of much research (Vonortas, 1991). Among others, spreading the costs and risks of innovation (Mowery, 1988), achieving economies of scale, and allowing for higher levels of knowledge exchange (Mowery et al., 1996) are some of the prominent reasons why organizations collaborate. The growing importance of collaborative R&D efforts emphasizes that the level of R&D spending can influence inter-organizational knowledge creation and transfer.

For instance, Cohen and Levinthal (1989; 1990) observed that absorptive capacity, measured as the amount of R&D investments made by an organization, is an important

determinant of organizational learning. Absorptive capacity refers to an organization's ability to recognize the value of new, external information, assimilate it, and apply it for competitive advantage. This ability of the organization facilitates the creation, retention, and the use of newly created knowledge. This line of research emphasizes the importance of studying financial commitments in R&D (as a measure of absorptive capacity), which, in turn, affect knowledge creation. Also, studies have shown that research joint ventures perform better than stand-alone alternatives (Vonortas, 1991). Collaboration in research ventures is beneficial if the participating organizations can achieve economies of scale and scope. However, in order to ensure the success of the collaboration, the participating organizations must develop a viable strategy to coordinate resource-sharing decisions.

Resource-sharing decisions in relation to knowledge-related activities have been the focus of much recent research (Ba, Stallaert, & Whinston, 2001; Gerchak & Parlar, 1999; Hopp, 1987; Machlup, 1980; Teece, 1998). While some attempts have been made to study organizations' efforts in knowledge creation activities, from the perspective of resource allocation within an organization (Gerchak et al., 1999), studies of inter-organizational knowledge creation analyzed as a dynamic, coordinated process are rare.

Furthermore, the long-term orientation and uncertain outcomes of knowledge creation activities make the identification of the appropriate amount of financial commitments to be made towards knowledge creation activities imperative. Adequate and timely allocation and sharing of resources are critical to the success of the collaboration, since it has been shown to have a statistically significant effect on the outcomes of the collaboration (Boddy, Macbeth, Charles, & Fraser-Kaus, 1998). However, a lack of theoretical understanding exists of how this resource-sharing takes place.

Literature on collaborations has documented several motivations, guided by several theories, for the formation of alliances or collaborations. Of these, the three main theories that pertain to this dissertation and their limitations as they relate to the current dissertation, are discussed here. A detailed discussion of the theories is presented in Section 2.1. Transaction cost economics (TCE) (Coase, 1937; Williamson, 1985) defines a transaction as "transfer across a technologically separable interface" (Williamson, 1985). A transaction is an event that occurs as a part of an exchange process; and, specifically, it involves the establishment of an agreement and the transfer of ownership rights (Nooteboom, 1999). Specifically, knowledge creation can be viewed as a transaction that occurs within an organization, whereby a transfer of resources within the organization that is necessary to create new knowledge. However, when gaining access to such resources within an organization becomes expensive, the organization experiences transaction costs. When the costs associated with accessing such resources are prohibitive, an organization seeks partners to share the transaction costs. Since knowledge creation is an expensive activity and when considered as a transaction, organizations are motivated to collaborate with other organizations in order to reduce transaction costs. Thus, from a transaction cost perspective, organizations are motivated to form alliances to reduce transaction costs (Kumar & van Diesel, 1996).

While this is true, one of the factors that needs attention is the risk of opportunism that the individual organizations may face from the partner (Jacobides, 2005; Wathne & Heide, 2000)- especially, when relation-specific investments are involved such as those involved in joint knowledge creation. TCE proposes contractual agreements as safeguards against opportunism; however, its recommendations are at a macro level. In this light, the current work takes importance, since it provides guidelines for developing expectations for the collaboration, and

hence a yardstick to evaluate partners, as well as aids in working out the details of contractual safeguards at the micro level.

Apart from sharing transaction costs, gaining access to resources that give an organization competitive edge is another motivation for organizations to collaborate. Resource dependency theory (RDT) (Pfeffer & Salancik, 1978) contends that firms collaborate in order to gain access to competitively crucial resources that are not available within a firm. Particularly when the resource in question is knowledge, collaborating with other organizations that have complementary knowledge becomes all the more imperative (Reid, Bussiere, & Greenaway, 2001). In this study, I assume that the collaborating organizations have symmetric levels of knowledge that are complementary. However, as explained in detail in Section 2.1, although RDT prescribes inter-organizational networks as a means for an organization to gain access to external resources, it does not delve into the detailed strategies that organizations can adopt while engaging in collaborations (Barringer & Harrison, 2000). The current work attempts to address this gap by enabling organizations to devise resource-sharing strategies while engaging in inter-organizational collaborations.

From an organizational learning theory (Levitt & March, 1988) point of view, it is believed that alliances create opportunities for organizations to build their resources and to develop abilities (that is, they create opportunities to learn). This, in turn, specifies the possible accumulation of new knowledge as the primary reason why organizations collaborate. However, it has been acknowledged in literature that the focus of the learning outcomes of inter-organizational learning has been restricted to inter-partner learning or to how much each individual organization has learned from the collaboration or to learning races. The need to

consider the joint outcomes for the collaboration has been emphasized in recent literature (Larsson, Bengtsson, Henriksson, & Sparks, 1998). Specifically, recent literature has emphasized that inter-organizational collaborations not only result in knowledge transfer (which can be equated to learning outcomes for individual organizations) (Powell, 1998; Powell, Koput, & Smith-Doerr, 1996) but also knowledge creation (joint learning outcomes for the collaboration) (Anand & Khanna, 2000; Kale, Dyer, & Singh, 2002). This dissertation addresses this issue by focusing on the joint outcomes for the collaboration as a unit in addition to evaluating the outcomes for individual organizations. Such a focus on the necessity to consider joint outcomes has been identified in recent research and initial studies are currently being conducted to this effect (Dyer & Singh, 1998; Larsson et al., 1998).

For instance, in the information systems literature, recent studies have identified the importance of evaluating the performance at the network level (Straub, Rai, & Klein, 2004), in addition to firm performance as the firm participates in a supply chain. However, organizational learning theory is in its nascent stage as it relates to studying joint inter-organizational outcomes from collaboration. In this regard, game theory explicitly allows one to model the payoffs for the individual organizations, as well as for the collaborations. In short, the motivation for this study is derived from transaction cost economics, resource-dependency theory and inter-organizational learning perspectives; and, game-theoretic analysis is used to further our understanding of the detailed dynamics of the collaboration that these theories fail to provide. As discussed in the three essays of this dissertation, such analysis has implications for the various stages of forming and maintaining the collaboration, including partner selection and renegotiation.

Another specific issue that is addressed in this dissertation is with regard to the nature of the marginal return functions with respect to knowledge creation investments for the collaborating organizations. Literature on the economics of knowledge has shown how the investments in knowledge creation always yield positive returns[1] by the way of better performance (Machlup, 1980). Literature bears sufficient evidence that the returns due to knowledge investments always increase (Arthur, 1989; Arthur, 1990; Arthur, 1996; Teece, 1986). However, there are two competing views as to whether such returns increase at an increasing rate or at a decreasing rate. For instance, according to one view, the performance due to knowledge creation investments has an intrinsic limit (Dosi, 1988). This view also suggests that the returns, due to knowledge creation, increase at a decreasing rate (Katila & Ahuja, 2002). That is, returns on knowledge creation investments increase at a decreasing rate as they approach the performance limit[2]. According to another view, returns due to knowledge creation investments increase at an increasing rate[3] (Knight, 1999; Knott, Bryce, & Posen, 2003; Teece, 1998). These two views are discussed in greater detail in Section 2.2. For the purpose of this dissertation, both of these views of the performance function are considered. Such consideration leads to the possibility that the performance due to knowledge creation investments, for each of the collaborating organizations, could increase either at an increasing rate or at a decreasing rate.

This, in turn, arouses one's interest in understanding the influence of the nature of marginal return function with respect to knowledge creation investments of each firm, on the resource-sharing decisions that are made within knowledge creation collaboration. This dissertation attempts to understand the dynamics underlying the resource-sharing decision-

[1] The returns discussed in this dissertation refer to the return on R&D investments. The performance that is discussed in this dissertation refers to the output that is achieved as a result of the R&D investment.
[2] That is, the marginal returns with respect to knowledge creation investments decrease.
[3] That is, the marginal returns with respect to knowledge creation investments increase.

making process in inter-organizational collaborations, while considering the several combinations of firms characterized by different performance functions.

The main research questions guiding this work are as follows:

What are the factors that determine an organization's share of resources required for collaborative knowledge creation, and how do they affect resource-sharing?

What are the conditions under which some of the potential partners become more attractive than others?

What is the set of resource-sharing conditions in which knowledge creation collaborations exist?

How does the nature of an individual firm's performance with respect to knowledge creation investment, influence the resource-sharing decisions?

These research questions can lead to insights about partner selection and how the partner organizations can renegotiate their share of resources after forming the alliance. The specific resource-sharing is measured by the "participation rate" of the organizations in the current efforts toward knowledge creation. It is this participation rate which guides the choice of each partner for collaborative knowledge creation. The current study focuses on investigating the resource-sharing conditions, identifying the factors that influence the determination of resource-sharing, and the effect that the nature of performance due to knowledge creation investments has on the resource-sharing decision and is therefore descriptive of the resource-sharing decision-making process. On the other hand, the current study has implications for practice – specifically for partner selection and incremental knowledge creation investments – and, is therefore a prescriptive study. Recent research has called for such partnership between descriptive and prescriptive research (Margolis & Walsh, 2003).

Both of the participating organizations may or may not have, and, consequently, may or may not bring unique prior knowledge to the collaboration that is directly relevant to the

knowledge creation endeavor at hand. In the event that one or both of the individual organizations bring unique prior knowledge to the collaboration, knowledge transfer during the knowledge creation process is inevitable. However, it has been observed in prior literature that large asymmetries in the partners' unique prior knowledge are detrimental to knowledge creation, since a considerable amount of time is spent in educating the partner with lesser unique prior knowledge (Hitt, Dacin, Levitas, Arregle, & Borza, 2000). Hence, I concentrate on partners with symmetric levels of unique prior knowledge.

1.3 Scope of the Study

The current dissertation attempts to study dyadic collaborations between organizations for the purpose of knowledge creation. Other types of collaborations, including licensing arrangements between partnering firms, mergers and acquisitions, and marketing and distribution alliances, are out of the scope of this study. Additionally, the multiparty alliances, such as those among several partners in a supply chain, are out of the scope of this study and are good candidates for extending this study in the future.

This study also assumes that the collaboration creates knowledge and generates financial outcomes from the created knowledge. Hence, for the purposes of this study, I assume that there will be positive financial gains to the individual organizations, as well as for the collaboration. In other words, collaborations that have failed and/or do not expect financial gains are out of the scope of this study and are reserved for future work. Why collaborations continue to invest in knowledge creation when there are negative returns needs to be further investigated. The current dissertation, in this respect, is descriptive of how to anticipate the behavior of the individual organizations in the collaboration. It is also prescriptive of how to share resources and benefits of collaboration and assumes that there are benefits arising out of the collaboration.

Chapter 2 THEORETICAL BACKGROUND

2.1 Collaborative Knowledge Creation

Knowledge creation has been defined from several vantage points in the literature (Davenport et al., 1998; Nonaka & Takeuchi, 1995; von Krogh, Ichijo, & Nonaka, 2000), and these perspectives can be broadly classified into two views - the "increase in stock view" and the "process view." Davenport and Prusak (1998), who are the main proponents of the increase in stock view, define "conscious and intentional" knowledge creation as the initiatives and activities that firms undertake to increase their stock of corporate knowledge.

This definition projects the view of the knowledge creation process as resulting in an increase in the knowledge stock, similar to a product, which accrues over repeated efforts of knowledge creation. This view suggests that each knowledge creation endeavor either creates new knowledge, or adds to the existing stock of corporate knowledge. Fundamentally then, it assumes some measure of knowledge stock and lends itself to the existence of a measurable return function (which is used in this dissertation), capable of capturing the benefits to the organizations involved. Since the main return on knowledge is achieved by its use, the effects of such use can be measured through performance, earnings, or patents, which then become(s) the yardstick to judge the value of the created knowledge (Machlup, 1980).

The new knowledge created could add to the existing stock in two ways, by recognizing "promising areas of inquiry" and "blind alleys." These two types of knowledge have been identified as positive knowledge and negative knowledge (Teece, 1998), respectively. Positive knowledge is the knowledge created previously, which is based on past successes and provides direction about what works. On the other hand, negative knowledge is the knowledge about failures and what does not work. Negative knowledge is positive in the sense that it can still guide current research efforts by steering it away from potential pitfalls.

Thus far I have expanded on the increase in stock view of knowledge creation, and now I turn to the process view. This view, advocated by Nonaka (1995), defines knowledge creation as a process, or a relationship:

> *"By organizational knowledge creation we mean the capability of a company as a whole to create new knowledge, disseminate it throughout the organization, and embody it in products, services and systems."* (Nonaka and Takeuchi, 1995 pp. 3)

This definition projects knowledge creation as a dynamic and interactive process that focuses on the relationships between creators of new knowledge. This view of knowledge creation complements and extends the earlier definition of the knowledge creation process as that which results in an increase in knowledge stock.

Nonaka (1994) presented a framework for knowledge creation based on two dimensions of knowledge. One is the epistemological dimension, which distinguishes tacit knowledge from explicit knowledge, and defines knowledge creation as the conversion of tacit knowledge into explicit knowledge and vice-versa. The other dimension is the ontological, which recognizes knowledge creation as a result of an exchange process of ideas and resources among various organizational units such as individuals and divisions, as well as extra-organizational entities that form a network.

In particular, the ontological dimension of the knowledge creation process could be better illustrated by the collaborative actions taken by organizations, as in the case of Honda's collaboration with its suppliers ICV and JFC for manufacturing the cup-holder (Choi & Hong, 2002). Honda's own R&D takes on the role of the individual that creates knowledge, which then shapes the processes that need to be in place in order to implement the design. In the next stage, once the product and process specifications are identified, Honda then partners with JFC, which has a patent for the material that is best suited to make cup-holders. Here Honda makes a

"knowledge" connection with potential suppliers and then chooses one that has previously created complementary knowledge. Honda's choice of suppliers with such complementary knowledge defines their supply chain design and exemplifies the knowledge creation process between different organizations.

Both the "increase in stock view" and the "process view" of knowledge creation are useful to my work since I am interested not only in examining the output of the knowledge creation process (in terms of a measurable response), but also in studying the dynamics of inter-organizational knowledge creation (in particular, the resource-sharing decisions). Thus, the increase in stock and process views of knowledge creation, complement each other.

As noted in the introduction, knowledge creation is an expensive activity that requires varied expertise. In the ensuing paragraphs, three major theories that contribute to the underlying motivations to form knowledge creation collaborations are discussed, culminating in the applicability of game theory to help better understand the dynamics of collaborative relationships.

According to TCE, a firm is considered as a governance structure that enables transactions among entities. The transactional dimensions of TCE are asset specificity, frequency of transactions, and uncertainty, while the behavioral assumptions underlying TCE are bounded rationality, opportunism and risk neutrality. Of these, asset specificity and opportunism are discussed in this dissertation because they have a direct bearing on how the collaboration arrives at contractual safeguards in order to reduce opportunism. Organizations can either produce their own assets or acquire them through transactions. The extent to which an asset is specified to an entity or process, by which characteristic it cannot be transferred to another process, entity, or location without prohibitive costs, is called asset specificity. Asset

specificity is of six types: (1) site specificity, (2) physical asset specificity, (3) human asset specificity, (4) brand name capital, (5) dedicated assets, and (6) temporal specificity. In relation to knowledge creation, Choudhury and Sampler (1997) have identified another type of specificity called information specificity, which refers to the extent that the cost of transferring and acquiring information from the environment is prohibitive. Information specificity, in turn, is comprised of knowledge specificity and time specificity.

Costs associated with the creation or transfer of the assets and in general with running an economic system, are transaction costs (Williamson, 1985). In relation to inter-organizational knowledge creation, transaction costs include the costs associated with creating the knowledge; using expertise that is needed to develop new knowledge, available within both of the organizations; and the costs that are associated with monitoring the relationship with the partners. Organizations choose governance structures that reduce transaction costs. In relation to this dissertation, the governance structure in place is a collaborative relationship, a hybrid form of governance structure.

Apart from transaction costs, partners' behavioral uncertainties give rise to risks of opportunism where one of the organizations seeks to gain advantage at the expense of its partner. Monitoring the relationship becomes necessary to reduce any risks of opportunism by either of the partnering organizations. Such risk of opportunism is reduced by laying certain safeguards in place in the form of contractual arrangements.

TCE prescribes several types of contracts. Classical contracts are those where the contractual details are very rigidly defined. The neoclassical contracts are at the other end of the continuum and are characterized by loosely-defined terms that leave room for flexibility. Neoclassical contracts are typically long-term and adequately accommodate uncertainty. These

are amenable to third-party arbitrations. Such contracts describe innovation-related contracts in the United States (Bolton & Malmrose, 1994); and for the purpose of this study, I assume that the collaborating organizations design neoclassical contracts with room for the renegotiation of terms. Another type of contract is known as a relational contract. This type considers the entire transaction as a relationship. Such contracts are self enforcing, and do not allow for third party arbitrations. Such contracts are descriptive of innovation-relation contracts in Japan (Bolton et al., 1994).

For instance, considering knowledge as an asset, organizations are motivated to collaborate in an attempt to gain access to knowledge specified to a partner organization at less than prohibitive costs. Thus, they enter into contractual agreements in order to arrive at appropriate safeguards and terms of access to the specified asset. This is true for collaborations where either or both of the partners have unique prior knowledge that they can contribute to the current collaboration. However, in collaborations where the partners do not possess unique prior knowledge, knowledge is very lowly specified; and hence, the partners might depend on loose contractual agreements to begin with, and then plan to redraft contracts subsequently as knowledge may become specified to either organization.

Although TCE identifies several types of contracts, when it comes to deciding on the details of the contract, game theory is helpful. Game theory has been used by researchers in marketing and R&D literature streams to arrive at resource-sharing decisions (Amaldoss, Meyer, Raju, & Rapoport, 2000; Baiman & Rajan, 2002; Vonortas, 1991) and is an appropriate tool that can be used to bridge the gap between macro and micro levels (Krishnan & Ulrich, 2001). Furthermore, a recognized limitation of transaction cost economics is its focus on minimizing transaction cost, thereby driving efficiency (Ghoshal & Moran, 1996).

As Coase (1988) notes:

> *"I consider that one of the main weaknesses of my article ... (is that) it gives an incomplete picture of the nature of the firm… I believe it misdirects our attention… The way in which I presented my ideas has, I believe, led to or encouraged an undue emphasis on the role of the firm as a purchaser of the services of factors of production and on the choice of the contractual arrangements which it makes with them. As a consequence of this concentration, on the firm as a purchaser of the inputs of its users, economists have tended to neglect the main activity of a firm, running a business."* pp.37.

In relation to knowledge creation alliances, application of TCE, and hence the focus on minimizing cost, diverts attention from the main objective of the collaboration - creating value in terms of new knowledge. A focus on minimizing transaction costs leads to what is referred to as static efficiency (Ghoshal et al., 1996), the refinement of existing processes, thereby ignoring dynamic efficiency, the creation of new processes. Dynamic efficiencies have been recognized as important for innovation (Ghoshal et al., 1996). On the other hand, the focus of game theory is value maximization - either in terms of payoffs for the individual organization or for the system as a whole. Such focus of value maximization has been recognized as an important objective that knowledge-creating collaborations require to focus on, in addition to the cost minimization objective (Dyer, 1997). Thus the application of game theory to the resource-sharing phenomenon is expected to complement TCE by focusing on value maximization, in addition to cost minimization.

Furthermore, critics have noted that the leading economic theories of boundaries of a firm pay no attention to organizational knowledge (Holmstrom & Roberts, 1998). In fact, in response to the above critique, Williamson (2002) conceded that:

> *"… the roles of organizational knowledge and learning… are the ones with which transaction cost economics deals with in only a limited way. This does not, however, mean that transaction cost economics does not or cannot relate to these issues. I would observe in this connection that transaction cost economics made*

> *early provision for firm-specific learning by doing and for tacit knowledge and that the organization of knowledge projects that differ in their needs for coordination are even now being examined in governance structure respects. Still, the study of these and other issues to which Holmstrom and Roberts refer are usefully examined from several lenses, of which the lens of transaction cost economics is only one."* pp.190 .

While TCE is useful in explaining the relationships that are defined by specific supply-demand conditions, resource dependence theory (RDT), on the other hand, is helpful in describing the strategies organizations adopt for change and survival (Tillquist, King, & Woo, 2002). RDT specifies that organizations form alliances in order to gain access to resources that are not available within (complementary resources). RDT proposes several inter-organizational structures that come into place in order to enable an organization to gain access to external resources. Joint ventures and networks of organizations are illustrations of such inter-organizational structures (Pfeffer et al., 1978). However, once the organization gains access to such resources, it seeks to reduce the dependency in order to balance power in the relationship. Thus, an organization needs to devise strategies in order to manage dependency. Although RDT recognizes the need to devise strategies to manage dependencies, it falls short in explaining the details about how to devise such strategies. In other words, RDT fails to explain how to determine the optimal set of resources that are required to derive economic rent or economic value (Hemphill & Vonortas, 2003). Game theory aids in this regard by identifying the optimal set of resources and participation rate that maximize whatever the collaboration's goal is-individual gain in case of leader-follower games or system gain in case of partnership games.

As noted earlier, RDT models an organization as one capable of adapting to the environment in order to gain access to or acquire resources that are essential for its survival (Pfeffer et al., 1978). During the course of gaining access to resources, organizations develop

dependencies with their partners. Such dependencies between the partnering organizations may be unilateral or mutual. In cases where there is mutual dependency, there is exchange of resources, and the partnering organizations adopt different structures to manage the dependencies appropriately so that resources are exchanged efficiently.

Cases with unilateral dependencies give rise to asymmetric relationships. The organization in the powerful position tries to obtain favorable payoffs or favorable conditions in the relationship. Such differences in dependencies call for different coordination mechanisms that will allow the organization to change its behavior. However, it is also possible that organizations change their dependencies based on changes in their goals and behavior (Tillquist et al., 2002). RDT does not account for such changes in an organization's dependencies. In relation to collaborative knowledge creation, due to the uncertainties involved in creating new knowledge, there is a possibility that the goals and behavior of the partnering organizations might change as the relationship unfolds. Such change in goals and behavior, in turn, might lead to a change in the dependencies between the collaborating organizations. Since RDT does not explain the changes in organizational dependencies, game theory is relied on in order to understand the dynamics that change the behavior of organizations as the relationship unfolds.

In short, RDT premises that a firm needs to interface with other organizations in the environment in order to obtain the necessary resources. However, RDT falls short in explaining what strategies organizations adopt in order to interface with other organizations, specifically, as Barringer and Harrison (2000) note:

> *"The theory focuses on the need for critical resources and the necessity for social exchange, rather than the more complex theoretical challenge of describing … how inter-firm transfers of competencies actually take place."*

While TCE stipulates reduction in transaction costs, and RDT stipulates gaining access to resources external to the organization as motivations for forming alliances, organizational learning theory specifies the intent to learn from potential partners as a motivation to form alliances. Learning theory has developed with its roots in the behavioral model of organizations and considers learning as one of the actions that organizations undertake in order to adapt to changing environments (Simon, 1991). Organizations devise rules, procedures, and routines in response to external shocks and which are more or less likely to be adopted according to whether they have positive consequences for the organization (Cyert & March, 1963). In other words, organizations learn the responses that would make them more adaptable to changing environments. Alliance formation is one such response to adapt to a changing environment.

Apart from providing a motivation for the formation of alliances, organizational learning theory also informs this study by linking accumulation of knowledge to changes in performance. In relation to group learning (learning among groups of organizations), Argote and colleagues (2003b) noted that group learning manifests itself through changes in knowledge and performance. Such changes in performance would eventually lead to revenue-generating tactics for the group under consideration. Thus, according to organizational learning theory, collaboration is one of the ways by which organizations adapt to changing environments, and accumulate knowledge through learning which results in performance consequences for the organizations (Huber, 1991). Recent literature in inter-organizational learning has highlighted the need to study inter-organizational outcomes for the collaboration, as a whole, in addition to focusing on learning outcomes for individual organizations (Larsson et al., 1998). Although attempts have been made or are being made to study the learning outcomes for the collaboration, such attempts are in the preliminary stages, with most studies still focusing on learning outcomes

for individual organizations. The current study acknowledges the need to study the outcomes for the collaborating unit and contributes in this direction. By applying game theoretic analysis, the current study attempts to quantify the performance consequences and returns for the collaboration as well as for the individual organizations. In turn, the current study has benefited from organizational learning theory in terms of formulating the revenue functions. Table 1 summarizes the theoretical background for the current work.

Theory	Motivation to form alliance	Gap in literature	Advantage of applying game theory
Transaction cost economics	Choosing a governance structure (alliance) that best reduces transaction costs.	Focus on cost minimization thereby diverting from the goal of profit maximization.	Explicitly models the value to individual organizations and for the dyad while modeling the costs as well.
	Contractual agreements are a way to enforce safeguards against opportunism.	Dynamics of how to arrive at details of contracts.	Provides guidance to member behavior according to the moves of the game and thus aids in arriving at terms of initial and subsequent contracts.
Resource dependence theory	Gaining access to resources that are available in the environment in which the organization operates. Dependencies shape behavior.	Changes in goals or behaviors might change dependencies- These are not explained.	Provides insights about the changes in behavior and how such changes might alter dependencies.
	Joint ventures and networks are inter-organizational structures that allow for external access of critical resources.	Specifics details about how inter-firm transfer of resources takes place are not explained.	Equilibrium values are computed in order to arrive at resource-sharing schemes.
Learning theory	Response to changing environment.	There is a need for studying inter-organizational outcomes of performance in addition to organizational outcomes.	Inter-organizational and organizational learning outcomes are quantified in terms of profits.

