"The Effect of Personnel Selection Schemes on Knowledge Transfer"

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Abstract

Many factors affect organizations' success in achieving competitive advantage. Some of those factors are tangible assets such as production technologies or economies of scale, and others factors are intangible assets such as knowledge. Nevertheless, for knowledge to be advantageous for the organization, it needs to be shared. Understanding the conditions under which individuals would be more likely to share their knowledge with other individuals becomes important. The purpose of this research work was twofold. The first purpose was to explore how breadth of skills, task experience, and group experience affect knowledge transfer within an organization and among organizations. The second objective was to explore how certain environmental attributes facilitate or hinder knowledge transfer among different organizations.

A simulation model based on constructural theory (Carley, 1990, 1991) was implemented. The results showed a significant effect of organizational structure on the amount of total knowledge transferred with and without turnover, with the fully-connected structure as the most beneficial for knowledge transferred, while the hierarchical structure was the most restrictive. Skill characteristics (generalist or specialist) had a significant effect on the amount of total knowledge transferred. Organizations with mostly generalist individuals transferred more knowledge within the organization than organizations composed of specialists. The best performance and learning rate occurred in the inter-groups turnover condition when groups performed the same task. Finally, there was a strong statistically significant effect of the set of activities and content of interaction on the total amount of general knowledge transferred, of task knowledge transferred, and of group knowledge transferred

In addition, the results showed that the two main attributes of the environment, uncertainty and competitiveness, had a statistically significant effect on the amount of articles published and retrieved as well as on the amount of patents published and retrieved. The higher the uncertainty, the lower the number of people transferred among organizations. Competition also affected positively the total number of transactions performed by the organizations. The data suggested that organizations with mostly generalist individuals retrieved more articles from the environment than organizations with specialists. Conversely, organizations with mostly generalist individuals were more likely to retrieve fewer patents from the environment than organizations with mostly specialists.

The model implemented the concept of location importance as a factor for determining interaction probabilities among the environmental actors. The results showed no significant effects of location importance, of the number of clusters of organizations in the environment, and no location importance by number of clusters interaction effects on any of the measures. However, a detailed analysis of the data revealed a strong effect of location importance and the number of clusters on the number of interactions among organizations.

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Chapter 1: Introduction

Many factors affect organizations' success in achieving competitive advantage. Some of those factors are tangible assets such as production technologies or economies of scale, and others factors are intangible assets such as knowledge. Nevertheless, for knowledge to be advantageous for the organization, it needs to be shared. Then, understanding the conditions under which individuals would be more likely to share their knowledge with other individuals becomes important. Following this line of thought, certain characteristics of individuals such as their skills and experience might affect the way individuals interact and, therefore, how knowledge is transferred among individuals. The main objective of this paper is to explore how breadth of skills, task experience, and group experience affect knowledge transfer.

The importance of knowledge transfer within an organization and among different organizations has been widely suggested (e.g. Argote, 1999; Benkard, 1997; Darr, Argote & Epple, 1995; Galbraith, 1990; Szulanski, 1994, 1996). Particularly, organizations would benefit in terms of productivity, implementation of best practices, development of new facilities, and mergers between organizations when they transfer knowledge from one unit to another.

Knowledge is embedded in the structure, technology, and in the organization's people (Argote, 1999). Thus, an understanding of the processes and mechanisms through which knowledge is transferred at each of those three levels is needed. Knowledge can be transferred among groups within an organization in different ways, such as training of the recipients, documentation (procedures, blueprints, organizational charts, etc), information systems, transfer of personnel, and effective communication mechanisms between donor and recipient (Argote, 1999). Knowledge transfer among organizations could potentially occur also through cooperative relationships, strategic alliances, joint ventures, and business groups such as the Japanese Keiretsus.

At the organization's people level, many factors must be considered when knowledge is shared among individuals who are members of a group (Argote, 1999). For instance, knowledge of how information is distributed among group members affects the integration of information, and awareness of the distribution of expertise within the group increases the likelihood of sharing knowledge uniquely held by the members. Research on groups has studied the effects of the characteristics of the individual's skills on group processes and group effectiveness (Cohen & Bailey, 1997). However, research on the effects of those characteristics on knowledge transfer at the group level is lacking.

The recruiting process of an organization can be based on two different selection schemes: expertise-specific or expertise-general. In an expertise-specific selection scheme, the abilities or expertise of the candidates in a particular functional area or task are the significant selection factors. In an expertise-general selection scheme, the general intelligence of candidates, independent from their functional or task expertise, is the main factor for selection. Research at the group level shows mixed results with regards to the effects of the generalist-specialist dimension. Selecting individuals with generalist skills improves the performance of top management teams (Liang, 1994). However, evidence suggests also that groups composed of individuals with different skills might be more effective in complex non-routine problems (Jackson, 1992).

When candidates are recruited they usually start working in a particular group within the organization. These individuals might have experience with the task to be performed or with the kind of team in which they will work. Experience has been shown to affect the way groups encode and retrieve information (Liang, Moreland & Argote, 1995), the level of performance they achieve (Gruenfeld & Hollingshead, 1993), and the amount of unique information shared among the group members (Kim, 1997).

This study focuses mainly on the organization's people and how different characteristics of the individuals' skills and experience affect the organization's knowledge and its knowledge transfer capabilities. In particular, this study explores the following questions: Does the expertise-specific/expertise-general (ESEG) dimension of the organizational members' skills affect knowledge transfer within and among organizations? Is there an interaction effect among skill characteristics, task experience, and group experience? And if there is an interaction effect, how is knowledge transfer affected?

The simulation model implemented in this study is based on constructural theory (Carley, 1990, 1991). It also draws on concepts and ideas from previous simulation models (Carley, 1992, Lin, 1994). According to the constructural theory, social change and stability results from changes in the distribution of knowledge as individuals interact and acquire and disseminate information (Carley, 1991). The basic model of this theory proposes that a society contains a certain number of pieces of information, or facts, that the individuals in that society can learn. An individual either knows each fact or does not. Interaction among the individuals is predicted in term of relative similarity. Relative similarity is represented in the model by allowing the probability that an individual *i* interacts with *j* at time *t*, denoted $P_{ij}(t)$, to be a function of how much information *i* and *j* share relative to the sum of how much information *i* shares with each member of the society (Carley, 1991). Carley and Krackhardt (1996) proposed the probability of interaction, $P_{ij}(t)$, as a function of opportunities for contact and knowledge similarity. Opportunities for contact can be thought of as social, organizational, or physical constraints on how much time individual can interact and how much time they must interact. The simulation model of this study implemented the interaction among the organizational members based on Carley and Krackhardt's definition.

Knowledge is also embedded in the organization's technology and structure. Therefore, in addition to modeling the interaction among individuals, this virtual experiment modeled three different organizational structures as well as three different group tasks. Carley (1992) studied the effects of personnel turnover on organizational learning in two types of organizations: hierarchies and teams. Lin (1994), in a theoretical study of measures of organizational design, modeled hierarchy, team and matrix organizational structures. This study modeled the team structure (as a fully-connected graph) and two variations of the hierarchical structure: a pure hierarchy (all individuals work separately under one manager) and a