Table 1: Summary of Theories Relevant to the Current Study

2.2 Nature of Marginal Returns with Respect to Knowledge Creation Investments

Recall from Chapter 1 that the investment made toward the creation of knowledge (*a*) is expected to result in performance (P). This performance, in turn, translates into return on investment (R). Consider the following illustration to clarify the terms "performance" and "return". Acme, Inc., is a manufacturing firm that produces parts for automobiles. In the recent past, it has noticed an error rate of 10 parts per million. In an effort to reduce the error rate, Acme Inc. has invested in investigating errors and in devising ways to reduce the error rate to 4 parts per million. Let this investment be *a*. At the end of the project, the reduction in the error rate, due to the knowledge created by investing $*a* is the performance. The cost savings for Acme, Inc., as a result of the reduction in error rate is the return.

As noted earlier in the introduction, investments in knowledge creation always yield increasing returns (Arthur, 1989; Arthur, 1990; Arthur, 1996; Teece, 1986). Subsequent literature has indicated that the returns from knowledge accumulate over time, regardless of the nature of the knowledge produced- positive or negative (Teece, 1998). For instance, according to the stock view of knowledge creation, which was discussed in Section 2.1 newly created knowledge adds to an organization's existing stock (Davenport et al., 1998; Teece, 1998), and its subsequent use does not deplete the stock of knowledge (Stephan, 1996). Thus, there is enough evidence that the returns to investments in knowledge creation always increase. However, the returns themselves could increase at either an increasing rate or a decreasing rate. That is, the marginal returns with respect to knowledge creation investments (henceforth referred to as marginal returns) can either increase or decrease.

2.2.1 Decreasing Marginal Returns Curve: Old Economy View

Literature on traditional learning curve, and other streams, has established the relationship between hours of labor per output and cumulative learning as a case of diminishing marginal returns (Epple, Argote, & Devadas, 1991). Furthermore, it is recognized that the rate of acquisition of knowledge decreases as the accumulation of knowledge stock increases (Epple et al., 1991). Thus, in relation to the amount of efforts expended in the knowledge creation endeavor, literature endorses diminishing returns on the cost expended on learning (Gaimon & Burgess, 2003). Additionally, it has been observed that during the product development life cycle, knowledge has more value when it is "new" than it does in later stages (Dorroh, Gulledge, & Womer, 1994). While knowledge creation increases the stock of existing knowledge, the increase in the performance of the organizations, due to increased knowledge stock, slows down as more efforts are expended in the same endeavor, similar to the notion of a learning curve (Argote, 1999).

Specific to accumulation of knowledge, Dosi (1988) noted that a knowledge trajectory has an intrinsic limit on its performance. When this performance limit is reached, benefits due to new knowledge, accumulated by focusing on the same knowledge element, increase at a decreasing rate (Katila et al., 2002) . That is, if an organization builds upon the same element of knowledge, as the knowledge accumulation trajectory progresses, the firm will experience diminishing marginal returns. This line of inquiry attests the presence of a performance asymptote for benefits due to knowledge and the decreasing rate at which benefits due to new knowledge increase. Furthermore, it also suggests that the rate of return on investments in making incremental contributions to the same knowledge element diminish with investment.

Hence, one can conclude that the performance function for knowledge creation is non-linear and exhibits decreasing marginal returns.

According to this view, a firm's return function is specified as $R = \alpha - xa^{-\gamma}$. Such specification of return function is similar to the sales response volume function prevalent in marketing literature. From the Introduction and from the beginning of Section 2.2, we know that R always increases with an increase in a and $\frac{\partial R}{\partial a} = \gamma x a^{-(\gamma+1)}$ is always positive. This is possible only when γ is positive. However, knowledge, as with most intangible assets, is characterized by decreasing marginal costs over production of subsequent units (Sanchez, 1994), or in other words, by economies of scale. This decrease in the costs for producing subsequent units, and hence the increase in incremental output, is captured by the nature of the marginal return function with respect to investment $\left(\frac{\partial R}{\partial a}\right)$. For firms whose marginal returns decrease, the sign of the second partial derivative the marginal return function with respect to knowledge creation investment $\left(\frac{\partial R^2}{\partial^2 a} = -(\gamma+1)\gamma x a^{-(\gamma+2)}\right)$, is negative. Since γ is always positive, the second partial derivative of the return function is always negative, which means that the marginal returns with respect to knowledge creation investments always decrease for all positive values of γ. For firms with decreasing marginal returns, the return function is thus specified as $R = \alpha - xa^{-\gamma}$.

2.2.2 Increasing Marginal Returns Curve: New Economy View

Alternately, work in the economics of knowledge considers knowledge as an intangible asset and characterizes production functions of knowledge assets as increasing in marginal returns (Arthur, 1989; Arthur, 1990; Arthur, 1996; Knott et al., 2003; Teece, 1998). For

instance, Teece (1998) and Arthur (1996) suggest that the marginal returns on intangible assets increase. They further observed, independently, that knowledge assets yield increasing marginal returns due to factors such as the development of dominant compatibility standards, high switching costs for customers, and negligible amount of investments to make copies of a developed technology such as a piece of software code. Echoing the increasing marginal returns view, Knott et al. (2003) modeled the production function for intangible assets as a Cobb-Douglas function with knowledge, labor, capital and industry spill-over [common knowledge within industry] as independent variables. Hence, this stream of literature identifies the presence of firms whose marginal returns with respect to knowledge investments increase at an increasing rate.

According to the increasing marginal returns view, performance (P) due to knowledge creation investments (a) is of the form $P(a) = a^{\gamma}$, where γ is the performance to investment sensitivity of knowledge creation investment[4]. This performance translates into return on the investment for the firm (Machlup, 1980) given by $R = xa^{\gamma}$. The return function is similar to the Cobb-Douglas production function (Fraser, 2002) [5] but with a single factor of production-investment in knowledge creation. Relevant to the current dissertation, the Cobb-Douglas function can be written as $Q = AL^{\beta_1}K^{\beta_2}a^{\gamma}$ where a and γ are as described above. Now the return function could be specified as $R = PQ = PAL^{\beta_1}K^{\beta_2}a^{\gamma}$, where P is proportionality constant. A further simplification of the return function yields the following: $R = xa^{\gamma}$ where $x = PAL^{\beta_1}K^{\beta_2}$.

[4]Performance to investment sensitivity of investment is a measure of sensitivity of the performance to investment.

[5] Cobb-Douglas production function is of the form $Q = AL^{\beta_1}K^{\beta_2}$ where Q is the output, L is labor and K is the capital. This production function was originally set up as a constant return to scale function with A, β_1 and β_2 as constants.

The rate of return on the investment toward creation of knowledge (a) is referred to as marginal return with respect to knowledge creation investment[6] $\left(\frac{\partial R}{\partial a} = \gamma x a^{\gamma-1}\right)$. Literature on the nature of return functions supports the notion that the return on investments (R) in intangible assets increases (Arthur, 1989; Arthur, 1990; Arthur, 1996; Teece, 1998). This implies that the marginal return is positive. For the marginal return function to be positive, γ must be positive.

The nature of the marginal return function is explained by the second partial derivative of the return function $\left(\frac{\partial^2 R}{\partial a^2} = (\gamma - 1)\gamma a^{\gamma-2}\right)$. When the second partial derivative is negative, the marginal returns decrease. This is possible only when γ is between 0 and 1. When the second partial derivative is positive, the marginal returns increase. This is possible when γ is greater than 1. In reference to the current dissertation, each firm in the collaboration is characterized by a different revenue function. For a firm that is characterized by increasing marginal returns, the return function is specified as above and γ is greater than 1. As detailed in the ensuing sub-sections, the nature of the marginal return function for each of the collaborating partners is expected to influence the resource-sharing schemes devised by the collaboration.

2.2.3 Knowledge Production Function: S-Shaped Curve

Thus, the old economy and new economy view of knowledge have offered alternate explanations regarding the nature of the marginal return with respect to the investments curve. Integrating knowledge of the dichotomous literature on the nature of the marginal returns curve, one would speculate whether there is an underlying function that explains how some firms are characterized by increasing marginal returns and others are characterized by decreasing marginal

[6] Henceforth notated for short as marginal returns.

returns. Literature on s-curves helps one argue that depending on the type of innovations it engages in, a firm's production function can be characterized by either increasing or decreasing marginal returns. For instance, a firm that engages in radical innovations typically encounters emerging technologies; and its production function is characterized by increasing marginal returns. On the other hand, a firm engaging in incremental innovations typically uses mature technologies, and its production function is characterized by decreasing marginal returns. Hence the nature of knowledge production function depends on the type of knowledge that is being created through radical innovation or incremental innovation.

Such functions have been the focus of much traditional research in production economics. In particular, Hall et al. (1986), Adams (1990), and Griliches (1984) have explored the relation between R&D investments and productivity growth. For instance, Adams (1990) modeled the relationship between stocks of knowledge and output of the firms as a Cobb-Douglas production function. A similar convention was used by Griliches (1984) to formulate the R&D productivity function. More recently, Knott et al. (2003) have followed suit while formulating a time-dependent model of intangible asset accumulation.

The origins of the discussion on the nature of the marginal returns curve can be traced to the classic economic literature on s-shaped growth curves (Griliches, 1957). For instance, Hotelling (1932) noted that the sales of a new commodity, based on an invention, do not grow for some time because the old methods still prevail in several regions at several levels. Thus the change to the new commodity takes place slowly at first, then more rapidly, and then slows down toward the completion of the change.

Similar to the above discussion, Brown (1991) argued that innovations in technologies follow the s-curve. Specifically he showed that the performance improvement per cumulative

R&D expenditure follows an s-curve with emerging technologies at the base of the curve, developed technologies at the middle of the curve, and mature technologies at the top of the curve, as shown in Figure 1. Note that at the base of the curve, the returns due to investments in knowledge creation actually decrease until the firm can realize any performance improvement due to the knowledge produced. This part of the curve that is characterized by negative marginal returns represents the "little learning" from Alexander Pope's (1711) quotation, "A little learning is a dangerous thing."

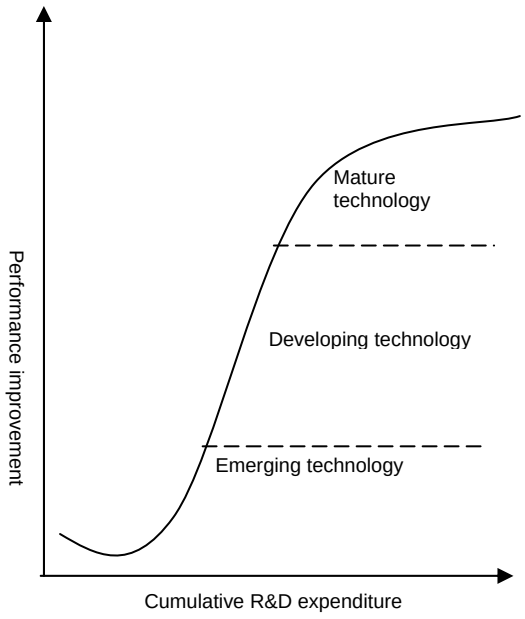

Figure 1: Performance Improvement per Cumulative R&D Expenditure Adopted from Brown (1991).

Organization theorists have observed that newer firms are capable of expanding into new areas of knowledge creation better than older firms (Sorensen & Stuart, 2000). Thus the return function for a firm's investment in knowledge creation can be construed to be dependent on the age of the firm. Newer, entrepreneurial firms typically engage in radical innovations that yield

increasing marginal returns, and older firms typically engage in incremental innovations resulting in decreasing marginal returns. Additionally, organization theory and innovation streams of literature have established the relationship between firm size and incremental investments. Larger firms typically tend to invest in incremental innovations while smaller, entrepreneurial firms tend to invest in radical innovations (Chandy & Tellis, 2000). Although it is possible to specify the return functions for individual firms as derived from the same underlying production function, for the purpose of this dissertation, the return functions for firms characterized by increasing and decreasing marginal returns are specified differently as noted in Section 1.2.

Chapter 3 METHODOLOGY

3.1 Game Theory

This dissertation applies game theory as a method to analyze the resource-sharing decision-making process during collaborative knowledge creation. Game theory has been recognized as a valid tool for analyzing transactions involving two or more parties. The resource-sharing decisions made by each organization within a dyadic collaboration can be better understood if viewed as a game between two players. Although I recognize that games can be categorized in several ways, for the purpose of this dissertation, based on the interaction between the players, games are classified as *cooperative* or *non-cooperative*. The goal of a cooperative game is to maximize the system gain, while the goal of a non-cooperative game is to maximize the individual gains of the players. In order to understand the dynamics of the decision-making process in cooperative games, especially in dyadic relationships, studying the partnership game is appropriate (Eliashberg & Winkler, 1981; Nash, 1950, 1953).

In partnership games, both of the collaborating organizations share the common interest of maximizing the expected system gain, however, they attempt to achieve this goal by not sacrificing their individual gains. During this process, they negotiate over how much each firm should contribute toward the total efforts that are required for the current knowledge creation project. It is during these negotiations where opportunism by collaborating organizations is manifested. Partnership game models have been widely applied in various areas of business to study risk-sharing phenomena (Eliashberg, 1986; Eliashberg et al., 1981; Huang, Li, & Mahajan, 2002; Huang & Li, 2001). Partnership-based arrangements have been recognized to be the most common and useful alliance structures for knowledge creation alliances such as new product development alliances (Millson & Raj, 1996). They are useful because of their unstructured nature and because they allow for flexibility, which has been recognized as important for

knowledge creation (Zollo, Reuer, & Singh, 2002). As I show later, an organization's share of contribution depends on i) its risk tolerance, and ii) its bargaining power in relation to the partner.

In order to understand the dynamics of the decision-making process in non-cooperative games, studying Stackelberg's leader-follower game is helpful (Scherer, 1996). The goal of each player in this game is to maximize its expected individual gain, as opposed to the goal in cooperative games, which is to maximize the expected system gain.

In leader-follower games, the leader is the organization with a more powerful position in the decision-making process and the one which has the potential to enforce its strategy on the other. The follower, on the other hand, is the organization that reacts to the leader's decision (Charnes, Huang, & Mahajan, 1995; Mesak & Mayyasi, 1995). Thus, a leader-follower game is played in two stages. In the first stage the leader makes a move, and in the second stage the follower reacts to the leader's move. Specifically, the leader organization decides on its share of the current knowledge creation effort that maximizes its individual gain. On the other hand, the follower organization determines the amount of current knowledge creation effort that maximizes its own individual gain. The individual players' opportunism is manifested in these two stages of the game. Typically, the organization that has more market power and/or is bigger in size within a dyad assumes the position of a leader. In collaborative knowledge creation context, I refer to the leader as the organization that has more decision-making power or experience in the domain specific area of knowledge creation.

The importance of leader-follower relationships in collaborative knowledge creation is evidenced by failures such as the MDF100 venture between McDonnell Douglas of USA and Fokker of Netherlands. One of the reasons for the failure of this dyadic collaboration has been

identified as the lack of a technologically and financially "senior" organization taking control of the collaboration (Mowery, 1988).

If the collaborating organizations have unique prior knowledge relevant to the knowledge creation endeavor at hand, some knowledge transfer during the knowledge creation process is inevitable. In such situations, the relative strength of an organization's unique prior knowledge could put that organization in the role of a leader or that of a follower. In the specific case where the leader organization enjoys more power by virtue of its unique prior knowledge, the leader-follower game is similar to the concept of strategic learning in which organizations take on the roles of teacher and student during knowledge transfer (Camerer & Ho, 2001; Lane & Lubatkin, 1998). The leader organization is analogous to the teacher, and the follower organization is analogous to the student. This model has been widely applied in areas such as advertising (Huang et al., 2002; Huang et al., 2001), supply chain interactions (Ertek & Griffin, 2002; Gerchak et al., 1999), distribution (Iyer & Villas-Boas, 2003), and decision-making (Cao & Leung, 2002).

In this dissertation, I model combinations of the nature of marginal return function with respect to knowledge creation investments and the type of games. In Chapter 4, I present the game theoretic analysis of the resource-sharing decision-making process as a partnership game, with the performance function of both of the organizations in the knowledge creation collaboration being characterized by increasing marginal returns (Essay 1). In the subsequent Chapters (5 and 6), I present the game-theoretic analysis of the resource-sharing decision-making process as a leader-follower game with a case where both of firms are characterized by increasing marginal returns (Essay 2) and with a mixed case, where the leader organization has decreasing and the follower has increasing marginal returns (Essay 3). The return functions are

incorporated in the gain functions for each individual organization and for the system as a whole. Specifically, the gain functions are specified as returns, less the investment, for each of the partners and for the system.

One issue that needs to be addressed while applying the game theoretic analysis is the universality of the assumptions of game theory. For instance, in both of the games applied in this dissertation, it is assumed that both players in the collaboration act rationally and that they have complete and perfect information about their partner's preferences and potential strategy. Such game-theoretic assumptions are very specific to the type of games used to model the collaborations in this dissertation. For instance, if the rationality does not hold true, and if there is a reason to believe that the players can behave irrationally, the current method of modeling cannot explain such behaviors. In such cases, the models need to explicitly incorporate the biases (Wade-Benzoni et al., 2002) to include the presence of such irrationality, as suggested by the behavioral economics literature, or model the relationship where actors operate with bounded rationality (Aumann, 1997). Similarly, another instance where the players in collaboration may not behave rationally is the case where the partners have a high level of trust (Gulati, 1995a) between them, owing to prior association, or due to information about the trustworthiness of a potential partner, gathered from informal networks (Ring & Van de Ven, 1989).

Similarly, the game-theoretic assumptions of complete and perfect information are not universal since they may not hold up well in several business situations. Organizations in a collaborative relationship may act with incomplete or imperfect information, either by choice, because they are not willing to share some information with potential partners, or due to ignorance. The games used in this dissertation do not account for imperfect and incomplete

information and, hence, are not applicable to relationships where such characteristics are suspected to be present.

3.2 Unit of Analysis

Several theories have established several organizational entities as units of analysis. Units of analysis among collaborations include a broad spectrum including individuals, groups (Chen & Edgington, 2005), divisions, strategic business units (Houston, Walker, Hutt, & Reingen, 2001), organizations, inter-organizational collaborations such as supply chains (Hardy, Phillips, & Lawrence, 2003; Hoang & Rothaermal, 2005), industries (Schilling & Steensma, 2001), countries, and functional entities such as contracts, or transactions (Ghosh & John, 2005), and organizational practices (Levina & Vaast, 2005). Dansereau and colleagues (1999) have conducted a longitudinal study on the levels of analysis employed in several studies. They acknowledge the several levels of analysis are currently prevalent and also contend that the levels of analysis change over a period of time. Some theories that are useful in studying collaborative relationships are discussed here from their units of analysis point of view.

For instance, transaction cost economics (Williamson, 1985) considers the transaction as a unit of analysis. Such an approach has been followed by researchers studying collaborations at the contractual level, transaction level, or other functional levels of analysis. However, the necessity to expand the scope of unit of analysis, beyond single transactions, has been emphasized as a way to arrive at composite governance structures that might be more amenable for collaborations (Rindfleisch & Heide, 1997). This necessity stems from the fact that transaction cost economics views each transaction as an independent exchange between the partners (Rindfleisch et al., 1997).

However, a collaborative relationship seldom comprises a single transaction (Sahlins, 1972). Transaction cost economics, is limited in accommodating the series of interrelated transactions that occur in a collaborative knowledge creation relationship. Thus, considering a

single transaction as a unit of analysis is inadequate for such a study. The fact that the term transaction itself is ill-defined (Williamson, 2002) makes it difficult for researchers to consider transaction as a unit of analysis. Instead, the appropriate unit of analysis would be one that encompasses the series of transactions between the interacting units of the collaboration.

Theory	Unit(s) of Analysis	Support to the current study
Transaction Cost Economics	Transaction	Very less- since it does not consider the series of transactions that occur in collaboration as dependent.
Agency Theory	Contract	Partial- only to relations where the partners are unequal (principal-agent relations).
Relational view	Collaborative relation (dyad)	Supports.
Learning theory	Single organization; Dyad	Supports.
Resource dependency Theory	Organization set	Supports only if the organization set consists of the dyad. Usually more applicable for network of organizations.
Game theory	System (consisting of the players)	Supports.

Table 2: Summary of Units of Analysis According to Several Theories

Similarly, agency theory considers the contract between an agent and the principal as the unit of analysis (Eisenhardt, 1989). However, the origin of agency theory is the relationship between the principal and the agent. In particular, behavior-oriented contracts become units of analysis in agency theory based studies. The principal is the entity that delegates work to the agent. This relationship suggests the presence of a superior-subordinate relationship between the contracting units. While such a relationship might be true among most, collaborations between equal partners who join for the purpose of knowledge creation (as is the case with those discussed in Essay 1 of this dissertation) are not unusual but are not included under the umbrella

of agency theory. Hence, an extension of the unit of analysis to include relations between both equal and unequal partners becomes necessary.

On the other hand, relational view considers the relation between collaborating entities as units of analysis (Dyer, 1997; Dyer et al., 1998). Specifically in line with knowledge creation, where the generation of rents can be attributed to processes that span organizational boundaries, inter-organizational dyads have been identified as viable units of analysis. This stream of literature is applicable to the current study since game theory also considers the collaboration between organizations as a unit. Such a consideration is in line with the organizational learning literature, which emphasizes the need for studying the inter-organizational entities as units of analysis (Hoang et al., 2005; Larsson et al., 1998; Rosenkopf & Almeida, 2003).

Resource dependency theory (Evans, 1966; Pfeffer et al., 1978), which is relevant to the study of inter-organizational collaborations, specifies the organizational set as the unit of analysis. According to resource dependency theory, organizations form collaborations in order to gain access to valuable resources that are external to the organizations. Such external sources of valuable resources consist of a set of firms, which, according to resource dependency theory, is a viable unit of analysis. In relation to this dissertation, the organization set - albeit that of two organizations- is an applicable unit of analysis.

Similarly, according to game theory, the unit of analysis is the system comprised of the players in a game. In relation to this dissertation, the relationship between the organizations in a dyadic collaboration, with interaction between the collaborators, becomes a point of interest. For studying such interactive relationships, game theory presents a viable unit of analysis where the gains to the system (collaboration) and the iterative interactions (or moves) between the collaborators (players) are modeled explicitly in the payoff functions of each game.

In line with the game-theoretic view, the unit of analysis for the current dissertation is the dyad of collaborating organizations. Such an aggregated unit of analysis, at the network level, has been the focus of recent research and is gaining importance with more studies focusing on areas such as supply chain management (Straub et al., 2004). When both of the organizations are small in size, the return function is specified for the whole firm. However, when either or both of the organizations are large, then it is possible that each of the profit-making units, or strategic business units (SBUs) in the organization, is characterized by its own return function. In such cases, the unit of analysis for this study would be the collaboration between the SBUs of large organizations. If one of the partnering firms is comparable in size to the SBU of its counterpart, then the collaboration consists of the SBU of the larger firm and whole of the smaller firm. Such a consideration of SBU as a viable unit of analysis has been documented in innovation literature (Berthon, Hulbert, & Pitt, 1999).

In the game-theoretic analysis that is used in this dissertation, the system return is a linear aggregate of the individual organizations' returns. Consequently, the expected gain function for the collaboration is aggregated as the sum of the expected gains of each individual organization in the collaboration. System gain is the gain that the collaboration appropriates due to investment in knowledge creation. The partnering organizations appropriate a portion of the aggregate system gain, based on their gains to performance ratios that act as weights to determine an organization's share of the system gain. Such methods of linear aggregation and weighted linear aggregation have been used in prior research especially in the marketing literature (Fisher, Solow, & Kearl, 1977; Johnson & Selnes, 2004) and in much recent information systems literature (Rai, Patnayakuni, & Patnayakuni, Forthcoming). For instance, in relation to cooperative advertising within manufacturer and retailer dyads, Huang and colleagues

(2002; 2001) have aggregated the system profit function as an additive of the profit functions of the manufacturer and retailer. Additionally, Johnson and Selnes (2004) have proposed the customer portfolio lifetime value as an aggregate of the weighted share of the value attributed to different types of customers. In much more current work in information systems literature, Rai and colleagues (Forthcoming) have developed a measure of firm performance by linearly aggregating three distinct dimensions: operations excellence, revenue growth and customer relationships. Although the dimension used in this dissertation is revenue growth, the revenue growth for the dyad is aggregated linearly across the collaborating organizations.

In relation to this dissertation, in collaborations where both of the firms are characterized by decreasing marginal returns, the system also exhibits decreasing marginal returns. In collaborations where both of the firms are characterized by increasing marginal returns, the system return function also exhibits increasing marginal returns.

In collaborations where one of the firms is characterized by decreasing marginal returns, and the partner firm is characterized by increasing marginal returns, the nature of the system return function depends on the value of γ. If γ is between 0 and 1, the system return function is characterized by decreasing marginal returns. If γ is equal to 1, then the system return function is characterized by constant marginal returns, and if γ is greater than 1, the system return function is characterized by decreasing marginal returns.

3.3 Background Work

As mentioned in Section 2.2, considering the nature of the performance function for a firm, there are four possible cases for how collaborations may be formed. Collaborations can be formed between organizations under the non-cooperative game structure such as in the leader-follower game. Examples include Case 1 collaborations where both of the firms have decreasing marginal returns; Case 2 where both of the firms have increasing marginal returns; Case 3 where the leader firm has decreasing marginal returns and the follower firm has increasing marginal returns; and Case 4 where the follower firm has decreasing marginal returns and the leader firm has increasing marginal returns.

Collaborations formed under the cooperative game structure, for instance, partnership game, can belong to one of the following three cases: Case 5 where both of the organizations are characterized by decreasing marginal returns; Case 6 where both of the firms are characterized by increasing marginal returns; and Case 7 where one of the organizations is characterized by increasing marginal returns and the other is characterized by increasing marginal returns. The current dissertation addresses Case 5 in Essay 1, Case 2 in Essay 2 and Case 3 in Essay 3. The ensuing paragraphs establish motivation for studying these three cases.

Recall from Section 2.2 that there is consensus within the literature that the performance function on knowledge creation investments is an increasing returns function. However, considerable ambiguity exists with regards to whether these returns increase at an increasing rate or a decreasing rate - old economy view and new economy view mentioned in Section 2.2. There is sufficient reason to believe that the nature of the marginal return function with respect to knowledge creation investments depends on the type of innovation that is underway.

The above cases draw one's attention because they can be evidenced in the practitioner world, and any theoretical guidance as to the explanation of the decision-making process within such collaborations is relevant. For instance, consider Case 5, which is the subject of Essay 1. Here, both of the organizations are characterized by decreasing marginal returns with respect to knowledge creation investment. Both of the organizations in this collaboration are expected to be involved in creating knowledge that builds on old knowledge (incremental innovation) and use mature technology. Also, typically such firms are expected to be incumbent firms that have been recognized as experts in the industry by virtue of the knowledge that they already possess. Given the recognized pitfall of incumbent firms that they are unwilling to make commitments in technology (Day & Schoemaker, 2000), it makes the study of the dynamics that unfold when two such organizations collaborate worthy of study. For instance, since both of the organizations in this case are unwilling to make commitments, it sparks ones interest to see how they determine the optimal levels of current knowledge creation effort and what factors take precedence while arriving at such levels. For instance, incumbent firms are more likely to have a base of unimitable resources that give the competitive advantage (Mathews, 2002), and it is known that the resource base of a firm shapes its alliance decisions (Gulati, 1995b). Hence Case 5 becomes an interesting candidate for study.

Essay 2 studies the Case 2 mentioned in the beginning of this section, with both of the collaborating firms characterized by increasing marginal returns. Such collaborations are illustrative of organizations involved in radical innovations and engaging in emerging technologies. Entrepreneurial firms are illustrations of firms engaging in radical innovations and using emerging technologies. Literature bears evidence that entrepreneurial firms are risk takers (George, Zahra, & Wilkund, 2005); and hence, the strategies that they develop during the

course of a collaboration may be guided by such preference to take risks. Yet, when two such firms collaborate, and specifically when one of them is in a dominant position as in Case 2 mentioned above, it is interesting to see how the preferences of each of the firms determine their participation rate and the investment they make in the current project. This would, in turn, arouse one's interest in determining what strategies each firm would adopt in the partner selection and in other stages of alliance formation and maintenance.

Essay 3 concerns collaborations between the leader organization, characterized by decreasing marginal returns, and the follower organization, characterized by increasing marginal returns (Case 3 from above). The leader firm in this case is an incumbent firm and the follower firm is an entrepreneurial firm. The leader firm typically engages in incremental innovation and is involved with mature technologies. The follower firm typically engages in radical innovation and is involved with emerging technologies. Such collaborations then would witness complex dynamics with a potential for a clash of each organization's preferences during the relationship. This would, in turn, spur interest to examine the strategies that the firms would adopt in order to make resource-sharing decisions. Additionally, it would be interesting to observe the factors that would be important to each of the organizations in the collaboration while making such decisions.

Case 4 is characterized by collaborations which are the opposite of Case 3 where the incumbent firm takes the place of the follower position and the entrepreneurial firm takes a dominant position. Although examples of such collaborations may be rare, it is still conceivable that an entrepreneurial organization plays a dominant role, owing to its conversance with emerging technologies and having potential for engaging in breakthrough research. An incumbent firm, on the other hand, might benefit from such propensity of the entrepreneurial

firm to engage in radical innovations and still maximize its own gain by leveraging its well-established commercialization channels. Although the current dissertation does not model such collaborations, it would be an interesting direction for future work.

Contrasting Case 5 and Case 2, one would anticipate the types of decisions made by Case 5 to be very different from those made by Case 2 collaborations. For instance, Case 2 collaborations might be more prone to making investments in infrastructure necessary for developing breakthrough knowledge, such as investments in new machinery. On the other hand, firms engaged in Case 5 collaborations could be more prone to investing in making modifications to existing infrastructure to create an environment more amenable to create incremental knowledge. Hence, the business decisions made by the firms belonging to both types of collaborations are expected to be different. Such disparity in the decisions made, as well as the decision-making process, sparks interest as to how the dynamics unfold when firms characterized by different performance functions collaborate.

Similarly, one would anticipate that the effect of the leader organization being characterized by decreasing marginal returns in Case 3 collaboration would be different from that in Case 2 collaboration. For instance, Case 2 collaboration consists of two entrepreneurial firms, while in the Case 3 collaboration the firm in a dominant position is an incumbent firm. As explained earlier, the decisions that an incumbent firm makes regarding resource commitments are markedly different from that of an entrepreneurial firm. Hence, one can anticipate that the Case 3 collaborations witness more complex dynamics than Case 2 collaborations specially because the collaborating, firms may have different preferences for certain types of investments.

The resource-sharing decision-making process has been modeled as a Stackelberg leader-follower game in my prior related work (Samaddar & Kadiyala, 2006). In particular,

Case 1 as noted above was modeled. Essay 1 models Case 5 as a partnership game. This differs from the background work in the type of game for which the relationship is modeled. Note that the collaborating firms in background work and essay 1 are characterized by decreasing marginal returns. The relationship is modeled as a leader-follower game in the background work, where each organization maximizes its individual expected gain (Case 1 from above). In essay 1, the relationship is modeled as a partnership game, where the collaborating organizations maximize the expected system gain (Case 5 from above).

In the background work, two scenarios of collaborative knowledge creation were presented, depending on the type of efforts that were being expended for the knowledge creation endeavor. Scenario 1 modeled collaborations with only current knowledge creation efforts, and Scenario 2 modeled collaborations with prior knowledge creation efforts, in addition to current knowledge creation effort. It was observed that in Scenario 1, the leader's participation rate is a function of the ratio of both organizations' gain to performance ratios. Specifically, this ratio must be greater than 1, plus the performance to investment sensitivity of the current knowledge creation efforts, in order for the leader organization to continue participating in the collaboration. In addition, it was observed that the follower organization has more to gain by collaborative knowledge creation activities than by individual knowledge creation activities. Furthermore, it was observed that the greater the leader's participation rate, the greater the current knowledge creation efforts. In Scenario 2, an observation of the equilibrium values for the current knowledge creation effort and the total expected system gain are now a function of prior knowledge creation efforts, in addition to the ratio of the gain to performance ratios and performance to investment sensitivity.

We compared the equilibrium values of current knowledge creation efforts, the leader's participation rate and the expected system gain under both scenarios. It was found that while the amount of optimal current knowledge creation efforts is lower when both of the organizations in the collaboration have already made prior knowledge creation efforts, the leader organization's participation rate remains the same, regardless of whether the two organizations have prior knowledge creation efforts or not. Also, the expected system gain is higher when there is a combination of current and prior knowledge creation efforts. The conditions under which the leader and follower make an independent decision to collaborate and subsequently stay in the collaboration were identified; and finally, the importance of maintaining adequate gain to performance ratio for the relationship to continue was recognized.

$$a_1 * = \left[\gamma\left(\rho_L - \rho_F \gamma\right)\right]^{\frac{1}{\gamma+1}}$$

$$t_1 * = \frac{\rho_F\left(\gamma+1\right) - \rho_L}{\rho_F \gamma - \rho_L} \; when \; \frac{\rho_F}{\rho_L} > \gamma + 1$$

$$\pi_1 * = \left(\rho_L + \rho_F\right)\left[\alpha - \left(\gamma\left(\rho_L - \rho_F \gamma\right)\right)^{\frac{-\gamma}{\gamma+1}}\right] - \left(\gamma\left(\rho_L - \rho_F \gamma\right)\right)^{\frac{1}{\gamma+1}}$$

Table 3: Equilibrium Values for the Leader-Follower Game - Case 1

Chapter 4 ESSAY 1: PARTNERSHIP-BASED COLLABORATIVE KNOWLEDGE CREATION- CASE OF BOTH FIRMS WITH DECREASING MARGINAL RETURNS

4.1 Partnership Game, Risk Tolerance and Bargaining Power

As mentioned in Section 3, it is appropriate to model the decision-making process as a partnership game, due to the flexibility that partnership games allow for, and due to the fact that the goal of the game is to maximize the system gain. However, as noted earlier, in order for the players to not sacrifice their interest in individual gains, the partners negotiate with respect to the participation rate. Thus, the balance of power in the collaborative relationship, with respect to the decision-making process, is a key to its understanding and success. An organization can enjoy more power than its current or potential partner by virtue of its economic resources, as well as other resources, including prior knowledge. This might define an organization's risk tolerance as well as its bargaining power in relation to those of its partner. Sitkin and Weingart (1995) define risk tolerance as an "individual's current tendency to take or to avoid risks," meaning that an individual could have low risk tolerance or a high risk tolerance. They have also identified risk tolerance as a causal antecedent to risk behavior. A high risk tolerance leads to a risk taking behavior, and vice versa. In relation to inter-organizational relationships, an organization's risk tolerance leads to its risk behavior.

An organization's risk tolerance is an issue of concern for researchers studying collaborations (Di Mauro & Maffioletti, 2004; Sundaramurthy & Lewis, 2003). For instance, Das and Teng (1996) have concluded that an organization's perception of the riskiness of the collaboration determines the type of governance structure that is adopted. In essence, the uncertainties associated with collaboration could be sources of risk for the involved parties. For instance, when there is uncertainty related to the performance of the collaboration, then there is performance risk; and when there is uncertainty about the partners' behavior with one another, there is a relational risk (Das et al., 1996). In a cooperative game, since both of the partnering

organizations cooperate with each other, I assume that there is little relational risk; and thus performance risk becomes a source of uncertainty, which needs to be reduced. An individual organization's risk tolerance determines the measures that are adopted to reduce this uncertainty, or in other words to "mitigate the risk." Thus the risk tolerance of an organization determines its behavior, and hence its utility function, in the current collaboration. However, the relation between an organization's risk tolerance and its participation rate has not been explored adequately in prior literature. It remains to be seen how the risk tolerance of an organization drives the organization to behave in a certain way or the other, which is addressed in this essay. Specifically, it would be interesting to note what effect the organization's risk tolerance has on its participation rate.

Another factor that has been shown to have a bearing on an organization's behavior in collaboration is its bargaining power in relation to its current or potential partner (Gerwin, 2004; Inkpen & Beamish, 1997; Yan & Gray, 1994). Bargaining power has been defined as a "bargainer's ability to favorably change the 'bargaining set' to win accommodations from the other party and to influence the outcome of a negotiation" (Yan et al., 1994). An organization can enjoy such power over its potential partner by virtue of its stakes in the negotiation and by virtue of the alternatives available to the organization. Researchers studying various forms of alliances have noted the relation between how much control an organization has in a relationship and its bargaining power (Yan et al., 1994). Such control manifests itself with respect to the organization's utility function, as well as, the extent to which the profits are shared by the partnering organizations. For instance, in a study of new product development (NPD) alliances, Gerwin (2004) found that the share of profits appropriated by an organization in an alliance depends on its bargaining power. However, not many studies have focused on the relation

between an organization's bargaining power and the participation rate in the current knowledge creation efforts. This study attempts to address this gap in literature.

4.1.1 The Partnership Model and Analysis

In a collaborative relationship, the efforts toward knowledge creation could be of two types: *current* or *prior*, which includes the prior knowledge base (Cohen et al., 1990). The current knowledge creation efforts consist of resources expended on the specific knowledge creation endeavor or alliance, while the prior knowledge creation efforts consist of resources expended by individual organizations before they formed the alliance on efforts that are directly relevant to the current knowledge creation project. Such prior efforts might include infrastructural and human resources, as well as, unique prior knowledge generated as the result of prior efforts. Unique prior knowledge could be measured in terms of the number of patents and publications (Agarwal & Henderson, 2002; Liebeskind, Oliver, Zucker, & Brewer, 1996; Shane, 2000; Teece, 1998). Thus current and unique prior knowledge creation efforts are the components of absorptive capacity, which, in turn, has a bearing on an organization's knowledge creation (Cohen et al., 1990).

The optimal sharing of resources is explored under two scenarios. Scenario 1 is where the collaborating organizations do not have any unique prior knowledge creation efforts or unique prior knowledge relevant to the knowledge creation project in focus; and the only resource that is allocated to the knowledge creation activity is the current knowledge creation effort. In other words, both organizations start the knowledge creation process from scratch. In Scenario 2, the collaborating organizations have made prior efforts and have, as a consequence, unique prior knowledge, in addition to their current knowledge creation efforts. In this section,

the optimal levels of current knowledge creation efforts and the optimal participation rate under both scenarios are examined and compared. The following sub-sections provide examples of both scenarios and propose mathematical models to arrive at sets of equilibrium values.

4.2 Scenario 1: Alliances between Organizations with No Prior Efforts

Instances of fairly recently formed organizations collaborating with each other illustrate this scenario well. Organizations that do not have considerable experience in creating knowledge are good examples of organizations without any prior investments in knowledge. Such organizations, which have not made substantial investments in knowledge creation or innovation have been shown to be better innovators in terms of producing the output than larger firms with substantial prior investments (Acs & Audretsch, 1987, 1988, 1990, 1991; Freeman, 1982; Patel & Pavitt, 1995; Schmookler, 1966).

The collaboration between MobilePro Corporation and Global Defense Corpoation (GDC) (Anonymous, 2004) is an example of the alliance between two recently-established organizations that could be reflecting Scenario 1. MobilePro Corporation was incorporated in the year 2000 and specializes in creating scalable and global wireless technologies and applications (Anonymous, 2004). Similarly, GDC was founded in 2003, and its focus was to bring advanced technologies to the defense and intelligence communities to help maintain the United States' technological lead in the areas of homeland security and global defense. The collaboration between MobilePro and GDC was established for the joint development of secure wireless applications for the defense industries. As is typical of firms with no prior investments in knowledge creation activities, the intent of this collaboration was to pool expertise that was available within both organizations to develop new applications. However, neither of the organizations had made any prior investments in the area of wireless security.

The response function quantifies the combined performance of both organizations in the dyad as a result of using the knowledge created by collaboration. Performance of a knowledge creating dyad is defined as the amount of output produced as a result of a specific mixture of

inputs. The main inputs that are referenced in this dissertation are financial inputs such as R&D investments. Patents, on the other hand, have been identified as valid indicators of the output or performance of a knowledge creation activity (Hall et al. 1986). Recall from Section 2.2 that the addition of newly-created knowledge to an organization's existing stock, and hence its consequent use, does not deplete it (Stephan, 1996). Also, during a product development life cycle, knowledge has more value when it is "new" than it does in later stages (Dorroh et al., 1994). Hence, the performance function for knowledge creation is non-linear.

New knowledge can be either positive or negative (Teece, 1998). Positive knowledge has been identified as adding to the existing stock of knowledge (Polanyi, 1967; Teece, 1998). However, one could argue that negative knowledge could be an important product of unique prior knowledge that either of the collaborating organizations might contribute to the current endeavor. Therefore negative knowledge itself might be a positive contribution from either organization in the form of unique prior knowledge. Thus knowledge is additive and leads to non-decreasing performance function. Since the investments expended in developing new knowledge can be measured in terms of performance (Machlup, 1980), the addition and application of new knowledge would lead to better performance. This is another reason why the performance function could be construed to be a non-decreasing function. Theoretically, one could argue that the return on knowledge does not decrease with time, although the gain to performance ratio from old knowledge might decrease with the decrease in the relevance of old knowledge.

The performance function for the collaboration $P(a)$ is affected by the current knowledge creation efforts in the project by both of the organizations, which is denoted by a. (See Appendix A for a complete list of symbols and their descriptions). The performance $P(a)$

reaches a saturation point α as a increases. α is called the performance saturation asymptote, which is the theoretical maximum of performance due to knowledge creation. The performance function can be expressed as:

$$P(a) = \alpha - a^{-\gamma} + \varepsilon \tag{1}$$

where α and γ are positive constants and ε represents the environmental uncertainty (random error). Assuming that the expected value of ε is zero, the expected performance function $\hat{P}(a)$ is:

$$\hat{P}(a) = \alpha - a^{-\gamma} \tag{2}$$

The expected performance is maximized as the current efforts are maximized. The parameter γ is called the "performance to investment sensitivity". The higher the value of γ, the greater is the influence of current knowledge creation efforts a on expected performance $\hat{P}(a)$. Also, it is assumed that the values of γ are the same for both of the collaborating firms.

4.2.1 Gain Functions and Equilibrium Values

Let ρ_1 and ρ_2 be the gain to performance ratios for organization 1 and organization 2, respectively, for each unit of performance that translates into earnings (Machlup, 1980). These parameters also signify how much the knowledge each organization appropriates by putting intellectual property protections such as patents, secrecy, know-how, and complementary sales and service in place, which will ultimately translate into earnings (Cohen, Nelson, & Walsh, 2000). Specifically, ρ_1 is the increase in the expected gain function $\hat{\pi}_1$ per unit increase in performance $\hat{P}(a)$ without taking into account the investment firm 1 makes in the venture (at).

Similarly, ρ_2 is the increase in the expected gain function $\hat{\pi}_2$, per unit increase in performance $\hat{P}(a)$, without taking into account the investment firm 2 makes in the venture (*a(1-t)*). ρ_1 and ρ_2 are henceforth referred to as gain to performance ratios. Let these be constants. Organization 1's participation rate, *t* with $0 \geq t \geq 1$, is its share of current knowledge creation efforts and that of organization 2 is 1-*t*. The expected gains for organization 1 and organization 2 and those for the entire system are:

$$\hat{\pi}_1 = \rho_1[\alpha - a^{-\gamma}] - at \tag{3}$$

$$\hat{\pi}_2 = \rho_2[\alpha - a^{-\gamma}] - a(1-t) \tag{4}$$

$$\hat{\pi} = (\rho_1 + \rho_2)[\alpha - a^{-\gamma}] - a \tag{5}$$

The following figure shows the system performance (*P(a)*) and system gain (π) as functions of the total current knowledge creation effort (*a*).

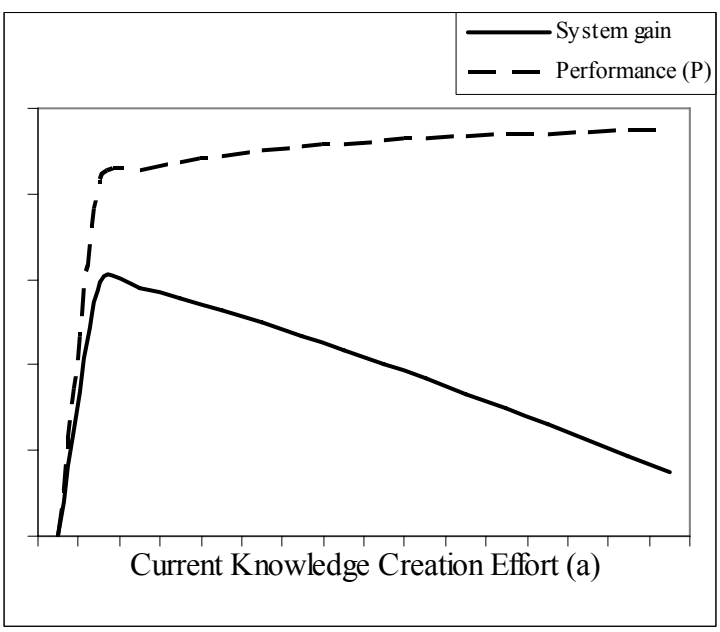

Figure 2: Performance and Expected System Gain as Functions of Current Knowledge Creation Effort

At this point, I wish to make a note on the universality of the parameters used in the model. Note that the parameters used in this essay and the following two essays, and the relationships among them, have been formulated to be appropriate for collaborations in which there is joint creation of knowledge. Such assumptions about the parameters and the relationships among them should be carefully examined before applying in other situations. For instance, while applying the model to non-knowledge creation alliances, specifically those that are formed for exchange of more tangible products, a parameter for depreciation should be factored into the model. Similarly, while applying the model to a licensing agreement, the licensing fee may be a better parameter than the participation rate that can be included in the model. Similarly, the applicability of the current model is expected to be limited in merger and acquisition scenarios because then the parameters, which illustrate the amount of autonomy the consumed organization has in the collaborative activities, have to be included.

By solving the gain function for the dyad with respect to the current knowledge creation efforts *a,* and by setting the first partial derivative to zero, one can determine the optimal value of current knowledge creation efforts as follows:

$$\frac{\partial \hat{\pi}}{\partial a} = (\rho_1 + \rho_2)\gamma a^{-(\gamma+1)} - 1 = 0 \qquad (6)$$

The optimal value of current knowledge creation efforts, a^* is:

$$a^* = \left[\gamma(\rho_1 + \rho_2)\right]^{\frac{1}{\gamma+1}} \qquad (7)$$

From Equation (7), one can deduce that the optimal value of the current knowledge creation efforts is a function of the sum of the organizations' individual expected profit and the performance to investment sensitivity of current knowledge creation efforts.

Substituting the optimal value for current knowledge creation efforts in Equation 5, we get the equilibrium value for the expected system gain as follows:

$$\hat{\pi}^* = (\rho_1 + \rho_2)\left\{\alpha - [\gamma(\rho_1 + \rho_2)]^{-\left(\frac{\gamma}{\gamma+1}\right)}\right\} - [\gamma(\rho_1 + \rho_2)]^{\frac{1}{\gamma+1}} \tag{8}$$

In order to arrive at a cost-sharing scheme for both partner organizations, it is now important to consider the equations for expected gain functions for the individual organizations, since the expected system gain is not a function of the participation rate. In a partnership game, although the expected system gain is maximized, the collaborating organizations achieve this while maximizing their individual gains. In other words, firm 1 prefers a participation rate that maximizes $\hat{\pi}_1$ and firm 2 prefers a participation rate that maximizes $\hat{\pi}_2$. As mentioned earlier, since there is no "single optimal value of *t*" that can be determined by optimizing the expected system gain, the players in the game are free to negotiate the participation rate.

Following Eliashberg's (1986) arbitration approach, it is specified that the "risk-sharing scheme" agreed on by both of the organizations depends on each organization's risk tolerance (b_i) and bargaining power (λ_i).

The organizations' risk tolerance can be captured in their individual utility functions for individual payoffs (Eliashberg et al., 1981). The individual utility functions are then aggregated into a utility function for the system (dyad). The aggregation weights that are used to combine the individual utility functions into a single system utility function are the individual bargaining powers of the organizations. Of the several types of multi-attribute utility functions, the additive forms have been recognized as the most appropriate to be used for decision analytic applications (Eliashberg et al., 1981; Huang et al., 2002) and also as the most popular ones (Eliashberg, 1986). Hence, I consider the system utility function to be additive of the individual utility

functions of the partner organizations. I assume that both organizations in the alliance have low risk tolerance and have the following utility functions:

$$u_1(\hat{\pi}_1) = 1 - e^{-(b_1\hat{\pi}_1)} \tag{9}$$

and

$$u_2(\hat{\pi}_2) = 1 - e^{-(b_2\hat{\pi}_2)} \tag{10}$$

These utility functions, when added along with the aggregation weights, give the system utility function, which is:

$$u(\hat{\pi}_1, \hat{\pi}_2) = 1 - \lambda_1 e^{-(b_1\hat{\pi}_1)} - \lambda_2 e^{-(b_2\hat{\pi}_2)} \tag{11}$$

where λ_1 and λ_2 are the aggregation weights and $\lambda_1 + \lambda_2 = 1$.

Partially differentiating *u* with respect to $\hat{\pi}_1$ and $\hat{\pi}_2$, subject to the constraint $\hat{\pi}_1 + \hat{\pi}_2 = \hat{\pi}$, gives the values of $\hat{\pi}_1$ and $\hat{\pi}_2$ that maximize the utility function weighted by bargaining power $u(\hat{\pi}_1, \hat{\pi}_2)$ as follows:

$$\hat{\pi}_1^* = \frac{b_1}{b_1 + b_2}\hat{\pi} + \frac{1}{b_1 + b_2}\ln\frac{\lambda_1 b_1}{\lambda_2 b_2} \tag{12}$$

or $\hat{\pi}_1^* = j\hat{\pi} + w$; where $j = \dfrac{b_1}{b_1 + b_2}$ and $w = \dfrac{1}{b_1 + b_2}\ln\dfrac{\lambda_1 b_1}{\lambda_2 b_2}$

Similarly:

$$\hat{\pi}_2^* = \frac{b_2}{b_1 + b_2}\hat{\pi} + \frac{1}{b_1 + b_2}\ln\frac{\lambda_2 b_2}{\lambda_1 b_1} \tag{13}$$

or $\hat{\pi}_2^* = (1 - j)\hat{\pi} - w$

We know from Equation (3) that $\hat{\pi}_1 = \rho_1[\alpha - a^{-\gamma}] - at$. By inserting the value of *a** into this equation, I find the optimal value for *t:*

$$\hat{\pi}_1 * = \rho_1[\alpha - (a*)^{-\gamma}] - a*t = j\hat{\pi} + w \text{ or}$$

$$t* = \frac{-j\hat{\pi} - w + \rho_1[\alpha - (a*)^{-\gamma}]}{a*} \tag{14}$$

Similarly, I find $t*$ from Equation (4) (expressed in terms of ρ_2) as follows:

$$\hat{\pi}_2 * = \rho_2[\alpha - a*^{-\gamma}] - (1-t)a* = (1-j)\hat{\pi} - w \text{ or}$$

$$t* = 1 + \frac{(1-j)\hat{\pi} - w - \rho_2[\alpha - (a*)^{-\gamma}]}{a*} \tag{15}$$

See Appendix D for proof that Equations (14) and (15) are equivalent.

The equilibrium values for total current knowledge creation efforts, expected system gain, and participation rate are summarized in Table 4 below.

$$a* = [\gamma(\rho_1 + \rho_2)]^{\frac{1}{\gamma+1}} \tag{16}$$

$$\pi* = (\rho_1 + \rho_2)\left\{\alpha - [\gamma(\rho_1 + \rho_2)]^{-\left(\frac{\gamma}{\gamma+1}\right)}\right\} - [\gamma(\rho_1 + \rho_2)]^{\frac{1}{\gamma+1}} \tag{17}$$

$$t* = \frac{-j\hat{\pi} - w + \rho_1[\alpha - (a*)^{-\gamma}]}{a*} = 1 + \frac{(1-j)\hat{\pi} - w - \rho_2[\alpha - (a*)^{-\gamma}]}{a*} \tag{18}$$

Table 4: Equilibrium Values for Scenario 1 (Current Knowledge Creation Efforts Only).

4.2.2 Analysis of Results

Based on the equilibrium results shown in Table 4, one can make the following observations, which are then generalized as propositions. The level of current knowledge creation efforts that maximizes the aggregate utility function, weighted by bargaining power, is a function of the combined gain to performance ratios of both organizations and the performance to investment sensitivity of current knowledge creation efforts. The optimal participation rate of

each organization in the current knowledge creation efforts is a function of its risk tolerance and its bargaining power. Hence, the analysis of the results is presented in the ensuing sub-sections as it relates to the consideration of risk tolerance of an organization, consideration of the bargaining power of an organization, and the joint consideration of the risk tolerance and bargaining powers. It has to be noted here that the model and the equilibrium values assume that the collaboration experiences some financial gains as a result of the collaborative knowledge creation. As mentioned in Section 1.3, the forensics of collaborations that do not make any gain are out of the scope of this study.

Consideration of Risk Tolerance

The risk tolerance of an organization has a considerable bearing on its participation in the current knowledge creation efforts. As shown by the first part of the equation for the equilibrium value of optimal participation rate, an organization with lesser risk tolerance[7] in other words, a risk averse organization contributes more toward current knowledge creation efforts. Since making an investment can be construed as taking risk, this observation is counter to the general notion that risk avoiding individuals or organizations tend to not make more investments in the joint venture.

In this regard, the results provide a different interpretation of risky behavior and the steps that a risk averse organization takes in order to mitigate the risk. There have been instances where joint ventures have been dissolved due to financial reasons[8]. Making adequate financial efforts could be one way by which low risk tolerant organizations exercise control over the

[7] Organizations with lesser risk tolerance are henceforth referred to as risk avoiding organizations, and those with high risk tolerance are referred to as risk seeking organizations.
[8] See the joint venture between Saab-Scania and Fairchild in Mowery, D. C. 1988. International Collaborative Ventures in US Manufacturing. Cambridge, MA: Ballinger., for a detailed exposition of the case and where the reason for the failure of this collaboration has been specified as financial burdens.

outcome of the joint venture (Child & Yan, 2003). If both organizations have the same amount of risk tolerance, they may participate equally in the collaboration, as illustrated by the presence of several equity joint ventures.

As shown by the second part of the equation for equilibrium value for the optimal participation rate, an organization with a higher risk tolerance or a risk seeking organization tends to get a better share of the overall system gain. This is again in tune with the notion prevailing in traditional finance literature that higher risk leads to greater rewards.

> *Proposition 1a: A higher risk-tolerant organization's participation rate in current knowledge creation efforts is less compared to that of the lesser risk-tolerant organization*[9].
>
> *Proposition 1b: A higher risk-tolerant organization is expected to get a greater share of the expected system gain.*

The above two propositions clarify the link between the risk tolerance and risk behavior. One would imagine that logically a lower risk tolerant organization would participate less compared to higher risk-tolerant organization. However, the results suggest otherwise. It is interesting to note that although the higher risk-tolerant organization tends to get away with lower participation rate (lesser share of the investment), it does get a better share of the system gain. This analysis reveals that greater investment does not always lead to greater returns. The reason why this happens could be because the higher risk-tolerant organization might seek other sources of information and might be able to take a calculated risk. On the other hand, the lower risk tolerant organization might want to ensure the success of the collaboration by primarily investing in it without the expectation of a higher share of the total gain.

In cases where the organizations are expected to have similar levels of risk tolerance, the participation rate is more likely to be comparable for both organizations. That is, both are likely

[9] Some of the propositions developed in this essay may seem circular with the assumptions made in the essay. An explanation is given clarifying the absence of such circularity for Essay 1 in Appendix E.

participate equally in the knowledge creation endeavor. For instance, consider the case of collaborations between giants such as Wal-Mart and Proctor and Gamble (P&G). Over the years the relationship between these two organizations has developed into that between equal partners from an earlier stage when P&G dominated the relationship. In the days of its dominance, P&G forced Wal-Mart into a higher participation rate by way of carrying more sizes of P&G's products and limited supply of products that were high in demand (Huang et al., 2002). As Wal-Mart grew, the relationship unfolded into one where systems were put in place to promote information sharing and joint planning. In such cases where both organizations have similar levels of risk tolerance, the current model predicts that their participation in the relationship is expected to be equal.

Consideration of Bargaining Power

The second part of Equation (18) brings to light the effect of the bargaining power of an organization on its optimal participation rate. According to the equilibrium value, an organization with greater bargaining power can negotiate and tilt the scales in their favor, thereby contributing less than the organization with less bargaining power. The result of the above analysis is intuitive since in negotiation games, whoever is in a better position to bargain tends to shift the scales in their favor by manipulating the potential or current partners. The consideration of bargaining power leads us to the following proposition:

> *Proposition 2: An organization with greater bargaining power will participate less in the current knowledge creation effort than that with lesser bargaining power.*

Similar to the situation for risk tolerance, when organizations that have equal bargaining power collaborate, the participation rate is expected to be equal.

Joint Consideration of Risk Tolerance and Bargaining Power

Having recognized in the previous analyses that the participation rate in the current knowledge creation efforts depends on both the risk tolerance and the bargaining power, a logical step in this direction would be to speculate the joint effect of risk tolerance and bargaining power on the organization's behavior in terms of being able to manipulate its potential or current partner. For instance, based on the various combinations of risk tolerance and bargaining power, the organizations could fall into one of the four categories depicted in Table 5.

		Risk Tolerance	
		Low	**High**
Bargaining Power	**Low**	1	2
	High	3	4

Table 5: Categories of Organizations Based on Risk Tolerance and Bargaining Power

An organization belonging to quadrant 1 is characterized with low risk tolerance and low bargaining power, and hence might not have any ability to manipulate either its potential partners or its current partners. By Propositions 1a, 1b, and 2, this organization might end up contributing more to the current knowledge creation efforts while getting a leaner share of the system gains. The organization in quadrant 4 is high in risk tolerance and has greater bargaining power. This puts the organization in an advantageous position along two lines. On the one hand, it can get away with participating less and getting a better share of the system gain in relation to its partner on the other. The organization in quadrant 2 is more risk tolerant with lower bargaining power than its partner. This might lead to the situation of lesser participation rate and lesser share of

the system gain. The third quadrant organization is characterized by low risk tolerance and high bargaining power. Such an organization not only contributes more towards current knowledge creation efforts but also gets a fair share of the system gain.

The above observations shed new light on the issue of how the benefits or economic rents (Madhok & Tallman, 1998) of collaboration efforts are distributed among participants. The supply chain literature has recognized the concerns regarding the distribution of gains due to collaboration. For example, Sengupta (2001) indicated that supply chain management benefits are always an issue of concern for collaborating organizations. However, little theoretical guidance exists to help determine the degree of this inequality and its impact on decision-making and the relationship that develops between collaborating organizations.

The above analysis has implications in the pre-alliance formation stage during partner selection. When shopping for partners, an organization can take into account their respective bargaining powers and the risk tolerance of potential partners and select the partner that might be best suited for the current knowledge creation endeavor. Current literature on partner selection stresses criteria such as reciprocity, past partnership outcomes, experience, (Li & Rowley, 2002) complementary capabilities, and financial assets (Hitt et al., 2000) for evaluating potential partners. In addition to these criteria, when informed by the above analysis, organizations can evaluate potential partners based on their risk tolerance and the characteristics that might put them in a more powerful position to bargain. Similarly, these propositions have implications for alliance re-negotiations in the post-alliance formation stage (Reuer, Zollo, & Singh, 2002). For instance, they noted that after formation, alliances could negotiate to change their alliance scope, division of labor and alliance relevance, technological experience, and partner-specific

experience. My analysis indicates that these re-negotiations can include the participation rate. These re-negotiations, in turn, might lead to changes in the alliance's governance structure.

This implication is within the purview of real options theory (Bowman & Hurry, 1993). Evaluating an organization's strategies in selecting partners and re-negotiating participation rate for continued collaboration are some options available to them in the pre- and post- formation stages open a rather novel line of enquiry in alliance literature. Hence, strategic decisions that organizations could make regarding future incremental investments in a collaborative effort might be guided by an evaluation of choices that are available to the organization at important turning points during the course of collaboration.

4.3 Scenario 2: Alliances between Organizations with Prior Efforts

In this sub-section, an example of Scenario 2 is presented, which illustrates a combination of prior and current efforts in knowledge creation, along with the corresponding performance function. The joint venture between Lucent and Phillips for the creation of a separate entity, Phillips Consumer Communications (PCC), in 1997, is an example of this type of joint venture. Both organizations were big players in their own markets and have created the joint venture PCC in order to harness the technology available from Phillips Research and Lucent Technologies/Bell Labs. The specific joint venture was formed to develop the PCS wireless phone and the Philips Digital PCS 1900 with Voice Dial™, featuring a smart phone add-on for wireless faxing, e-mail and World Wide Web access.

The performance function for Scenario 2 $P(a, q_1, q_2)$ is affected by the total current knowledge creation efforts a (as in Scenario 1), and additionally by prior knowledge creation efforts (q_1 and q_2) made by each organization, independently, before entering the alliance. The performance $P(a, q_1, q_2)$ approaches a saturation point α as a or q_1 and q_2 increase. The performance functions (1) and (2) from Scenario 1 are now modified as

$$P(a, q_1, q_2) = \alpha - a^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2} + \varepsilon \tag{19}$$

and

$$\hat{P}(a, q_1, q_2) = \alpha - a^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2} \tag{20}$$

where α, γ,. δ_1 and δ_2 are positive constants

In agreement with the discussion of the performance function for Scenario 1, this function is non-linear, and non-decreasing. When a, q_1 and q_2 tend to infinity, then $\hat{P}(a, q_1, q_2)$ tends to α the "performance saturation asymptote" mentioned in Section 3.1. The parameters

γ δ_1 and δ_2 are called the performance to investment sensitivities. The higher the value of γ, the greater the influence of current knowledge creation efforts on performance; and the higher the values of δ_1 and δ_2, the greater the influence of prior knowledge creation efforts on performance. I assume that γ is greater than both δ_1 and δ_2, which means that current knowledge creation efforts have a higher performance to investment sensitivity than prior knowledge creation efforts. This is due to the notion that any current knowledge creation effort is expected to have more effect on the performance of a particular project than prior knowledge creation efforts, whose returns are spread over a longer time period and over many projects and activities. As in Scenario 1, t an organization's participation rate, continues to affect the individual and system gains.

In the next sub-section, I present the gain functions of the individual organizations, and the dyad. I then present the equilibrium values for current knowledge creation efforts, participation rate, and the dyad's gain under the second scenario.

4.3.1 Gain Functions and Equilibrium Values

The expected gain functions for both organizations in the dyad and that for the entire system are given by:

$$\hat{\pi}_1 = \rho_1[\alpha - a^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2}] - at \tag{21}$$

$$\hat{\pi}_2 = \rho_2[\alpha - a^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2}] - a(1-t) \tag{22}$$

$$\hat{\pi} = (\rho_1 + \rho_2)[\alpha - a^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2}] - a \tag{23}$$

By first maximizing the system gain function and setting the first partial derivative to zero, one can determine the optimal value of current knowledge creation efforts as follows:

$$\frac{\partial \hat{\pi}}{\partial a} = (\rho_1 + \rho_2)\left[a^{-(\gamma+1)} q_1^{-\delta 1} q_2^{-\delta_2} \gamma\right] - 1 = 0 \tag{24}$$

Then we get the optimal value of current knowledge creation efforts as:

$$a^* = \left[(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})\right]^{\frac{1}{\gamma+1}} \tag{25}$$

By inserting the value of $a*$ from Equation (25) into Equation (23) we get the optimal value of the expected system gain, which is:

$$\hat{\pi}* = (\rho_1 + \rho_2)\{\alpha - [(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})]^{-\left(\frac{\gamma}{\gamma+1}\right)} q_1^{-\delta_1} q_2^{-\delta_2}\} - [(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})]^{\frac{1}{\gamma+1}} \tag{26}$$

The optimal value for t is calculated in the same way as under Scenario 1, and the results yield $t*$ as follows:

$$t* = \frac{\rho_1[\alpha - ((a*)^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2})] - j\hat{\pi} - w}{a*} \text{ or} \tag{27}$$

$$t* = 1 + \frac{\rho_2[\alpha - ((a*)^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2})] + (1-j)\hat{\pi} - w}{a*} \tag{28}$$

$$a^* = \left[(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})\right]^{\frac{1}{\gamma+1}} \tag{29}$$

$$t* = \frac{\rho_1[\alpha - ((a*)^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2})] - j\hat{\pi} - w}{a*} =$$

$$1 + \frac{\rho_2[\alpha - ((a*)^{-\gamma} q_1^{-\delta_1} q_2^{-\delta_2})] + (1-j)\hat{\pi} - w}{a*} \tag{30}$$

$$\pi* = (\rho_1 + \rho_2)\{\alpha - [(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})]^{-\left(\frac{\gamma}{\gamma+1}\right)} q_1^{-\delta_1} q_2^{-\delta_2}\} - [(\rho_1 + \rho_2)(\gamma q_1^{-\delta_1} q_2^{-\delta_2})]^{\frac{1}{\gamma+1}} \tag{31}$$

Table 6: Equilibrium Values for Scenario 2 (Combined Prior and Current Knowledge Creation Efforts)

4.3.2 Analysis of Results

By inspecting the equilibrium values of current knowledge creation efforts $a*$ and the participation rate $t*$ in Table 6, I conclude the following: first, the equilibrium value for the current knowledge creation efforts $a*$ is a function of both organizations' prior knowledge creation efforts, in addition to their gain to performance ratios; second, the participation rate is still a function of the risk tolerance and bargaining power of each organization. Hence, the presence of prior knowledge creation efforts does not affect the participation rate in the current knowledge creation effort.

The expected system gain is a function of prior knowledge creation efforts as well as a function of gain to performance ratios and performance to investment sensitivities. The propositions made for Scenario 1 still apply for Scenario 2, and hence will not be repeated here. However, the results of Scenario 2 are better understood in comparison with those of Scenario 1, which is presented as a cross-scenario analysis in the next sub-section.

4.4 Cross-scenario Analysis

A comparison of the equilibrium values under both scenarios reveals two dissimilarities and one similarity. The first dissimilarity is that the optimum current knowledge creation efforts are lower when organizations in the dyad have expended prior knowledge creation efforts. The equilibrium value for a in Scenario 2 is less than that in Scenario 1 by a factor of the products of prior knowledge creation efforts. This suggests that when organizations already have some prior knowledge creation efforts in the form of R&D infrastructure, or a unique prior knowledge base, fewer resources are needed to start a new R&D project. This observation reconfirms the theoretical notion that experience is important, in addition to investment in inter-organizational learning (Lane et al., 1998).

The second dissimilarity is that system gain is higher under Scenario 2, with prior knowledge creation efforts than with only current knowledge creation efforts by a factor of the product of the prior knowledge creation efforts. This is again intuitive in the sense that when there are indirect and current knowledge creation efforts, the overall gain for the dyad is higher because of lower expenses. Both of these dissimilarities can be stated as the following propositions

> *Proposition 3a: The optimal value of current knowledge creation efforts is lower in the presence of prior knowledge creation efforts (Scenario 2) than without prior knowledge creation efforts (Scenario 1).*

> *Proposition 3b: The optimal expected system gain is higher in the presence of prior knowledge creation efforts (Scenario 2) than without prior knowledge creation efforts (Scenario 1).*

Proposition 3a appears intuitive since organizations that have made prior efforts toward knowledge creation would have to make lower efforts for current knowledge creation. In tune

with traditional production economics, if the efforts made toward knowledge creation could be considered to include fixed costs and variables costs, organizations with prior knowledge creation efforts would have already made some investments, in terms of fixed costs (Scenario 2) and would have to expend only variable costs that might be typical for the current knowledge creation endeavor. In contrast, collaborations where both organizations have not made any prior efforts towards knowledge creation (Scenario 1) would have to expend both fixed costs and variable costs for the current knowledge creation endeavor.

Similarly, Proposition 3b appears intuitive since having prior efforts in knowledge creation (Scenario 2) will give rise to higher net system gain because total costs would be lesser than when there are no prior efforts in knowledge creation (Scenario 1). Propositions 3a and 3b imply that organizations are better off partnering with other organizations that have made some prior efforts toward knowledge creation than partnering with those starting afresh. In scenarios where one of the organizations has made considerably less prior efforts in knowledge creation than the other, the organization with less prior efforts stands to gain more by collaborating, rather than creating knowledge on its own. This is true since the organization with less prior efforts would still share a better portion of the system gain when in collaboration, than without collaboration.

As in the analysis for Scenario 1, the above two propositions have implications for partner selection. These propositions endorse prior research, with respect to partner selection, that capabilities have to be taken into consideration while choosing alliance partners (Doz & Hamel, 1998; Hitt et al., 2000; Luo, 1997). Unique prior knowledge, or prior efforts in knowledge creation, give the firms capabilities that could be extended to the current knowledge creation endeavor (Hagedoorn & Duysters, 2002). Hence, organizations with prior efforts in

knowledge creation are better potential partners than those with no prior knowledge creation efforts.

The similarity between Scenario 1 and Scenario 2 is that the optimal participation rate does not change across the scenarios. The analysis of similarities provides some insights, about the relationship between the collaborating organizations, which are stated as the proposition below:

> *Proposition 4: The participation rate of an organization in the current knowledge creation efforts is negatively associated with both its risk tolerance and bargaining power, regardless of its prior knowledge creation efforts.*

Proposition 4 reveals that, structurally, the participation rate in the current knowledge creation efforts depends on risk tolerance and bargaining power with or without prior efforts. The proportion of profits shared by an organization is a function of its risk tolerance, as can be observed from the optimal value for the participation rate t^*. So the organization that can take higher risks is the one to appropriate a greater proportion of expected system gain. In other words, an organization that can participate more, will, in fact, appropriate a greater proportion of expected system gain. Additionally, the organization with a greater bargaining power will participate less in the collaboration. In any cooperative agreement, one partner's dependence on the other's resources might put it in a situation which might give rise to the existence of bargaining power (Inkpen et al., 1997). Hence, in a partnership-based collaboration, it is possible that one organization is in a more powerful position than the other and uses this power to bargain for a participation rate closer to 0. The organization in the dependent position attempts to get the first organization to commit to a participation rate closer to 1.

4.5 Discussion

In Essay 1, a partnership-based framework for examining the resource-sharing decisions between two collaborating knowledge creation organizations is presented. Two likely scenarios suitable for collaborative knowledge creation were identified and investigated. Scenario 1 is where the only effort expended is current knowledge creation effort, and Scenario 2 is where prior knowledge creation effort including unique prior knowledge has been expended. The resource-sharing model was developed under both of these scenarios, and the equilibrium values were found for current knowledge creation efforts *a*, prior knowledge creation efforts q_1 and q_2, an organization's participation rate *t*, and expected system gain $\hat{\pi}$.

Risk tolerance and bargaining power of an organization were identified as factors that determine its share in the current knowledge creation efforts. With regard to the nature of relationship, risk tolerance and bargaining power were found to have a negative effect on the participation rate. In other words, an organization with high risk tolerance has a lesser participation rate as does an organization with more bargaining power. Additionally, a link was identified between the risk tolerance and bargaining power of an organization to the share of the total system gain appropriated by it. An organization with high risk tolerance appropriates a greater proportion of system gain. This answers the first research question about what are the factors that determine the resource participation rate and how do they influence the participation rate.

In order to find the conditions under which some of the potential partners become more attractive than others, the equilibrium values of current knowledge creation efforts, participation rate, and the system gain were compared for both of the scenarios. It was found that while the amount of optimal current knowledge creation efforts is lower when both organizations in the

collaboration have already made prior knowledge creation efforts in the knowledge domain where new knowledge is being created, the participation rate remains the same, regardless of whether the two organizations have made prior knowledge creation efforts. Also, the system gain is higher when there is a combination of direct and prior knowledge creation efforts. Thus, this answers the second research question about what are the conditions under which some of the potential partners become more attractive than others. The third research question regarding the conditions, under which collaborations exist, however, is not answered in this essay since the equilibrium values hold true under all conditions.

The theoretical implications of the current essay are manifold. Recall the two limitations of TCE identified in Section 2.1. First, although TCE proposes the motivation for the formation of collaborations, it does not provide micro level direction (Krishnan et al., 2001) about how to devise resource-sharing strategies. Second, TCE is limited in that it focuses on cost minimization, as opposed to value maximization (Dyer, 1997). The current essay compliments TCE by providing details of what factors come into play while making resource-sharing decisions. For instance, informed by Propositions 1a, 1b and 2, a potential partner's demonstrated risk tolerance and bargaining power are recognized as factors that play a role in the resource-sharing decisions that the collaborating organizations make. Additionally, the partnership game, with a goal of maximizing the expected system gain, reiterates the value maximization proposition that TCE is recognized to overlook.

One of the limitations of RDT is that it does not provide the nuances of how inter-firm transfer of resources takes place during the course of the collaboration (Barringer et al., 2000). This essay thus enhances our understanding of inter-firm collaborations. Specifically, Propositions 1a and 2 inform the collaborating organizations about which factors determine the

resource-sharing rate and how these factors affect the resource-sharing decisions. The essay further complements the theory by providing guidance about partner selection strategies. Specifically, Propositions 3a and 3b inform how the potential partners with prior knowledge creation effort compare to those without such prior efforts.

This essay also is in the line of enhancing the organizational learning theory in the following way. The basic structure of the game where the goal of the game is to maximize the expected system gain addresses one of the necessary directions (Larsson et al., 1998) that has been recognized for learning theory to progress if its contributions were to go beyond inter-partner learning or learning races.

Chapter 5 ESSAY 2: COLLABORATIVE KNOWLEDGE CREATION AS A LEADER-FOLLOWER GAME- CASE OF BOTH FIRMS WITH INCREASING MARGINAL RETURNS

5.1 Introduction to Essay 2

In this essay, Case 2 identified in Section 3.3, where the performance function for both of the organizations is formulated with the increasing marginal returns with respect to knowledge creation investments and is studied as a leader-follower game (Stackelberg, 1934). In this game, the leader is the one in a position to make decisions, and the follower is the organization that reacts to the leader's decisions. In the two-stage game, the leader chooses a participation rate (*t*). In the second stage, the follower observes the leader's choice of the participation rate (*t*) and chooses a value of the current knowledge creation effort (*a*).

The Stackelberg game is played under the assumption of complete and perfect information (Savaskan, Bhattacharya, & van Wassenhove, 2004; Van Cayseele & Furth, 2001). Although the leader makes the first move in this game, the equilibrium value of the game is determined through backward induction by solving for the follower's reaction function first (Gibbons, 1997). By solving for the follower's function first, one can arrive at a preferred value of current knowledge creation effort (*a*), which maximizes its individual gain $(\hat{\pi}_F)$ as a function of the leader's participation rate (*t*). Such preferred value of current knowledge creation effort (*a*) is called the "best response value" for the follower. Given the follower's best response value, the leader's best response value equilibrium value of its participation rate (*t*) that maximizes its individual gain $\hat{\pi}_L$ is computed. The equilibrium values for the current knowledge creation effort (*a*), the leader's participation rate (*t*), and the expected total system gain $(\hat{\pi})$ are derived and analyzed.

Essay 2 includes a logical addition to the performance function by introducing the organizations' capacity to commercialize commonly-produced knowledge. For instance, the model in Section 4.2 was specified exclusively with respect to investment, which has been

captured in two ways: current efforts and prior efforts. Theoretically, these types of investments represented the portions of economic rents generated by the current effort and prior efforts that could be useful for the current knowledge creation endeavor. In this essay, a factor of production, which represents the capacity of each firm to commercialize the knowledge produced, is modeled into the performance function and eventually into the gain functions in addition to current knowledge creation effort. Literature has evidence that the appropriability of knowledge created influences level of R&D investments (Veugelers & Cassiman, 1999). Specifically, low levels of appropriation may provide a disincentive to invest further in R&D, since a firm may not be able to realize the full benefit of its investment (Arrow, 1962; Spense, 1984). The theoretical concept linking such a capacity of a firm to "understand, assimilate and apply new knowledge to commercial ends" is absorptive capacity (Cohen et al., 1990).

5.2 Collaborations between Organizations with Increasing Marginal Returns

As mentioned in Section 2.2, organizations that are characterized by increasing marginal return are newer, entrepreneurial firms, typically engaged in radical innovation or in the creation of a new stream of knowledge rather than building on existing knowledge. This also applies to alliances in highly knowledge-intensive industries such as biotechnology. In such knowledge-intensive industries, research alliances between firms are commonplace. For instance, the strategic research alliance between Genzyme General and Genovo Incorporated to develop gene therapy products for lysosomal storage disorders, a class of rare genetic diseases (Anonymous, 1999). Genzyme's expertise lies in developing therapy for lysosomal storage disorders, and that of Genovo's lies in developing gene therapy knowledge. The motivation behind the collaboration has been articulated as the access to each other's expertise and the subsequent combination of resources to develop new gene therapy products. Since both of the organizations are involved in developing breakthrough products, it is logical to assume that both of them are characterized by increasing marginal return functions.

5.3 Gain Functions and Equilibrium Values

The performance function for Case 2 is specified as:

$$P(a,c) = a^{\gamma} c^{\phi} + \varepsilon \tag{32}$$

where P is the performance, which is a function of investment in the current knowledge creation endeavor (*a*) and the capability (*c*) of a firm to commercialize common knowledge. The commercialization of knowledge is a parameter that is being included in the model to accommodate the capacity of the firm to translate the knowledge generated into actual monetary value. The parameter γ is the performance to investment sensitivity of current knowledge creation effort, and ϕ is the sensitivity of the commercialization capacity.

The expected performance function could be modified as:

$$\hat{P}(a,c) = a^{\gamma} c^{\phi} \tag{33}$$

It is assumed that the values of γ are the same for both of the collaborating firms. However, the vales of ϕ differ for the organizations.

The expected gain function for a firm *i* is specified as a function of the firm's performance and its risk tolerance (*b*). For collaborations where both firm are characterized by increasing marginal returns, the returns increase infinitely for infinite investment. This would result in infinite optimal investment. Since, in reality, infinite investments are not possible, the factor of risk tolerance is introduced in order to arrive at an optimal investment. The risk tolerance factor is a positive fraction and is less than $\frac{1}{\gamma}$ (that is, $b < \frac{1}{\gamma}$ or $\gamma b < 1$). The value of the product γb has to be less than 1 in order for the existence of a finite optimal investment value. Lower values of risk tolerance mean that the collaboration is less willing to take risks, and higher values of risk tolerance mean that the collaboration is willing to take risk. The expected

gain function for firm i is now modified as follows $\hat{\pi}_i = \left(\rho_i a^{\gamma} c^{\phi}\right)^b - a(t_i)$ where (t_i) is the participation rate.

The expected gain function for the leader organization is given by:

$$\hat{\pi}_L = \left(\rho_L [a^{\gamma} c_L^{\phi_L}]\right)^b - at$$

Let $L_2 = \left(\rho_L c_L^{\phi_L}\right)^b$. Then the expected gain function for the leader can be written as

$$\hat{\pi}_L = L_2 a^{\gamma b} - at \tag{34}$$

The expected gain function for the follower organization is given by:

$$\hat{\pi}_F = \left(\rho_F [a^{\gamma} c_F^{\phi_F}]\right)^b - a(1-t)$$

Let $F_2 = \left(\rho_F c_F^{\phi_F}\right)^b$. Then the expected gain function for the follower is:

$$\hat{\pi}_F = F_2 a^{\gamma b} - a(1-t) \tag{35}$$

$$\hat{\pi} = \hat{\pi}_L + \hat{\pi}_F = [L_2 + F_2]\left(a^{\gamma b}\right) - a \tag{36}$$

The performance and the expected gain as functions of the current knowledge creation effort *(a)* are shown in the Figure 3. Note that the discussion regarding the universality of assumptions presented in Section 4.3 still holds true for the assumptions made in this essay.

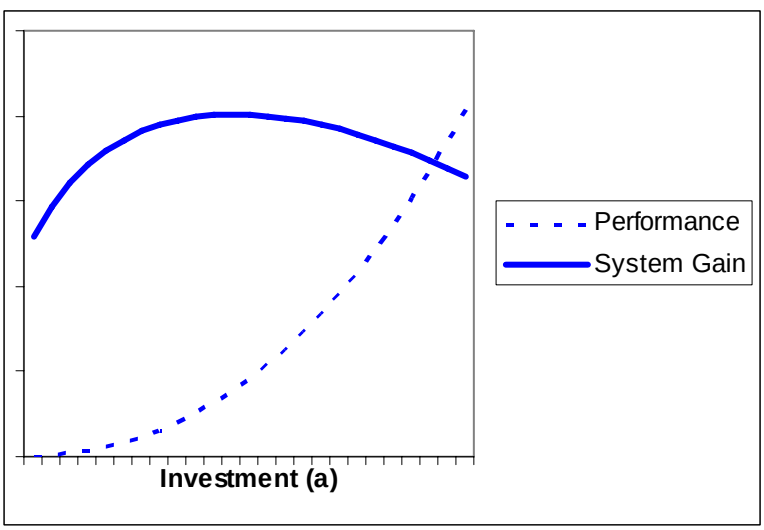

Figure 3: Performance and Expected System Gain as Functions of Investment

The follower's best response value of the current knowledge creation effort (a) is computed by setting the first partial derivative of the follower's expected gain function in Equation (35) to zero.

$$\frac{\partial \hat{\pi}_F}{\partial a} = F_2 \gamma b a^{\gamma b - 1} - (1 - t) = 0 \tag{37}$$

Then, we get the value of current knowledge creation effort that maximizes the follower's expected gain as a function of t as follows:

$$a^* = \left(\frac{1 - t}{F_2 \gamma b} \right)^{\frac{1}{\gamma b - 1}} \tag{38}$$

Given the follower's best response value of a^*, the leader's best response value for its participation rate (t) is computed as one that maximizes its expected gain $\hat{\pi}_L$. In order to arrive at the value of t that maximizes $\hat{\pi}_L$, the leader's expected gain function is maximized with respect to t subject to the constraint in Equation (38)

$$\underset{t}{Max}\, \hat{\pi}_L = L_2 [a^{*\gamma b}] - a^* t \tag{39}$$

subject to the constraint $0 < t < 1$ where a^* is as expressed in Equation (38).

Substituting the value for a^* as in Equation (38) in Equation (39) gives the optimization problem for the leader organization as:

$$\frac{\partial \hat{\pi}_L}{\partial t} = \frac{\partial \left(L_2 \left(\frac{1 - t}{F_2 \gamma b} \right)^{\frac{\gamma b}{\gamma b - 1}} - \left(\frac{1 - t}{F_2 \gamma b} \right)^{\frac{1}{\gamma b - 1}} t \right)}{\partial t} = 0 \tag{40}$$

subject to $0 < t < 1$. Solving (40) for *t*, we get the value of *t* that maximizes the leader's expected gain as follows:

$$t_2 * = \frac{F_2(\gamma b - 1) + L_2}{F_2 \gamma b + L_2}$$

For the leader's participation rate to be between 0 and 1, $\frac{L_2}{F_2} > 1 - \gamma b$.

Substituting the value of $t_2 *$ first in Equation (38) and then the values of t_2* and a_2* in Equation (36), one can arrive at the equilibrium values for the current knowledge creation efforts and the leader's participation rate for the leader-follower game as shown in Table 7 below.

For simplicity sake, the term L_2 will henceforth be referred to as leader term and the term F_2 as follower term for Case 2. The equilibrium values have a subscript of 2 to denote that they represent those for Case 2.

$$a_2 * = \left(\gamma b\left[F_2 \gamma b + L_2\right]\right)^{\left(\frac{1}{1-\gamma b}\right)} \tag{41}$$

$$t_2 * = \frac{F_2(\gamma b - 1) + L_2}{F_2 \gamma b + L_2} \tag{42}$$

$$\hat{\pi}_2 * = \left\{\left[L_2 + F_2\right]\left(\gamma b\left[F_2 \gamma b + L_2\right]\right)^{\left(\frac{\gamma b}{1-\gamma b}\right)}\right\} - \left(\gamma b\left[F_2 \gamma b + L_2\right]\right)^{\left(\frac{1}{1-\gamma b}\right)} \tag{43}$$

Table 7: Equilibrium Values for Leader-Follower Game-Case 2

5.4 Analysis of Results

The equilibrium values presented in the above table help one make the following observations. First, all three of these values are a function of the leader term, follower term, risk tolerance, and performance to investment sensitivity of current knowledge creation effort. To simplify the analysis of results, the leader term (L_2) and the follower term (F_2) are set equal (L_2=F_2). A further investigation of the equilibrium value for current knowledge creation effort (a_2*) reveals that with everything else being constant, the equilibrium value of the current knowledge creation effort (a_2*) slowly increases as its performance to investment sensitivity increases as shown in Figure 4.

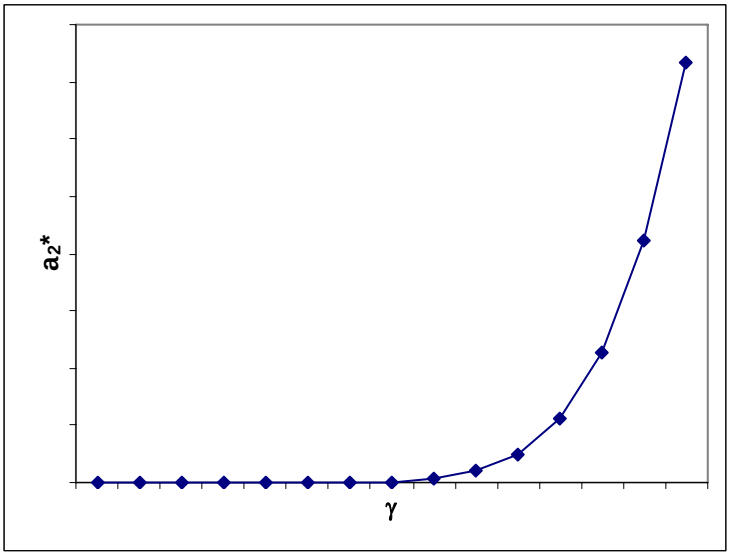

Figure 4: Equilibrium Value of Current Knowledge Creation Effort as a Function of its Performance to Investment Sensitivity

Proposition 1a: The equilibrium value of current knowledge creation effort is a concave upward function of the performance to investment sensitivity of current knowledge creation effort.[10]

A higher value for γ means that the change in the performance is more sensitive to the change in the current knowledge creation effort. Proposition 1a implies that as the sensitivity of the performance to the investment in the current knowledge creation project increases, so will the investment in the current project. That is, the greater the promise of performance, the higher the total investment in the current knowledge creation project will be.

Similarly, with an increase in b, the equilibrium values of the current knowledge creation effort increase as shown in Figure 5.

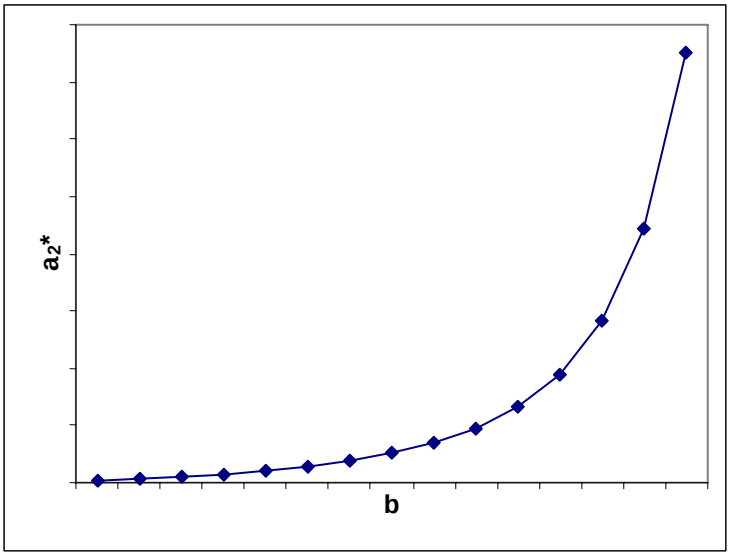

Figure 5: Equilibrium Value of Current Knowledge Creation Effort as a Function of Risk Tolerance

Proposition 1b: The equilibrium value of current knowledge creation effort is a concave upward function of the risk tolerance.

[10] Some of the propositions developed in this essay may seem circular with the assumptions made in the essay. An explanation clarifying the absence of such circularity for Essay 2 is given in Appendix F.

Proposition 1b means that the organizations that are more risk tolerant invest more in the current knowledge creation project to ensure better performance. The above Propositions 1a and 1b have implications for setting expectations for the collaboration. Informed by the propositions above, the leader organizations can set expectations of what the follower's preferred current knowledge creation investment would be.

Second, the relation between the leader's participation rate and the performance to investment sensitivity of current knowledge creation effort is similar to the above relation. That is, for higher values of the performance to investment sensitivity of current knowledge creation effort, the leader's participation rate will be higher, as shown in Figure 6.

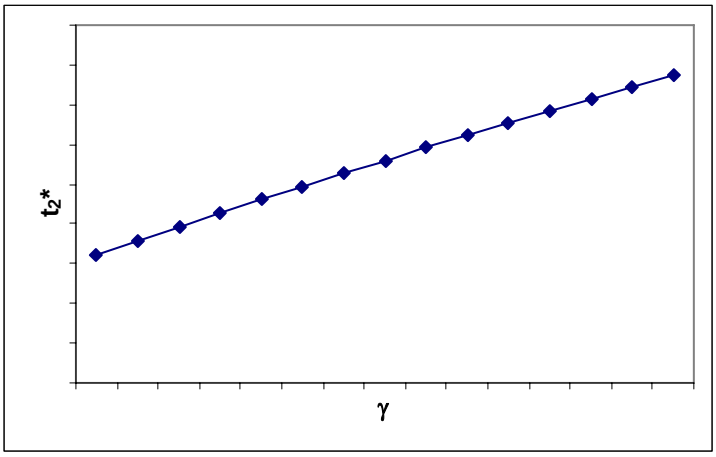

Figure 6: Equilibrium Value of Leader's Participation Rate as a Function of Performance to Investment Sensitivity of Current Knowledge Creation Effort

Proposition 2a: The leader's participation rate is an increasing function of the performance to investment sensitivity of current knowledge creation effort.

Similar to the implications for Proposition 1a, Proposition 2a implies that the leader's participation rate is a function of γ. This implies that the leader is willing to contribute more toward the project if the performance is more sensitive to the increase in investment. Hence, the follower organization would consider certain factors such as availability of substitutes as

indicators of performance to investment sensitivity, while setting expectations from the collaboration and hence determining its best response value of current knowledge creation effort. For the follower organization, a higher γ not only means that there is a higher level of current knowledge creation effort, but also, that the leader's participation rate is higher.

The leader's participation rate is a function of risk tolerance as shown in Figure 7.

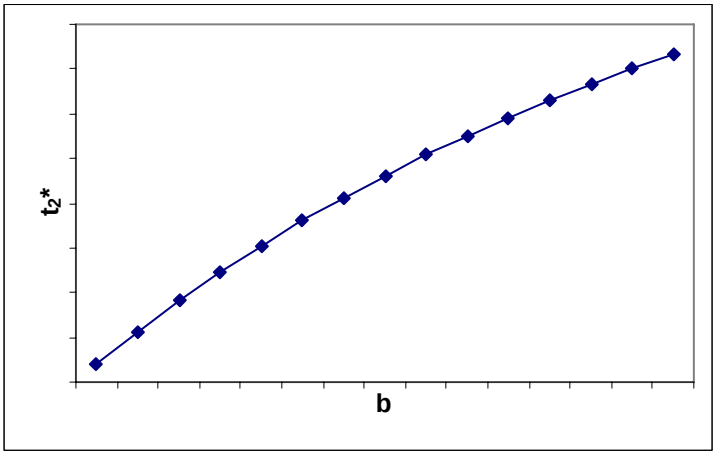

Figure 7: Equilibrium Value of Leader's Participation Rate as a Function of Risk Tolerance

Proposition 2b: The equilibrium value of the leader's participation rate is a convex upward function of risk tolerance.

Proposition 2b means that for collaborations with lower risk tolerance, the leader's participation rate will be low. That is, the leader organization participates less with a follower organization less willing to take risk than that with higher risk tolerance. In conjunction with Proposition 2a, Proposition 2b implies that for lower values of performance to investment sensitivity of current knowledge creation effort, and for lower values of a risk tolerance, lower is the leader's participation rate.

Third, an examination of the equilibrium value for t_2* reveals that the ratio $\frac{L_2}{F_2}$ has to be greater than $1-\gamma b$ for the leader to participate.

Proposition 3: The leader participates and hence the collaboration exists only when $\frac{L_2}{F_2} > 1-\gamma b$.

The above proposition means that the leader will participate only if the ratio of leader term to the follower term is greater than $1-\gamma b$. Recall that γb is between 0 and 1, and L_2 and F_2 are positive constants. Then, Proposition 3 provides a lower bound for the ratio, which is a positive fraction.

Finally, the equilibrium value of the expected system gain (π_2*) is also a function of the performance to investment sensitivity of current knowledge creation effort as shown in Figure 8.

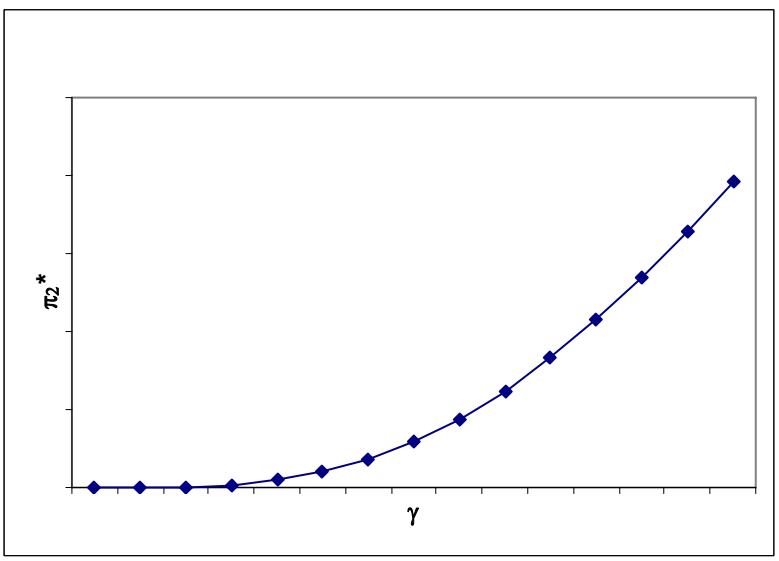

Figure 8: Equilibrium Value of Expected System Gain as a Function of Performance to Investment Sensitivity of Current Knowledge Creation Effort

Proposition 4a: The equilibrium value of the expected system gain is a concave upward function of performance to investment sensitivity of current knowledge creation effort.

The above proposition has implications for the expectations that each organization has from the results of the collaboration. This proposition informs the partnering organizations about the nature of the gains they could expect for the collaboration as a whole. Note that in leader-follower game, the players maximize their own expected gain functions and not the system gain function. Hence Proposition 4a is descriptive of how the system gain changes for several values of γ. Thus Proposition 4a serves a descriptive purpose in setting expectations, rather than serving a prescriptive purpose of aiding decision-making.

Similarly, the equilibrium value of the expected system gain is a function of risk tolerance. For lower and moderate values of risk tolerance, the expected system gain increases slowly; while for higher values, the expected system gain increases rapidly as shown in Figure 9.

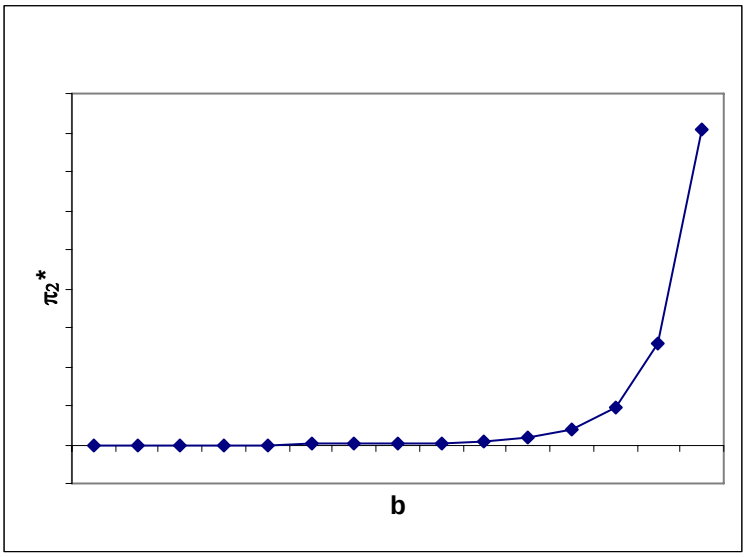

Figure 9: Equilibrium Value of Expected System Gain as a Function of Risk Tolerance

Proposition 4b: The equilibrium value of the expected system gain is a concave upward function of risk tolerance.

Propositions 4b also describes how the expected system gain is a function of risk tolerance. This relation is also descriptive of setting expectations rather than serving a prescriptive purpose of aiding decision-making.

5.5 Discussion

In this essay, I provide a framework for studying resource-sharing between two organizations engaged in collaborative knowledge creation. The collaboration is analyzed as a Stackelberg Leader-Follower game between two organizations with increasing marginal returns.

The analysis reveals that the relation between the equilibrium value of the current knowledge creation effort and performance to investment sensitivity is concave upward, as is the relation between the equilibrium value of the current knowledge creation effort and risk tolerance.

Similarly, the relation between the equilibrium value of the expected system gain and performance to investment sensitivity is concave upward, as is the relation between the equilibrium value of the expected system gain and risk tolerance.

The equilibrium value of the leader's participation rate is a function of performance to investment sensitivity and the risk tolerance. Additionally, the collaboration is possible and the leader participates only if $\frac{L_2}{F_2} > 1 - \gamma b$.

With respect to collaborations for knowledge creation, the propositions made here have implications from several vantage points, ranging from establishing expectations from the collaboration for the organizations to explaining the conditions under which collaborations exist.

Propositions 2a and 2b specify that the leader's participation rate is a function of the performance to investment sensitivity and risk tolerance. These propositions answer the research question which factors influence participation rate. Similarly, Proposition 3 specifies a condition for the collaboration to exist, which is the third research question specified in the Introduction.

The results of the analysis in Essay 2 can be used to compare potential partners by each of the collaborating organizations and thus answer the second research question. For instance, informed by Propositions 1a, 1b, 2a, 2b, 4a and 4b, the organization in the leader's position may form expectations about the amount of investments the current collaboration might require, its participation rate and the expected system gain. Specifically, if the performance to investment sensitivity is high, then the leader organization can expect a higher current knowledge creation investment. Also, with similar information, the leader organization can expect a higher system gain and a higher share in the current knowledge creation investment. Similarly, the three values - current knowledge creation investments, participation rate and expected system gain - can also be expected to be higher when the follower organization has high risk tolerance than those for a follower organization with low risk tolerance. Thus when choosing partners, the leader organization can compare the risk tolerance and performance to investment sensitivity of a portfolio of potential partners and choose the one that is expected to give the best tradeoff between investments, gains and participation rate.

The follower organization, on the other hand, can use similar information about the leader organization and choose a partner that is expected to give the best tradeoff between investments, gains and participation rate. Thus, the propositions inform practice and answer three out of the four research questions.

For researchers, this essay provides an insight into how the collaborations between organizations with increasing marginal returns can be modeled as a leader-follower game. Specifically, for organizations that are characterized by increasing marginal returns, the current model provides a way to identify a value of current knowledge creation effort that will

maximize its returns by introducing the risk tolerance parameter. It is this risk tolerance that gives a finite limit on the returns due to knowledge creation investments.

Propositions 1a and 1b complement TCE by aiding in the identification of the most preferred value of current knowledge creation investments that the follower determines. This information can be used to identify the total resource commitments that are expected to be required for the project. This can be one of the contractual details that the partnering organizations agree upon. Similarly, Propositions 2a and 2b complement TCE by providing a way to arrive at the optimal share of resources that the leader organization is willing to commit to, given specific values for the performance to investment sensitivity and risk tolerance parameters. Hence, the current essay provides a way for collaborating organizations to arrive at the micro level details of the contracts (Krishnan et al., 2001), which is one of the recognized limitations of economic theories such as TCE.

The results of this essay further complement TCE in that they provide a means for organizations to follow both cost minimization and profit maximization propositions. Propositions 1a, 1b, 4a and 4b, when used in combination can guide the collaborating organizations to arrive at a scheme that reduces transaction costs (current knowledge creation effort) and maximizes transaction value (expected system gain). This essay also aids in modeling the opportunistic behavior of each of the partners. Specifically, in the leader-follower game, both of the organizations adopt strategies that are guided by opportunism, because the goal of each organization is to maximize its individual gain. Each organization makes decisions or adopts strategies that maximize its individual gain. Recall from Section 2.1 that Williamson (2002) has noted reasons for using multiple theories to supplement TCE in explaining

phenomena in the organizational knowledge and learning domains. The current essay provides a game theoretic lens to the understanding of inter-organizational knowledge creation process.

By modeling the relationship as a leader-follower game, the current essay complements RDT by specifying the strategies that each of the partnering organizations would adopt when in a relationship where one of the potential partners is expected to have more power over the other. Recall from the Section 2.1 that the criticism of RDT (Barringer et al., 2000) is that although it proposes inter-organizational relationships as a viable means to gain access to external resources, it does not inform one about the details of the strategies that organizations need to adopt in inter-organizational relationships. The current essay thus complements RDT by providing the expected strategies of both players in the relationship and setting expectations for the collaboration.

Modeling the payoff functions for the individual organizations, and for the system gain as a whole, is a step in the direction that has been recognized as important in the organizational learning theory literature. The current essay contributes to learning theory by modeling the joint payoff for both organizations (expected system gain) in addition to focusing on payoffs for individual organizations (individual expected gains for leader and follower organizations) in the collaborations, which has been recognized as an important step toward enhancing the theory (Larsson et al., 1998).

One of the extensions of Essay 2 would be to consider the case in which the leader organization is characterized by decreasing marginal returns and the follower organization is characterized by increasing marginal returns (Case 3 of Section 3.3). This case is discussed in the next sub-section.

Chapter 6 ESSAY 3: COLLABORATIVE KNOWLEDGE CREATION AS A LEADER-FOLLOWER GAME- CASE OF LEADER WITH DECREASING MARGINAL RETURNS AND FOLLOWER WITH INCREASING MARGINAL RETURNS

6.1 Introduction to Essay 3

In the third essay, Case 3 presented in Section 3.3 is analyzed and discussed. This is a mixed case where the leader firm is characterized by decreasing marginal returns with respect to knowledge creation investments, and the follower organization is characterized by increasing marginal returns with respect to knowledge creation investments. Thus, the leader organization is typically an incumbent firm, which engages in incremental innovation. On the other hand, the follower organization is typically an entrepreneurial firm that engages in radical innovation. Research partnerships between mature, large pharmaceutical companies and new, small biotechnology firms, which have recently seen a surge (Audretsch & Feldman, 2003), provide instances of such collaborations. The two stages of the game are similar to those specified in Chapter 5. The equilibrium values of the game are computed by backward induction. Here it is assumed that the leader organization is risk neutral and the follower organization is risk averse.

6.2 Collaboration between Organizations with Dissimilar Marginal Return Functions

GalxoSmithKline (GSK), one of the leading research-based pharmaceutical and healthcare companies, entered into research partnership with Biosynexus, a private biotech-pharmaceutical company (Anonymous, 2002). The research partnership in focus was formed to co-develop BSYK-A110 and to facilitate the development of a vaccine for new-borns and adults. This collaboration was intended to engage in product development using Biosynexus' expertise in the development of vaccines for prevention and treatment of hospital acquired infections and GSK's expertise in developing and marketing biologicals and vaccines. For the purposes of this essay, GSK is considered the leader organization and Biosynexus is considered to be the follower.

6.3 Gain Functions and Equilibrium Values

The performance function *P* for the leader organization is specified as:

$$P_L(a, c_L) = \alpha - a^{-\gamma_L} c_L^{-\phi_L} + \varepsilon$$

where α is the performance asymptote, *a* is the current knowledge creation effort, γ_L is the sensitivity of leader's performance to current knowledge investment, c_L is the leader's commercialization capacity, ϕ_L is the sensitivity of the performance to leader's commercialization capacity, and ε is the error term.

The leader's expected performance function is specified as:

$$\hat{P}_L(a, c_L) = \alpha - a^{-\gamma_L} c_L^{-\phi_L}$$

The performance function *P* for the follower organization is specified as:

$$P_F(a, c_F) = a^{\gamma_F} c_F^{\phi_F} + \varepsilon$$

where *a* is the current knowledge creation effort, γ_F is the sensitivity of follower's performance to current knowledge investment, c_F is the follower's commercialization capacity, ϕ_F is the sensitivity of the performance to follower's commercialization capacity and ε is the error term.

The expected performance function is specified as:

$$\hat{P}_F(a, c_F) = a^{\gamma_F} c_F^{\phi_F}$$

The expected gain function for the leader organization is as follows

$$\hat{\pi}_L = \rho_L[\alpha - a^{-\gamma_L} c_L^{-\phi_L}] - at$$

Let $L_3 = \rho_L c_L^{-\phi_L}$. Then,

$$\hat{\pi}_L = \rho_L \alpha - L_3 a^{-\gamma_L} - at \qquad (44)$$

The expected gain function for the follower organization is as follows:

$$\hat{\pi}_F = \rho_F{}^b [a^\gamma c_F{}^{\phi_F}]^b - a(1-t)$$

Let $F_3 = \left(\rho_F c_F{}^{\phi_F}\right)^b$. Then,

$$\hat{\pi}_F = F_3 a^{\gamma_F b} - a(1-t) \tag{45}$$

where b is the risk tolerance factor as described in Section 4.3. However, the leader organization is assumed to be risk neutral, and the follower organization is assumed to be risk averse because the leader's investment in the current knowledge creation project may be a much lower proportion of its assets, compared to that of the follower.

The expected system gain:

$$\hat{\pi} = \hat{\pi}_L + \hat{\pi}_F = \rho_L \alpha + F_3 a^{\gamma_F b} - L_3 a^{-\gamma_L} - a\,. \tag{46}$$

Note that the discussion about universality of assumptions presented in Section 4.3 still holds good for this essay.

By setting the first partial derivative of $\hat{\pi}_F$ with respect to *a*, to zero, one can determine the follower's best response value of the current knowledge creation effort that maximizes the follower's expected gain $\hat{\pi}_F$ as follows:

$$\frac{\partial \hat{\pi}_F}{\partial a} = F_3 \gamma_F b a^{\gamma_F b - 1} + (1-t) = 0 \tag{47}$$

Let $\gamma_F b = k$

The best response value of the current knowledge creation effort as a function of the leader's participation rate (*t*) is as follows:

$$a^* = \left(\frac{1-t}{F_3 k}\right)^{\frac{1}{k-1}} \tag{48}$$

Given the follower's best response value of a^*, the leader's best response value for its participation rate (t) is computed as one that maximizes its expected gain $\hat{\pi}_L$. In order to arrive at the value of t that maximizes $\hat{\pi}_L$, the leader's expected gain function is maximized with respect to t subject to the constraint in Equation (48).

$$\underset{t}{Max}\,\hat{\pi}_L = \rho_L \alpha - L_3 a^{*-\gamma_L}\, c_F^{\;-\phi_L} - a^* t \tag{49}$$

subject to the constraint $0 < t < 1$ where a^* is as expressed in Equation (48).

Substituting the value for a^*, as in Equation (48) in Equation (49), gives the optimization problem for the leader organization as:

$$\frac{\partial \hat{\pi}_L}{\partial t} = \frac{\partial\left(\rho_L \alpha - L_3\left(\frac{1-t}{F_3 k}\right)^{\frac{-\gamma_L}{k-1}} - \left(\frac{1-t}{F_3 k}\right)^{\frac{1}{k-1}} t\right)}{\partial t} = 0 \tag{50}$$

subject to $0 < t < 1$. By setting the partial derivative of $\hat{\pi}_L$ in Equation (50), with respect to t, equal to zero, and solving for t, one gets the general equilibrium condition for the leader's participation rate (t) given by:

$$(1-t^*)^{-1}\left[1 - Z(1-t^*)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] = \gamma_F b \tag{51}$$

where $Z = L_3 \gamma_L \left(F_3 \gamma_F b\right)^{\frac{-(\gamma_L+1)}{1-\gamma_F b}}$.

Equation (51) does not result in a closed form expression for t. However, it gives a lower bound for the equilibrium value for t, i.e. t_3^* as:

$$t_3^* > 1 - \frac{F_3 \gamma_F b}{\left(L_3 \gamma_L\right)^{\frac{1-\gamma_F b}{1+\gamma_L}}} \tag{52}$$

For the inequality (52) to hold true, $\left[1 - Z(1-t^*)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] > 0$. If this inequality is violated, $\left[1 - Z(1-t^*)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] < 0$, which implies that $\gamma_F b$ is negative. $\gamma_F b$ is negative only when γ_F is negative. This, in turn, means that the follower exhibits negative performance with increase in investment *a*. In such cases, the leader is motivated not to participate. From Equation (51) we can find the equilibrium value of $t_3^*=t_3$ such that $\left(1-t_3\right)^{-1}\left[1 - Z(1-t_3)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] = \gamma_F b$.

Substituting this value of t_3^* gives the equilibrium values for the current knowledge creation effort and the expected system gain for the leader-follower game as shown in Table 8 below.

$$a_3^* = \left(\frac{1-t_3}{F_3 \gamma_F b}\right)^{\frac{1}{\gamma_F b - 1}} \tag{53}$$

$$t_3^* = t_3 \text{ such that } \left(1-t_3\right)^{-1}\left[1 - Z(1-t_3)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] = \gamma_F b \tag{54}$$

$$\hat{\pi}_3^* = \rho_L \alpha + F_3\left(\frac{1-t_3}{F_3 \gamma_F b}\right)^{\frac{\gamma_F b}{\gamma_F b - 1}} - L_3\left(\frac{1-t_3}{F_3 \gamma_F b}\right)^{\frac{-\gamma_L}{\gamma_F b - 1}} - \left(\frac{1-t_3}{F_3 \gamma_F b}\right)^{\frac{1}{\gamma_F b - 1}} \tag{55}$$

Table 8: Equilibrium Values for Leader-Follower Game- Case 3

6.4 Analysis of Results

An analysis of the previously-stated results leads to the observations that the equilibrium value for the leader's participation rate cannot be expressed in a closed form. However, any value of t that satisfies the condition $(1-t_3)^{-1}\left[1-Z(1-t_3)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right]=\gamma_F b$ can provide an equilibrium value. The values of a_3*, t_3* and π_3* are presented here as functions of γ_F for varying values of γ_L.

The first observation one can make is that a_3* is an increasing function of γ_F as shown in Figure 10.

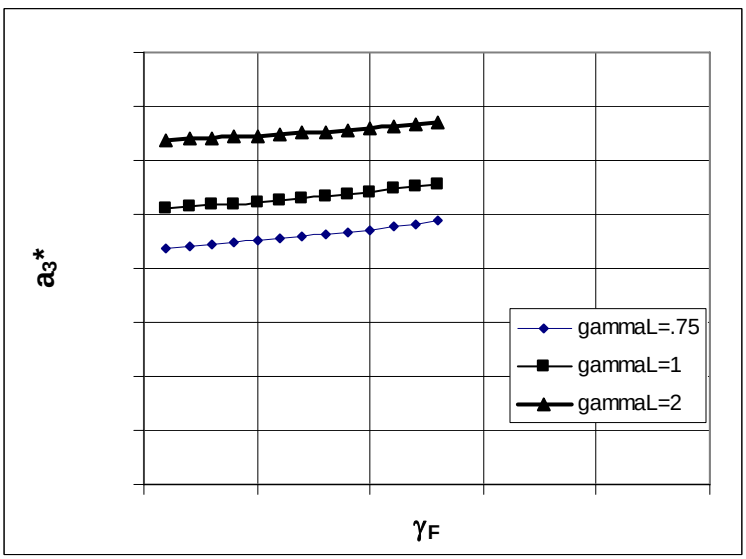

Figure 10: Equilibrium Value of Current Knowledge Creation Effort as a Function of Follower's Performance to Investment Sensitivity

Proposition 1: The current knowledge creation effort is an increasing function of the follower's performance to investment sensitivity across the values of the leader's performance to investment sensitivity.[11]

[11] Some of the propositions developed in this essay may seem circular with the assumptions made in the essay. An explanation clarifying the absence of such circularity for Essay 3 is given in Appendix H.

The proposition stated above implies that the collaborating organizations can use the follower's performance to investment sensitivity of current knowledge creation effort to be informed about the investment to be made in the current knowledge creation project. That is, for higher promise of performance for the follower, the collaboration invests more in the current knowledge creation. This implies that as the performance is more sensitive to the current knowledge creation effort, greater is the investment.

Second, the leader's participation rate is higher for lower values of the follower's performance to investment sensitivity of current knowledge creation efforts. This means that as the follower's performance is more sensitive to the total investment in current knowledge creation effort, the leader participates less, as shown in Figure 11.

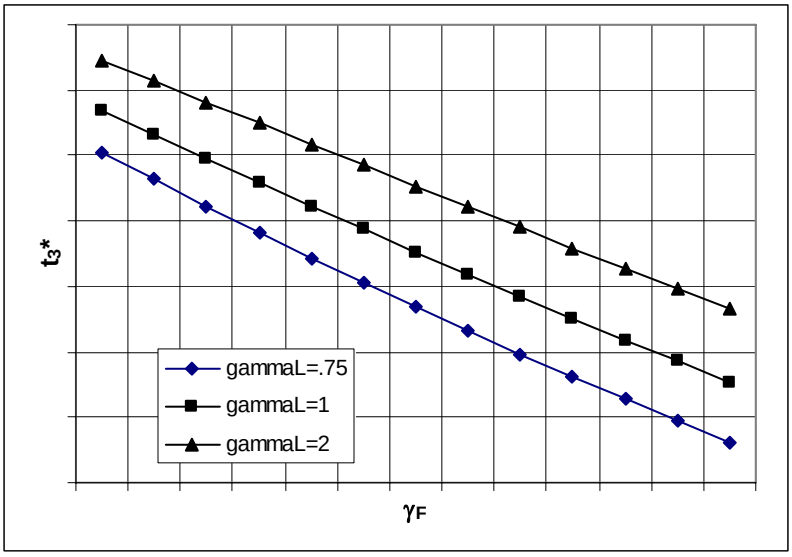

Figure 11: Equilibrium Value of the Leader's Participation Rate as a Function of Follower's Performance to Investment Sensitivity

Proposition 2: The leader's participation rate is lower for higher values of the follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity.

Informed by the above proposition, the leader organization can determine its participation rate as a function of the follower's performance to investment sensitivity. For higher values of the follower organization's performance to investment sensitivity, the leader will participate less in the collaboration. The follower organization can also be informed, by the above proposition, to estimate what the leader's participation rate will be. Thus, Proposition 2 aids collaborating organizations in making resource-sharing decisions.

Third, the computation of t_3* gives a lower bound for the leader's participation rate as $t_3 * > 1 - \frac{F_3 \gamma_F b}{(L_3 \gamma_L)^{\frac{1-\gamma_F b}{1+\gamma_L}}}$. That is, when the equilibrium value for the leader's participation rate is between 1 and $1 - \frac{F_3 \gamma_F b}{(L_3 \gamma_L)^{\frac{1-\gamma_F b}{1+\gamma_L}}}$ then the collaboration exists.

Proposition 3: The collaboration exists only when the solution to the equation $(1-t*)^{-1}\left[1 - Z(1-t*)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right] = \gamma_F b$ is between 1 and $1 - \frac{F_3 \gamma_F b}{(L_3 \gamma_L)^{\frac{1-\gamma_F b}{1+\gamma_L}}}$.

The leader's participation rate below this lower bound is possible only when the follower exhibits negative returns for increase in investment. In such cases, the leader is not motivated to participate, and hence the collaboration does not exist. This lower bound for the leader's participation rate equips the follower with a decision aid during the partner selection stage of the alliance formation.

Fourth, the equilibrium value of the leader's expected gain is a monotonically increasing function of the follower's performance to investment sensitivity as shown in Figure 12.

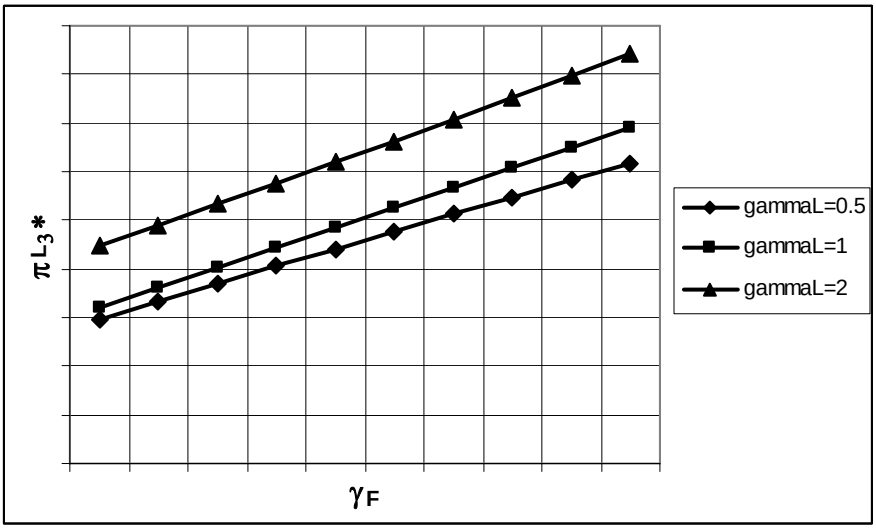

Figure 12: Equilibrium Value of Leader's Expected Gain as a Function of Follower's Performance to Investment Sensitivity

Additionally, the equilibrium value of the follower's expected gain is a monotonically decreasing function of the follower's performance to investment sensitivity as shown in Figure 13.

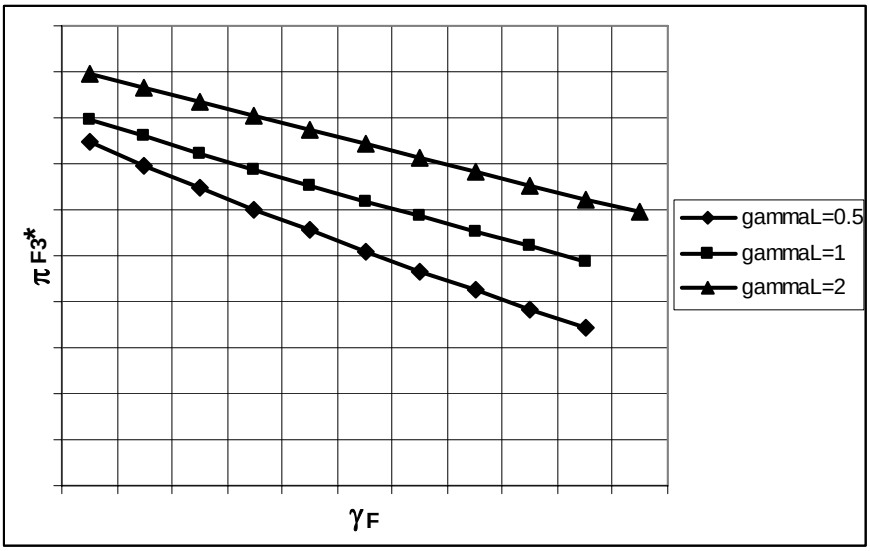

Figure 13: Equilibrium Value of Follower's Expected Gain as a Function of Follower's Performance to Investment Sensitivity

Proposition 4a: The equilibrium value of the leader's expected gain monotonically increases as a function of the follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity.

Proposition 4b: The equilibrium value of the follower's expected gain monotonically decreases as a function of the follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity.

This means that for higher values of the follower's performance to investment sensitivity of current knowledge creation effort, the leader's expected gain is higher, and the follower's expected gain is lower. The collaborating organizations can be informed by the above propositions in gauging what to anticipate in terms of their expected gains. Recall from Proposition 1 that for higher values of γ_F, the value the current knowledge creation effort increases. Additionally, recall from Proposition 2 that for higher values of γ_F, the values of the leader's participation rate decreases. Hence, the collaborating organization can be informed by Propositions 1, 2, 4a and 4b while making decisions about how much investment they should expend in order to get the desired expected gains. Specifically, the collaboration might prove more advantageous to the leader than the follower because as the performance becomes more sensitive to the follower's investment, the leader organization participates less and has a higher expected gain.

Finally, an examination of the relation between the equilibrium value of the expected system gain and the follower's performance to investment sensitivity reveals that for lower values of the leader's performance to investment sensitivity, the relation is non-monotonic. That is, for lower values of γ_L, π_3* is a non-monotonic function of γ_F. This leads to an interesting observation that the system gain is lower for moderate values of γ_F as shown in Figure 14.

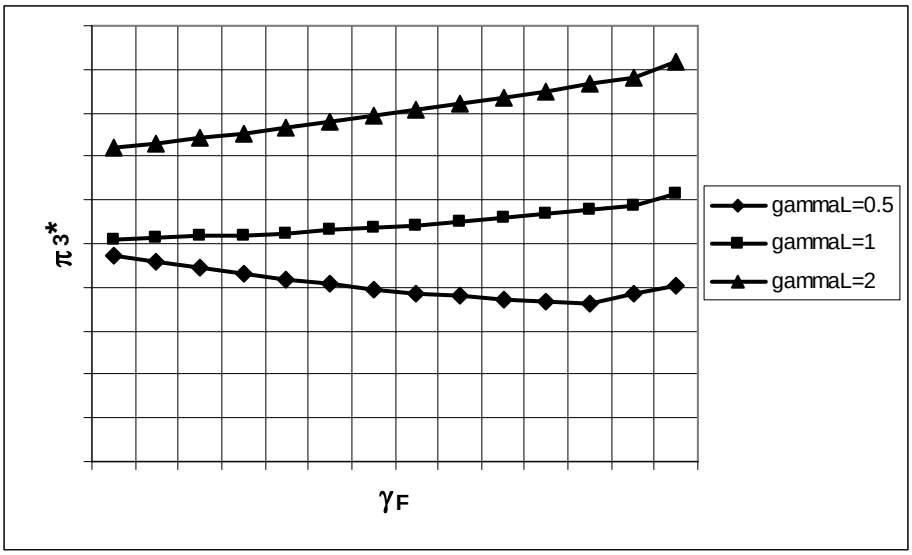

Figure 14: Equilibrium Value of Expected System Gain as a Function of Follower's Performance to Investment Sensitivity for Several Values of Leader's Performance to Investment Sensitivity.

Proposition 5a: The relation between the equilibrium value of expected system gain and the follower's performance to investment sensitivity is non-monotonic for lower values of the leader's performance to investment sensitivity.

Proposition 5b: The equilibrium value of expected system gain monotonically increases with the follower's performance to investment sensitivity for higher values of the leader's performance to investment sensitivity.

Note how the equilibrium value of expected system gain is a monotonically increasing function of the follower's performance to investment sensitivity for the leader's performance to investment sensitivity values of 1 and 2. This means that when the leader's performance is less sensitive to the investment, as the follower's sensitivity increases, the expected system gain first decreases, then increases. This is an interesting observation (Davis, 1971) because it has implications for identifying the conditions under which the collaboration is beneficial to the follower and the leader. For instance, when the follower's performance is less sensitive to investment, the follower might be at more advantageous position than the leader since the

follower's expected gain is higher than the leader's expected gain. However, as the follower's sensitivity increases, the follower's expected gain decreases and the leader's gain increases. Hence, the follower is in an advantageous position when both its sensitivity and the leader's sensitivity are low. This has implications for the follower organization in terms of deciding on a preferred partner.

6.5 Discussion

In the third essay, I provide a framework for studying resource-sharing between two organizations engaged in collaborative knowledge creation. The collaboration is modeled as a Stackelberg Leader-Follower game between two organizations where the leader organization is characterized by decreasing marginal returns and the follower organization is characterized by increasing marginal returns. The equilibrium values for the current knowledge creation effort, the leader's participation rate, and the total system gain are analyzed.

The computation of Nash equilibrium for the game reveals that the equilibrium value of the leader's participation rate cannot be expressed in a closed form. The equilibrium values presented here are contingent upon the condition that $(1-t_3)^{-1}\left[1-Z(1-t_3)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right]=\gamma_F b$. An examination of the relation between the follower's performance to investment sensitivity of current knowledge creation effort and the equilibrium values, reveals that the current knowledge creation effort is an increasing function of the follower's performance to investment sensitivity; while the leader's participation rate is a decreasing function of the follower's performance to investment sensitivity, across several values of leader's performance to investment sensitivity. However, the expected system gain is an increasing function of the follower's performance to investment sensitivity for higher values of leader's performance to investment sensitivity. It first decreases, and then increases, for higher values of leader's performance to investment sensitivity.

With respect to collaborations for knowledge creation, the propositions made here have implications from several vantage points, ranging from establishing the condition under which the leader is motivated to collaborate and hence for explaining the conditions under which

collaborations exist to comparing potential partners. For instance, informed by Proposition 3, the leader and follower organizations can identify one condition under which the collaboration is possible. The lower bound for the leader's participation rate reveals the condition for the leader to be motivated to form the collaboration, answering the third research question about the conditions for the existence of the collaboration. Additionally, the lower bound for the leader's participation rate informs the leader about the minimum share of its investment, if it were to reap the benefits of collaboration. Further, Propositions 4a and 4b inform the organizations that the expected system gain is a non-monotonic function of the follower's sensitivity for low values of the leader's sensitivity. This finding answers the second research question about the conditions under which some potential partners become more attractive than others. For the follower organization, a potential partner with high performance to investment sensitivity becomes more attractive than one with the low value of the same parameter.

Proposition 2 specifies that the leader's participation rate depends on the follower's performance to investment sensitivity, and it decreases as a function of the parameter. This answers the first research question as to the factors that determine the leader's participation rate and how they influence the leader's participation rate. Thus, while evaluating potential partners, the leader organization might consider partnering with an organization with high performance to investment sensitivity, since it can get away with participating less. On the other hand, a higher performance to investment sensitivity means that the current knowledge creation effort and the system gain are higher. Hence, by choosing a partner with high values of performance to investment sensitivity parameter, the leader organization can ensure high levels of current knowledge creation investment, higher system gain (provided its own performance to

investment sensitivity is higher) and a lower participation rate. Thus the current essay has implications for practice and answers three of four research questions.

The above observations also have important implications for research. This essay provides an insight into how the collaborations between organizations with different marginal return functions - a case that is widely observed in the biotechnology–pharmaceutical alliances – can be modeled as leader-follower games and how they compare to the collaborations between organizations characterized by decreasing marginal returns as well as collaborations of firms characterized by increasing marginal returns. Furthermore, the non-monotonic behavior of the expected system gain for low values of the leader's performance to investment sensitivity poses a fertile line of future investigation.

The contributions of the current essay to specific theories are as follows. Recall from Section 2.1 that the two main ways in which TCE falls short in explaining collaborations are with regard to arriving at the micro level details of contracts (Krishnan et al., 2001) and with regard to ignoring the value maximization proposition, which is important for knowledge creation (Dyer, 1997) and the general conduct of business (Coase, 1988). Proposition 1 complements TCE by aiding in the identification of the most preferred value of the current knowledge creation investments that the follower determines. This information can be used to identify the total resource commitments that are expected to be required for the project. This is one of the details of the contract that needs to be agreed upon by the collaborating organizations and included in the contract. Similarly, Proposition 2 complements TCE by providing a way to arrive at the optimal share of resources that the leader organization is willing to commit to, given specific values for the follower's performance to investment sensitivity. This is the other detail that is included during designing the contract.

Additionally, the interesting observation about the relationship between expected system gain and the follower's performance to investment sensitivity, for lower levels of leader's performance to investment sensitivity, highlight another important way in which the current essay complements TCE. This finding reiterates the importance of focus on value maximization (Dyer, 1997).

Recall from Section 2.1 that the main way in which RDT falls short in explaining inter-organizational collaborations is that it does not explain the specific strategies that firms devise while engaging in inter-organizational collaborations, in order to gain access to resources available within the environment (Barringer et al., 2000). Such strategies could include partner selection strategies. Specifically, in relation to deciding which of the potential partners is suitable for collaboration, when informed by the current essay, the leader organization can choose a partner with greater performance to investment sensitivity, provided its own performance to investment sensitivity is high. Furthermore, the follower organization, based on its own performance to investment sensitivity, and informed by the Propositions 2, 4a and 4b, can choose leader partners that will provide a good mix of participation rate and expected system gain. Note that the system gain is an additive of the individual expected gains.

With respect to organizational learning theory, the current essay contributes by modeling the payoff functions for the individual organizations and for the system. This is recognized as an important learning outcome for collaborations that warrants further study (Larsson et al., 1998). The current essay contributes to learning theory by modeling the joint payoff for both of the organizations (expected system gain) in addition to focusing on payoffs for individual organizations (individual expected gains for leader and follower organizations) in the collaborations.

Chapter 7 CROSS-ESSAY ANALYSIS OF RESULTS

7.1 Cross-essay Comparisons and Contrasts

In this section, I compare and contrast the results of the analyses presented for Essay 1, Essay 2 and Essay 3. Specific comparisons of the equilibrium values are not permissible given that the parameters used in the performance functions in the three essays are markedly different. However, some general comparisons and contrasts are attempted.

Recollect that Essay 1 consists of the relationship between two firms characterized by decreasing marginal returns with respect to knowledge creation investments, modeled as a cooperative game via the partnership game. In Essay 2, the relationship between both of the firms characterized by increasing marginal returns, is modeled as a non-cooperative game via the leader-follower game. Essay 3 also models the relationship as a leader-follower game, but the leader organization is characterized by decreasing marginal returns, and the follower organization is characterized by increasing marginal returns. Since the characteristics of the organizations, in terms of their marginal return functions, and the type of game used to model the relationship – partnership or leader-follower- are markedly different across the three essays, the comparisons and contrasts are discussed for Essays 2 and 3. Additionally, the results of the background work discussed in Chapter 3 are used to compare and contrast with the results of Essay 1 and Essay 3.

Essay 2 and Essay 3 are amenable for comparison and contrasts because they have commonalities in terms of the non-cooperative relationship. Essay 1 is compared and contrasted with the background work because, although the relationships were modeled as different games (partnership in Essay 1 and leader-follower in background work), the collaborating firms are characterized by similar marginal return functions. Both organizations in these relationships are characterized by decreasing marginal returns. Essay 3 is then compared with the background

work because the relationship is modeled as a leader-follower model in both of these cases, and the leader organization is characterized by decreasing marginal return function.

The similarity between Essay 2 and Essay 3 is that the equilibrium value of current knowledge creation effort increases with an increase in the performance to investment sensitivity. That is, with promise of better performance, the amount of investment that the collaboration, as a whole, makes toward the current knowledge creation project increases. This similarity has implications for collaborating organizations because the organizations can be assured that under different types of relationships, the main factor that determines the level of current knowledge creation effort is the performance to investment sensitivity rather than the behavior of the partner.

Contrasting Essays 2 and 3, the leader's participation rate increases as the performance to investment sensitivity increases in Essay 2, while in Essay 3, it decreases as the follower's performance to investment sensitivity increases. This contrast has implications for partner selection in the following ways. An organization in the follower's position is better off collaborating with an organization in the leader's position, when the leader's performance function is characterized by increasing marginal returns, with respect to knowledge creation investments when the performance to investment sensitivity is high. Conversely, the follower organization is better off collaborating with a leader organization whose performance function is characterized by decreasing marginal returns with respect to knowledge creation investments, when the performance to investment sensitivity is low.

Another contrast between Essay 2 and Essay 3 is that both essays have a condition under which the collaboration exists. However, the difference between these conditions is that for Essay 2, the condition is with respect to the ratio of the leader's revenue term to the follower's

revenue term, and for Essay 3 the condition for the collaboration gives the minimal value of the leader's participation rate beyond which the leader's participation rate is zero. For the follower organization, this implies that irrespective of the leader organization's marginal return function, there are conditions for the existence of the collaboration. Further, these conditions highlight the specific parameters that the follower organization should consider while attempting to choose between potential partners.

The last contrast between Essay 2 and Essay 3 is that the relationship between expected system gain and the follower's performance to investment sensitivity in Essay 3 exhibits different behavior for different values of the leader's performance to investment sensitivity. For instance, for low values of the leader's performance to investment sensitivity, the above relationship is non-monotonic. On the other hand, in Essay 2, the relationship between the expected system gain and the performance to investment sensitivity is a monotonically increasing one. This contrast implies that when the follower organization chooses a partner, it needs to pay attention to the performance to investment sensitivity of the leader organization. The follower organization is better off choosing a partner with a higher value, especially when the leader organization is characterized by decreasing marginal returns.

The similarity between the background work and Essay 1 is that the relations between the parameters in the equilibrium values remain the same, with or without prior knowledge. For instance, the relationship between the leader's participation rate and the gain to performance ratios remains the same across scenarios in the background work, as does the relationship between participation rate, the risk tolerance, and bargaining power parameters. This implies that no matter how the relationship is modeled, the organizations having made some prior

investments in knowledge creation activities does not influence the factors that determine the participation rate.

Contrasting Essay 1 with the background work, one can infer that while the leader's participation rate is a function of the leader's and follower's gain to performance ratio in the background work, it is a function of risk tolerance and bargaining power in Essay 1. The implication of this observation is that when the goal of the collaboration is to maximize the system gain, the organizations need to consider factors that are external to the model, such as risk tolerance and bargaining power, while making the resource-sharing decisions. Thus, the goal of the collaboration, as the relationship is modeled, plays an important part in determining the factors that influence the resource-sharing decisions.

A comparison and contrast of Essay 3 with the background work leads to the following observations. The first similarity is that in both cases there are specific conditions for the existence of the collaborations. Specifically, the conditions for the leader's participation rate become conditions under which the collaborations exist. For the leader organization, this similarity implies that, irrespective of the nature of the follower organization's marginal return function, the leader organization can still identify the conditions of its participation rate for the collaboration to exist.

The contrast between the background work and Essay 3 is that the leader's participation rate is a function of the follower's performance to investment sensitivity in Essay 3; whereas, it is a function of the leader's and follower's gain to performance ratios in the background work. That is, when the firms in the collaboration have dissimilar marginal return functions, the leader's participation rate depends on the follower-specific parameter; whereas, when the firms in the collaboration have similar marginal return functions, the leader's participation rate

depends on the parameters specific to both the leader and the follower. Additionally, this contrast also highlights that when the firms have similar marginal return functions, the leader's participation rate depends on the gain to performance ratios; while in the other case, it depends on how sensitive the performance is to the investment. This implies that in the case of similar marginal return functions, the leader focuses more on the firms' relative ability to appropriate knowledge while deciding on the participation rate. On the other hand, in case of dissimilar return functions, the leader focuses on the way the investments transform into performance, while deciding on the participation rate. This, in turn, educates the leader organization to align priorities depending on the potential follower organization's marginal return functions.

7.2 A Note on the Generalizability of Results

In this sub-section, I address the issue of generalizability of the results of this thesis to other contexts. In doing so, I rely on the generalizability framework provided by Lee and Baskerville (2003) to discuss the applicability of the results of the thesis to other settings. Specifically, two of the four types of generalizations presented by Lee and Baskerville (2003) take relevance with respect to this thesis- theory to empirical (TE) generalizations and theory to theory (TT) generalizations. For instance, they identify the TE generalization as the extension of the theoretical concepts to contexts other than the one in which the theory has been developed and tested. Given that the essays in this thesis focus on theory development and not on testing the theory, the generalizability of the results presented in this dissertation to other empirical settings is unclear at this point. In this regard, the constraints within which the results of these essays can be applied to other contexts can be determined only after the conduct of a thorough empirical study that would ultimately refine and test the theoretical claims made in this thesis.

However, the results of the essays discussed in the current dissertation complement other theories that explain the formation and popularity of alliances and hence contribute to the synthesis of alliance literature which Lee and Baskerville (2003) qualify as a TT generalization. For instance, the results of this work complement TCE and RDT by providing a way of arriving at the details of the contracts and by providing a guide to formulate strategies for the several stages of collaboration. Thus, these results contribute toward synthesizing the alliance literature by filling the gap left behind by a few theories that are discussed here and explaining the dynamics that take place within alliances.

On the other hand, while the results of the thesis do contribute toward filling gaps in the alliance literature, one still needs to exercise caution while generalizing the findings across

different types of alliances. For instance, in their review of inter-organizational relationships literature, Barringer and Harrison (2000) identified six types of inter-organizational relationships: joint ventures; networks (bound by social, rather than legal contracts); consortia; alliances; trade associations; and interlocking directorates. Out of these six types of inter-organizational relationships, the results of the current thesis are relevant to joint ventures and alliances, only when the relationship is between a dyad of firms. Also, as mentioned in Section 4.3, the current results are only applicable when the focus of the collaboration is joint knowledge creation. When expanding the results to other collaborations, where the primary focus is not knowledge creation, it is essential that the current model be expanded to include the characteristics specific to the goal of the collaboration. Additionally, as explained in Section 3.1, when there is sufficient reason to believe that the new context is characterized by irrationality, incomplete or imperfect information, or a combination of all, the results of this study cannot be applied without altering the mathematical models used in this thesis.

Chapter 8 CONCLUSION

8.1 Summary

The current research analyzes the resource-sharing decision-making process in collaborative knowledge creation from a game theoretic perspective. Specifically, two games are discussed - the partnership game and the leader-follower game. Under the partnership game, the marginal return curve with respect to knowledge creation investment is specified as decreasing for both of the firms; and under the leader-follower game, two cases are modeled in Essays 2 and 3. Essay 2 is modeled with both of the organizations characterized by increasing marginal returns with respect to knowledge creation investment. In Essay 3, the collaboration is modeled as a leader-follower game, with leader firm being characterized by decreasing marginal returns with respect to knowledge creation investment, and the follower firm being characterized by increasing marginal returns with respect to knowledge creation investment. The Nash equilibrium values were derived for the partnership game and for both of the cases under the leader-follower game. These equilibrium values were further analyzed to have implications for several stages of collaboration, ranging from partner selection to continuance of the collaboration.

The observations drawn from the results of the partnership game in Chapter 4 have important implications for practice and research. In practice, organizations can be informed that having some prior investment in knowledge creation, either by means of experience or prior efforts, is better because of cost, infrastructure, negative knowledge, development speed advantage, etc., (Cohen et al., 1990) because such prior efforts make organizations more attractive potential partners. This extends the current understanding that prior experience leads to greater absorptive capacity. As organizations explore ways to collaborate, they would be better off choosing partners who have made some investments toward knowledge creation. This

has implications for partner selection, which was one of the research questions posed in the Introduction.

Organizations can use information on potential partners' demonstrated risk tolerance as an indicator of their participation rate in the current endeavor. Similarly, organizations can gauge their potential partners' bargaining power and anticipate the preferred participation rate of their partners. Using this information on relative risk tolerance and relative bargaining powers, organizations can create a portfolio of potential partners and anticipate their moves in partnership games. Thus the model presented here provides guidelines for decision makers about investment and partner selection for knowledge creation, which is the essence of the second research question.

The research provides a foundation for exploring the dynamics of collaborative relationships, especially when the collaboration results in new product development or product and process improvements, as opposed to licensing, marketing or distribution collaborations. It focuses attention on factors that are not included in the response function (risk tolerance and bargaining power) that influence an organization's resource commitment in collaboration. This answers the first research question about the factors that might have an influence on the participation rate. In Essay 1, such factors are identified as risk tolerance and bargaining power.

Essay 2 models the collaborative relationship as a leader-follower game with both of the collaborating firms being characterized by increasing marginal returns with respect to knowledge creation investment. This essay draws attention to the conditions under which the leader organization participates in the collaboration. The results show that the equilibrium values of the current knowledge creation effort, leader's participation rate, and the system gain are functions of the follower's performance to investment sensitivity of current knowledge creation effort and

risk tolerance. Specifically, the equilibrium values of the current knowledge creation effort and system gain increase monotonically for higher values of the follower's performance to investment sensitivity and risk tolerance. Similarly, the values for the participation increase as a function of the follower's performance to investment sensitivity and risk tolerance. The results inform the potential partners in setting expectations from the collaboration. In particular, the equilibrium condition concerning the ratio of the leader term to the follower term ($\frac{L_2}{F_2}$) specifies the condition for existence of the collaboration. Such conditions discussed in the analysis of case 2 answer the research question about the conditions for the collaborations to exist and subsequently for the determination of the leader's participation rate.

Essay 3 is concerned with collaborations where the leader organization is characterized by decreasing marginal returns with respect to knowledge creation investment; and the follower organization is characterized by increasing marginal returns with respect to knowledge creation investment. The role of the follower's performance to investment sensitivity of current knowledge creation efforts on all the key equilibrium values was observed. This analysis revealed that the current knowledge creation effort increases as a function of follower's performance to investment sensitivity across the several values of leader's performance to investment sensitivity (γ_L). The leader's participation rate decreases as a function of the follower's performance to investment sensitivity over several values of leader's performance to investment sensitivity (γ_L). The leader's expected gain increases monotonically as a function of the follower's performance to investment sensitivity and the follower's expected gain decreases monotonically as a function of the follower's performance to investment sensitivity.

The cross essay analysis revealed that an organization in the follower position is better off collaborating with an organization with increasing marginal returns than that with decreasing

marginal returns under conditions of high risk tolerance. This result makes an initial attempt at answering the research question about the preference of marginal return functions in choosing partners.

8.2 Contributions to Literature

This work enhances the current understanding of the organization science, information systems, alliance, and decision analysis literature streams. First, this study enhances the knowledge management and organizational learning literature by addressing knowledge creation. Knowledge management literature recognizes that there have been more studies on knowledge transfer and retention than those that address knowledge creation (Argote, 1999; Argote, McEvily, & Reagans, 2003a). For instance, Argote (1999) noted that,

> *"We know relatively more about knowledge retention and transfer than we know about knowledge creation in organizations." pp. 203.*

Additionally, the study focuses on the dynamics of knowledge creation alliance and on the negotiation process, while making decisions regarding each organization's participation in the endeavor, as well as, its share of the gains. Although prior studies have noted that cost sharing is one of the motives for the formation of R&D or knowledge creation alliances, the current study enhances this understanding by answering the question of "how" these resources are shared. Also, the current study answers the question of "what determines" the resource participation rate.

In relation to the variables included in the study, this work is in line with the future directions for knowledge management research laid out in recent literature. For instance, Argote et al. (2003b) recently noted that dyadic research could investigate the influence of variables such as power and conflict on knowledge management outcomes. This study addresses the need for such new variables in knowledge management literature by answering the research question raised as to what factors determine the resource-sharing rates of the partner firms and how do they affect the resource-sharing rate. However, I recognize that I provide game theoretic factors

that affect the participation rate. There might be other factors contributed by other theoretical lenses that aid in determining the resource participation rate of the organizations. For instance, Heiman and Nickerson (2002) noted that knowledge attributes, such as tacitness, determine the knowledge management practices adopted in inter-firm alliances and hence determine the choice of governance structure. They argue that such knowledge management practices including collaborative knowledge creation determine whether the chosen governance structure – equity-based alliance or non equity-based alliance – is adopted.

Second, viewing alliances as games between partnering organizations is a contribution to the growing literature, which applies game theory to understand the dynamics of collaborations. Alliances have been examined from several theoretical viewpoints such as transaction cost economics, resource dependency theory, and organizational learning theory (Barringer et al., 2000). However, studies that have viewed alliances as games are rare, and this study provides a viable theoretical lens to understand the resource-sharing decision-making process. Additionally, this study contributes to the alliance literature in terms of adding risk propensity and bargaining power as two additional criteria - as informed by the application of game theory - to be considered during the partner selection phase of alliance management. Such consideration of bargaining power and risk propensity adds to the currently prevalent factors for partner selection identified in literature (Hitt et al., 2000). Some of the other factors are goal congruence between potential partners, level of cultural compatibility, political support for the alliance within the partners' hierarchy, and resource complementarity (Doz et al., 1998; Sinha & Cusumano, 1991; Spekman, Forbes III, Isabella, & MacAvoy, 1998).

In relation to TCE, this study takes the main tenets of the theory that are proposed at the macro level and presents a bridge that managers can use to put the principles of TCE into

practice. Game theory, in particular complements TCE by allowing the organizations to explicitly model the decision-making process of the contract details and accommodating the changes that unfold during the relationship. Additionally, as expected, game theory allows modeling the collaborative relationship as a value maximization proposition, in addition to a cost minimization proposition, by enabling the specification of payoffs and investments.

Similarly, the current work enhances the resource dependency theory (RDT) by extending its recommendation that organizations need to devise strategies to manage dependencies by claiming ownership over the knowledge produced and by agreeing on a participation rate. Game theory allows one to model the collaboration as a relationship, and a similar analysis can be conducted at subsequent stages when the dependencies between the organizations, and hence their individual behaviors, change.

The current study encourages the shift in the information systems (IS) field's focus from "techno-centric" to a "technology/organizational/management/social focus," which makes IS a reference discipline (Baskerville & Myers, 2002) rather than a discipline safe in its silo. Such expansion in focus is important to improve the applicability of the concepts developed in the IS discipline to explain processes outside of its general lines of inquiry.

In relation to the IS literature, the contributions of this study are manifold. First, similar to the recognition in the learning theory literature, there is a recognition in the IS literature that there is a need to focus attention on the knowledge generation and realization processes and on exploring the relationship between strategy and knowledge processes (Grover & Davenport, 2001). This study contributes to IS literature by addressing knowledge generation and realization. By focusing on knowledge creation collaborations, this study enhances the current understanding of inter-organizational knowledge management. The inter-organizational focus of

this study is a step in the direction of developing inter-organizational systems for facilitating the joint creation of knowledge. Also, the gain to performance ratio parameter used in the model is an explicit attempt to incorporate the extent to which an organization realizes gain from the knowledge created.

Second, knowledge creation has been the target of recent studies (Ravichandran & Rai, 2003). However, such studies focus more on the impact of the knowledge created in achieving outcomes for the organizations – that is on the post knowledge creation stage - and on translating the knowledge created into performance improvements or capability accumulation for the organizations. The current study enhances the understanding of the knowledge creation process itself by unveiling the dynamics involved in this complex process, how those dynamics might impact how organizations realize the value of the knowledge created. By specifying the relationship between investments and payoffs in the production function, this study has provided a ground for modeling inter-organizational knowledge creation relationships from a value creation and gain maximization viewpoint.

Third, recent advances with respect to knowledge accumulation have identified three types of learning processes - learning-by-investment, learning-by-doing and learning-from-others- through which organizations accumulate knowledge (Ryu, Kim, Chaudhury, & Rao, 2005). One of the fundamental limitations of the referenced study is that it considers the three types of learning as independent of each other, which is suitable for the study of individuals. However, in an inter-organizational knowledge creation context, there is a necessity to consider these three types of learning in conjunction with one another. For instance, in dyadic knowledge creation collaboration, it is more likely that the collaborating organizations make joint investments, learn from one another and other sources external to the dyad, and also accumulate knowledge by

doing. This study enhances this current stream of IS literature by considering the creation of knowledge as a result of joint investments and building on the prior knowledge available with each partner.

The study contributes to the alliance literature in the following ways. First, this study focuses on the dynamics that unfold before the formation of the collaboration that eventually lead to the contractual agreements between the partners. Next, this study focuses on the collaborative relationship as a unit of analysis, which has been particularly stressed upon as important by the learning theory literature (Dyer et al., 1998; Larsson et al., 1998).

The current study contributes to the decision analysis literature in the following ways. First, it augments the current work in the growing application area of decision modeling inter-organizational behavior under the realm of knowledge management and supply chain management literature (de Cesare & di Liddo, 2001; Li, 2002; Rogers, 2001). The application of concepts such as game theory, to other new literatures such as knowledge management, has been recently recognized as one of the ways decision analysis literature is extended (Clemen & Kleinmuntz, 2004). Specifically, the current study models the relationship between organizations as games between players and provides a way to model the decision-making process as a game comprised of strategies that players can follow with payoffs for the players.

8.3 Limitations

The first limitation of this study is that only continuous return functions are included, not the discontinuous. For instance, if one considers the creation of knowledge, which results in a single product, the knowledge creation investment may not yield any return until the product is complete, at which stage there is a sudden increase in return as shown in the Figure 16. Until the knowledge creation investment reaches $M there is no return (R=0), and from then onwards, the organization starts to realize a return starting from $N. In contrast, if one considers the creation of knowledge that results in a performance improvement, as could be the case with the Cobb-Douglas function, the return due to increase in the investment *a* increases continuously as in Figure 15 rather than discretely as in Figure 16. For the purpose of this dissertation, I assume that the return function is continuous.

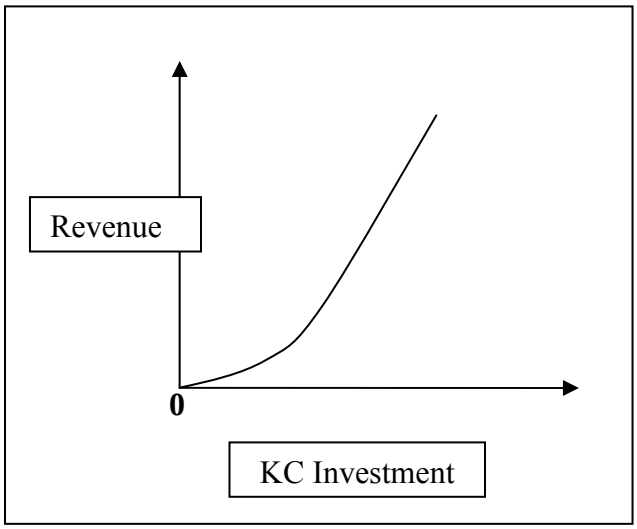

Figure 16: Continuous Function

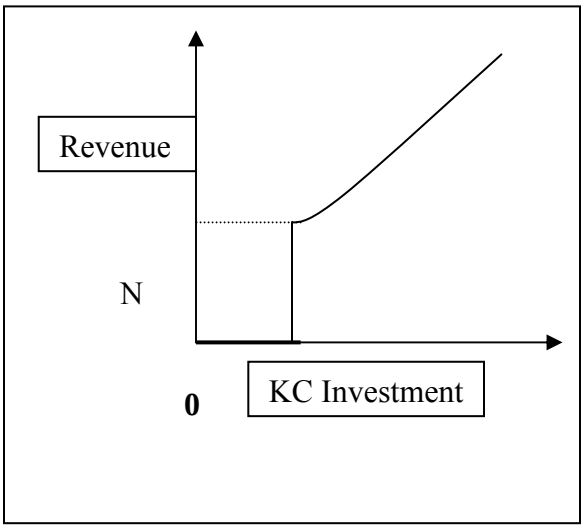

Figure 16: Discontinuous Function

A second limitation of this study, by virtue of applying game theory is that it assumes that the collaborating organizations are rational actors. Additionally, complete and perfect

information about each others' moves and intentions is assumed. However in reality, this assumption may not hold true (Samuelson, 2002). One or both of the organizations may neither behave rationally nor may have complete, perfect information about the partner's preferences. In such cases, the relationship cannot be modeled as the games presented here, since the assumptions of perfect and complete information have to be true, in order to be able to arrive at the Nash equilibrium.

The third limitation is that this study includes only those collaborations that are expected to generate financial gains. However, collaborations may not always succeed, and this study does not accommodate or explain collaborations that failed to perform. For instance, if one considers the net present value (NPV) of the partnering firms as an indicator of performance (Tallon, Kauffman, Lucas, Whinston, & Zhu, 2002), when firms experience negative NPV, most firms consider that as a signal to discontinue investment. However, sometimes negative NVP could still generate potentially valuable options in future (Kambil, Henderson, & Mohsenzadeh, 1993).

The fourth limitation of this study is that several variables that might influence the resource-sharing decision-making process have not been included in the model. For instance, literature on inter-organizational networks has recognized the importance of variables such as trust (Parker, 2005; Welty & Becerra-Fernandez, 2001) in determining the extent of resource-sharing specifically information sharing. For instance, in relation to resource-sharing in keiretsu members, Parker (2005) noted that trust and commitment generated through ongoing close relationships among the members lead to the development of resource-sharing mechanisms. Trust can be built within a network of organizations by repeat collaborations with the same partner (Gulati, 1995a; Gulati & Gargiulo, 1999).

8.4 Directions for Future Research

The current research could be further extended along the three directions of mathematical extensions, theoretical extensions and extensions informed by practice.

Along the direction of enhancing the mathematical model, the following are identified as directions for future research. First, as noted in Section 7.3, one of the limitations of the current work is its exclusion of discontinuous production functions. Discontinuous production function could be target of future work. Similarly, a natural extension of this work would be to understand the collaborations reporting negative NPV from a real options perspective. As noted in the introduction, collaborations with negative returns have been excluded from this study, yet there is enough evidence in the literature that collaborations with negative returns continue to invest in anticipation of future returns.

Additionally, the type of knowledge created can determine the nature of the performance function. For instance, if the collaboration is engaged in building a competency that is easily imitable by other firms or collaborations, then the performance function is likely to be of an inverted U shape (Onyeiwu, 2003). The current work also needs to be extended to include collaborations with such performance functions and determine why collaborations would continue to invest in collaborations.

Further, another way to model the four collaborations specified in this dissertation would be to specify the return functions for the collaborating organizations as portions of a unified logistic function such as the Gompertz (1825) logistic curve. This would be a more unified approach to the specification of the return functions, in contrast to the separate treatment of the performance functions based on Cobb-Douglas function and the sales response volume function. This becomes another direction for future study.

Theoretical extensions of the current work include modeling collaboration under the assumptions of incomplete information or imperfect information or both. Such collaborations could be modeled as games that allow for the presence of imperfect and incomplete information and equilibrium other than Nash equilibrium could be arrived at. Collaborations under assumptions of incomplete information can be modeled as Bayesian games (Harsanyi, 1967); and those with imperfect information can be modeled along the lines of von Neumann and Morgenstern's (1953) classic work Additionally, alternative ways of modeling the possibility of irrational behavior, such as including biases in the model (Wade-Benzoni et al., 2002), could be explored in future.

Variables that might have influence on the collaboration dynamics such as trust, due to prior association, could be included in the model in another possible theoretical extension. If trust were to be included in the model, prior relationship with the same partner – operationalized as partner-specific alliance experience (Gulati et al., 1999; Hoang et al., 2005) – is a suitable variable to be included in future research.

Appropriation concerns are well-documented in literature (Cohen, 1998; Hunoley, Jacobson, & Park, 1996) and deserve much detailed treatment. The necessity to appropriate the new knowledge produced can have an effect on the type of governance structure that is used for the inter-organizational relationship. For instance, Duysters and Hagedoorn (2002) note that the governance structures adopted by an inter-organizational relationship - either strategic partnerships, mergers and acquisitions or mixed structures - depend on the appropriability regime of the organization. Although the capacity of the organization to commercialize new knowledge has been modeled as a parameter in Essays 2 and 3, no significant results were derived as function of this parameter. Another extension of the current study would be to investigate the

influence of the organizations' commercialization capacities on the current knowledge creation effort, participation rate and the expected system gain.

Additionally, note that the current thesis models Cases 2, 3, and 5 presented in Section 3.3. This thesis builds on the background work that examines relationships illustrative of Case 1. Hence, a natural theoretical extension of the current work would be to examine the relationships modeled as Cases 4, 6 and 7.

The third direction along which the current work could be extended is with respect to the observations made in literature about growing trends in supply chain management practices. For instance, in a supply network (Choi, Dooley, & Rungtusanatham, 2001; Choi et al., 2002) where typically more than two organizations are involved, relationships are bound to become more complex; and therefore, studying the dynamics of the relationships in a supply network appears to be an important direction for future research. Specifically such relationships could comprise those between one buyer and many suppliers (1 to n) (Li, 2002) or within a network of suppliers and buyers (m to n) (Choi et al., 2002). Such many-to-many relationships can be studied when a few of the partners form a coalition, or as those where all of the collaborating organizations operate as a coalition.

The current study can also be extended to model collaborations whose primary objective is not knowledge creation. For instance, when collaborations are formed for the purpose of accessing each other's distribution channels or market segments, this model might still be applicable, however with modification. For instance, in a collaboration that is formed for the development of a non-knowledge asset or a tangible asset, depreciation of assets has to be factored into the current model to account for the difference between the tangible assets and knowledge. Additionally, when collaborations are formed between organizations with prior

complementary knowledge, such knowledge has to be factored in – as was done in Scenario 2 of Essay 1. Thus, an additional direction for future research would be to extend this model to include a combination of knowledge and non-knowledge assets.

APPENDICES

Appendix A: Essay 1 Symbols and their Descriptions

Symbol	Description
P	Performance due to knowledge creation investments
$\hat{P}$	Expected performance
a	Total current knowledge creation effort (total dollar amount expended by both of the organizations in the collaboration exclusively toward the current project)
α	Performance saturation asymptote (limit on the performance improvements that can occur due to knowledge created)
γ	Performance to investment sensitivity for the current knowledge creation effort (percentage change in revenue with percentage change in current investment $\gamma_{R,a} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial a}{a}\right)}$)
ε	Environmental uncertainty
ρ_1	Organization 1's gain to performance ratio (change in profit for organization 1 for unit change in performance)
ρ_2	Organization 2's gain to performance ratio (change in profit for organization 2 for unit change in performance)
$\hat{\pi}_1$	Organization 1's expected gain (the expected profit for organization 1; revenue less the cost expended)
$\hat{\pi}_2$	Organization 2's expected gain (the expected profit for organization 2; revenue less the cost expended)
$\hat{\pi}$	System's expected gain (the expected profit for the system comprising of organization 1 and organization 2; revenue less the cost expended)
t	Organization 1's participation rate
q_1	Organization 1's unique prior knowledge creation efforts (includes only investments made prior to the current project)
q_2	Organization 2's unique prior knowledge creation efforts (includes only investments made prior to the current project)
δ_1	Performance to investment sensitivity for the organization 1's unique prior knowledge creation efforts (percentage change in revenue with percentage change in unique prior knowledge creation investment $\delta_{1R,q_1} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial q_1}{q_1}\right)}$)
δ_2	Performance to investment sensitivity for the organization 2's unique prior knowledge creation efforts ((percentage change in revenue with percentage change in unique prior knowledge investment $\delta_{2R,q_2} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial q_2}{q_2}\right)}$)

Appendix B: Essay 2 Symbols and their Descriptions

Symbol	Description
P	Performance due to knowledge creation investments
$\hat{P}$	Expected performance
a	Total current knowledge creation effort(total dollar amount expended by both of the organizations in the collaboration exclusively toward the current project)
γ	Performance to investment sensitivity for the current knowledge creation effort (percentage change in revenue with percentage change in current investment $\gamma_{R,a} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial a}{a}\right)}$)
ε	Environmental uncertainty
b	Risk tolerance
ρ_L	Leader's gain to performance ratio (change in profit for leader organization per unit change in performance)
ρ_F	Follower's gain to performance ratio (change in profit for follower organization per unit change in performance)
$\hat{\pi}_L$	Leader's expected gain (the expected profit for leader organization; revenue less the cost expended)
$\hat{\pi}_F$	Follower's expected gain (the expected profit for follower organization; revenue less the cost expended)
$\hat{\pi}$	System's expected gain(the expected profit for the system comprised of both of the organization ; revenue less the cost expended)
t	Leader's participation rate
c_F	Capability of the follower to commercialize new knowledge
c_L	Capability of the leader to commercialize new knowledge
ϕ_L	Sensitivity for the leader's performance to its commercialization capacity (percentage change in revenue with percentage change in leader's commercialization capacity $\varphi_{L\,R,c_L} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial c_L}{c_L}\right)}$)
ϕ_F	Sensitivity for the follower's performance to its commercialization capacity (percentage change in revenue with percentage change in follower's commercialization capacity $\varphi_{F\,R,c_F} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial c_F}{c_F}\right)}$)

Appendix C: Essay 3 Symbols and their Descriptions

Symbol	Description
P	Performance due to knowledge creation investments
$\hat{P}$	Expected performance
a	Total current knowledge creation effort(total dollar amount expended by both of the organizations in the collaboration exclusively toward the current project)
α	Performance saturation asymptote (limit on the performance improvements that can occur due to knowledge created)
γ_F	Follower's performance to investment sensitivity for the current knowledge creation effort (percentage change in revenue with percentage change in current investment for the follower organization
ε	Environmental uncertainty
γ_L	Leader's performance to investment sensitivity for the current knowledge creation effort (percentage change in revenue with percentage change in current investment for the leader organization
b	Risk tolerance
ρ_L	Leader's gain to performance ratio (change in profit for leader organization per unit change in performance)
ρ_F	Follower's gain to performance ratio (change in profit for follower organization per unit change in performance)
$\hat{\pi}_L$	Leader's expected gain (the expected profit for leader organization; revenue less the cost expended)
$\hat{\pi}_F$	Follower's expected gain (the expected profit for follower organization; revenue less the cost expended)
$\hat{\pi}$	System's expected gain(the expected profit for the system comprised of both of the organization ; revenue less the cost expended)
t	Leader's participation rate
c_F	Capability of the follower to commercialize new knowledge
c_L	Capability of the leader to commercialize new knowledge
ϕ_L	Sensitivity for the leader's performance to its commercialization capacity (percentage change in revenue with percentage change in leader's commercialization capacity $\varphi_{L\,R,c_L} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial c_L}{c_L}\right)}$)
ϕ_F	Sensitivity for the follower's performance to its commercialization capacity (percentage change in revenue with percentage change in follower's commercialization capacity $\varphi_{F\,R,c_F} = \frac{\left(\frac{\partial R}{R}\right)}{\left(\frac{\partial c_F}{c_F}\right)}$)

Appendix D: Proof Showing that both Essay 1 Values of t* are Equivalent.

Proof that Equation (14) is equivalent to Equation (15)

$$t^* = \frac{-j\hat{\pi} - w + \rho_1[\alpha - (a^*)^{-\gamma}]}{a^*} \tag{14}$$

$$t^* = 1 + \frac{(1-j)\hat{\pi} - w - \rho_2[\alpha - (a^*)^{-\gamma}]}{a^*} \tag{15}$$

For Equation (14) to be equivalent to Equation (15)

$$a^* + \hat{\pi} - j\hat{\pi} - w - \rho_2[\alpha - (a^*)^{-\gamma}] = -j\hat{\pi} - w + \rho_1[\alpha - (a^*)^{-\gamma}]$$

$$a^* + \hat{\pi} - \rho_2[\alpha - (a^*)^{-\gamma}] = \rho_1[\alpha - (a^*)^{-\gamma}]$$

$a^* + \hat{\pi} = (\rho_1 + \rho_2)\left[\alpha - a^{*-\gamma}\right]$ or

$\hat{\pi} = (\rho_1 + \rho_2)\left[\alpha - a^{*-\gamma}\right] - a^*$ which is the expected system gain with the value of *a* that maximizes $\hat{\pi}$.

Appendix E: Explanation Clarifying Seemingly Circular Propositions in Essay 1

Essay 1	
Propositions	**Explanation Clarifying Seemingly Circular Propositions**
Proposition 1a: A higher risk tolerant organization's participation rate in current knowledge creation efforts is less compared to that of the lesser risk tolerant organization. *Proposition 1b: A higher risk tolerant organization is expected to get a greater share of the expected system gain.* *Proposition 2: An organization with greater bargaining power will participate less in the current knowledge creation effort than that with lesser bargaining power.*	The expected gain functions specify the relationship among the parameters expected gains (for individual organizations as well as the system), current knowledge creation effort (investment) and participation rate. Note that these functions do not have a parameter of either risk tolerance or bargaining power. These two game-theoretic factors appear in the utility functions for the individual organizations and for the system. The utility is a function of expected gain, risk tolerance and bargaining power. No relationship is assumed among expected gain and risk tolerance or no such relationship can be derived without considering the conditions of optimality. Also, no relationship can be derived among the parameters participation rate, risk tolerance and bargaining power unless under the conditions of optimality. Hence the Propositions 1a, 1b and 2 are not circular.
Proposition 3a: The optimal value of current knowledge creation efforts is lower in the presence of prior knowledge creation efforts (Scenario 2) than without prior knowledge creation efforts (Scenario 1). *Proposition 3b: The optimal expected system gain is higher in the presence of prior knowledge creation efforts (Scenario 2) than without prior knowledge creation efforts (Scenario 1).* *Proposition 4: The participation rate of an organization in the current knowledge creation efforts is negatively associated with both its risk tolerance and its bargaining power, regardless of their prior knowledge creation efforts.*	In Scenario 2, the expected gain functions specify the relationships among the expected gain, prior knowledge creation efforts in addition to the current knowledge creation efforts and the participation rate. As with Propositions 1a, 1b and 2, no relation can be established among the expected system gain, current knowledge creation effort, bargaining power, risk tolerance and participation rate directly from the expected gain functions, and utility functions, except under the conditions of optimality. Furthermore, the Propositions 3a, 3b and 4 are comparisons of Scenarios 1 and 2. No assumptions are made to suggest how the relationships among the variables change from one scenario to the other.

Appendix F: Explanation Clarifying Seemingly Circular Propositions in Essay 2

Essay 2	
Propositions	**Explanation Clarifying Seemingly Circular Propositions**
Proposition 1a: The equilibrium value of current knowledge creation effort is a concave upward function of the performance to investment sensitivity of current knowledge creation effort. *Proposition 1b: The equilibrium value of current knowledge creation effort is a concave upward function of the risk tolerance.*	The expected gain functions specify the relationships among the parameters expected gain, current knowledge creation effort, performance to investment sensitivity and risk tolerance. The relations among the current knowledge creation effort, performance to investment sensitivity and risk tolerance become evident only under conditions of optimality.
Proposition 2a: The leader's participation rate is an increasing function of the performance to investment sensitivity of current knowledge creation effort. *Proposition 2b: The equilibrium value of the leader's participation rate is a convex upward function of risk tolerance.*	The expected gain functions also specify the relationship among the expected gain and participation rate, but do not establish any direct relationship of performance to investment sensitivity and risk tolerance with participation rate, except under conditions of optimality.
Proposition 3: The leader participates and hence the collaboration exists only when $\frac{L_2}{F_2} > 1 - \gamma b$.	When the model is set up, no assumption is made with respect to the parameters that establish conditions for the collaboration to exist. By determining the equilibrium values, one can identify the conditions under which the equilibrium values hold true and thus the collaboration exists. Hence Proposition 3 is not circular.
Proposition 4a: The equilibrium value of the expected system gain is a concave upward function of performance to investment sensitivity of current knowledge creation effort. *Proposition 4b: The equilibrium value of the expected system gain is a concave upward function of risk tolerance.*	The expected system gain function establishes the relationship among the parameters expected system gain and current knowledge creation effort. The relationships between expected system gain and performance to investment sensitivity, and that between expected system gain and risk tolerance, are established only at the equilibrium condition.

Appendix G: Derivation for Essay 3 Equilibrium Value of t.

Essay 3 : Leader is characterized by decreasing marginal return function.
Follower is characterized by increasing marginal return function.

$$\hat{\pi}_L = \rho_L \left[\alpha - a^{-\gamma_L} c_L^{-\phi_L}\right] - at$$

Let $L_3 = \rho_L c_L^{-\phi_L}$. Then

$$\hat{\pi}_L = \rho_L \alpha - L_3 a^{-\gamma_L} - at$$

$$\hat{\pi}_F = \rho_F^{\ b} a^{\gamma_F b} c_F^{\ \phi_F b} - a(1-t)$$

Let $F_3 = \left(\rho_F c_F^{\ \phi_F}\right)^b$. Then

$$\hat{\pi}_F = F_3 a^{\gamma_F b} - a(1-t)$$

$$\hat{\pi} = \rho_L \alpha + F_3 a^{\gamma_F b} - L_3 a^{-\gamma_L} - a$$

Setting the first derivative of $\hat{\pi}_F$ to 0, we get:

$$\frac{\partial \hat{\pi}_F}{\partial a} = F_3 \left(\gamma_F b\right) a^{\gamma_F b - 1} - (1-t) = 0.$$

Let $k = \gamma_F b$

$$F_3 k a^{k-1} - (1-t) = 0$$

$$F_3 k a^{k-1} = (1-t)$$

$$a^{k-1} = \frac{(1-t)}{F_3 k} \text{ or}$$

$$a^* = \left(\frac{(1-t)}{F_3 k}\right)^{\frac{1}{k-1}}$$

$$\hat{\pi}_L = \rho_L \alpha - L_3 \left(\frac{(1-t)}{F_3 k}\right)^{\frac{-\gamma_L}{k-1}} - \left(\frac{(1-t)}{F_3 k}\right)^{\frac{1}{k-1}} t$$

$$\hat{\pi}_L = \rho_L \alpha - \frac{L_3(1-t)^{\frac{-\gamma_L}{k-1}}}{(F_3 k)^{\frac{-\gamma_L}{k-1}}} - \frac{t(1-t)^{\frac{1}{k-1}}}{(F_3 k)^{\frac{1}{k-1}}}$$

Let $X = \dfrac{1}{(F_3 k)^{\frac{1}{k-1}}}$ and

Let $Y = \left(\dfrac{1}{(F_3 k)^{\frac{-\gamma_L}{k-1}}}\right) L_3$ or $Y = X^{-\gamma_L} L_3$

$$\hat{\pi}_L = \rho_L \alpha - Y(1-t)^{\frac{-\gamma_L}{k-1}} - Xt(1-t)^{\frac{1}{k-1}}$$

$$\frac{\partial \hat{\pi}_L}{\partial t} = -Y\left(\frac{-\gamma_L}{k-1}\right)(1-t)^{\frac{-\gamma_L}{k-1}-1}(-1) - X(1-t)^{\frac{1}{k-1}} - Xt\left(\frac{1}{k-1}\right)(1-t)^{\frac{1}{k-1}-1}(-1)$$

$$-Y\left(\frac{\gamma_L}{k-1}\right)(1-t)^{\frac{-\gamma_L}{k-1}-1} - X(1-t)^{\frac{1}{k-1}} + Xt\left(\frac{1}{k-1}\right)(1-t)^{\frac{1}{k-1}-1} = 0 \qquad \text{(G.1)}$$

Recall that $Y = X^{-\gamma_L} L_3$. Then Equation (G.1) can be written as:

$$-X^{-\gamma_L} L_3\left(\frac{\gamma_L}{k-1}\right)(1-t)^{\frac{-\gamma_L}{k-1}-1} - X(1-t)^{\frac{1}{k-1}} + Xt\left(\frac{1}{k-1}\right)(1-t)^{\frac{1}{k-1}-1} = 0$$

$$Xt\left(\frac{1}{k-1}\right)(1-t)^{\frac{1}{k-1}-1} - X^{-\gamma_L} L_3\left(\frac{\gamma_L}{k-1}\right)(1-t)^{\frac{-\gamma_L}{k-1}-1} = X(1-t)^{\frac{1}{k-1}}$$

Factoring out X on both sides, we get:

$$\left(\frac{t}{k-1}\right)(1-t)^{\frac{1}{k-1}-1} - X^{-\gamma_L-1} L_3\left(\frac{\gamma_L}{k-1}\right)(1-t)^{\frac{-\gamma_L}{k-1}-1} = (1-t)^{\frac{1}{k-1}}$$

Factoring out $(1-t)^{\frac{1}{k-1}}$ on both sides, we get:

$$\left(\frac{t}{k-1}\right)(1-t)^{-1} - \frac{X^{-\gamma_L-1} L_3 \gamma_L}{k-1}(1-t)^{\frac{-(\gamma_L+k)}{k-1}} = 1$$

$$t(1-t)^{-1} - X^{-\gamma_L-1} L_3 \gamma_L (1-t)^{\frac{-(\gamma_L+k)}{k-1}} = k-1 \qquad \text{(G.2)}$$

Let $Z = X^{-\gamma_L - 1} L_3 \gamma_L$ and $t(1-t)^{-1}$ be written as $-1 + (1-t)^{-1}$. Then Equation (G.2) can be rewritten as

$$-1 + (1-t)^{-1} - Z(1-t)^{\frac{-(\gamma_L + k)}{k-1}} = k - 1$$

$$(1-t)^{-1}\left[1 - Z(1-t)^{\frac{-(\gamma_L + 1)}{k-1}}\right] = k \qquad \text{(G.3)}$$

RHS (k) is always less than 1, since $k = \gamma_F b$

On LHS, $\frac{1}{1-t} > 1$

This implies that in order to satisfy Equation (G.3), $0 < 1 - Z(1-t)^{\frac{-(\gamma_L + k)}{k-1}} < 1$

$1 - Z(1-t)^{\frac{-(\gamma_L + k)}{k-1}} > 0$ implies that

$$(1-t)^{\frac{-(\gamma_L + k)}{k-1}} < \frac{1}{Z}$$

$$(1-t) < \left(\frac{1}{Z}\right)^{\frac{1-k}{1+\gamma_L}}$$

$$t > 1 - \left(\frac{1}{Z}\right)^{\frac{1-k}{1+\gamma_L}} \qquad \text{(G.4)}$$

recall that $Z = X^{-\gamma_L - 1} L_3 \gamma_L$ and $X = \frac{1}{(F_3 k)^{\frac{1}{k-1}}}$

Then

$$Z = \left(\left[\frac{1}{F_3 k}\right]^{\frac{1}{k-1}}\right)^{-\gamma_L - 1} L_3 \gamma_L$$

$$Z = L_3 \gamma_L \left[\frac{1}{F_3 k}\right]^{\frac{-(\gamma_L + 1)}{k-1}}$$

$$\frac{1}{Z} = \frac{1}{L_3\gamma_L}\left[F_3 k\right]^{\frac{-(\gamma_L+1)}{k-1}}$$

$$\left(\frac{1}{Z}\right)^{\frac{1-k}{1+\gamma_L}} = \left[\frac{1}{L_3\gamma_L}\left[F_3 k\right]^{\frac{-(\gamma_L+1)}{k-1}}\right]^{\frac{1-k}{1+\gamma_L}}$$

$$\left(\frac{1}{Z}\right)^{\frac{1-k}{1+\gamma_L}} = \left[\frac{1}{L_3\gamma_L}\right]^{\frac{1-k}{1+\gamma_L}}\left[F_3 k\right] \text{ recall that } k = \gamma_F b$$

$$\left(\frac{1}{Z}\right)^{\frac{1-k}{1+\gamma_L}} = \frac{F_3\gamma_F b}{\left(L_3\gamma_L\right)^{\frac{1-\gamma_F b}{1+\gamma_L}}}$$

Now, Equation (G.4) can be rewritten as $t > 1 - \left(\frac{F_3\gamma_F b}{\left(L_3\gamma_L\right)^{\frac{1-\gamma_F b}{1+\gamma_L}}}\right)$, which serves as a lower bound for t.

From Equation (G.3), we can compute one possible expression for t_3*. Substituting γ_Fb for k, Equation (G.3) can be written as:

$$(1-t)^{-1}\left[1 - Z(1-t)^{\frac{-(\gamma_L+1)}{k-1}}\right] = \gamma_F b.$$

Appendix H: Explanation Clarifying Seemingly Circular Propositions in Essay 3

Essay 3	
Propositions	**Explanation Clarifying Seemingly Circular Propositions**
Proposition 1: The current knowledge creation effort is an increasing function of the follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity. *Proposition 2: The leader's participation rate is lower for higher values of follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity.*	The expected gain function establishes the relationship among the parameters expected gain, current knowledge creation effort and participation rate. However, the relationship between the current knowledge creation effort and the follower's performance to investment sensitivity is established only under the conditions of optimality. Hence Proposition 1 is not circular. Similarly, the relationship between the leader's participation rate and the follower's performance to investment sensitivity is established only under the conditions of optimality. Hence, Proposition 2 is not circular.
Proposition 3: The collaboration exists only when the solution to the equation $(1-t^*)^{-1}\left[1-Z(1-t^*)^{\frac{(\gamma_L+1)}{1-\gamma_F b}}\right]=\gamma_F b$ is between 1 and $1-\frac{F_3\gamma_F b}{(L_3\gamma_L)^{\frac{1-\gamma_F b}{1+\gamma_L}}}$.	When the model is set up, the only assumption made with regard to the leader's participation rate is that it is between 0 and 1. Thus, no assumption is made with respect to the existence of any other lower bound for the leader's participation rate t, than 0. Proposition 3 specifies such a lower bound for the leader's participation rate and hence is not circular.
Proposition 4a: The equilibrium value of leader's expected gain monotonically increases as a function of follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity. *Proposition 4b: The equilibrium value of follower's expected gain monotonically decreases as a function of follower's performance to investment sensitivity across the values of leader's performance to investment sensitivity.*	The expected system gain functions for the leader and follower organizations establish the relationship among the parameters expected system gain and current knowledge creation effort. However, the relationships between the leader's expected system gain and the follower's performance to investment sensitivity, and that between follower's expected system gain and the follower's performance to investment sensitivity, are established only at the equilibrium condition. Hence, Propositions 4a and 4b are not circular.

Proposition 5a: The relation between the equilibrium value of expected system gain and the follower's performance to investment sensitivity is non-monotonic for lower values of the leader's performance to investment sensitivity. *Proposition 5b: The equilibrium value of expected system gain monotonically increases with the follower's performance to investment sensitivity for higher values of the leader's performance to investment sensitivity.*	The expected system gain function establishes the relationship among the parameters expected system gain and current knowledge creation effort. The relationship between expected system gain and follower's performance to investment sensitivity is established only at the equilibrium condition. Moreover, the Proposition 5a is interesting because it unravels the effect that the leader's performance to investment sensitivity has on the relationship between the expected system gain and the follower's performance to investment sensitivity. Hence, Propositions 5a and 5b are not circular.

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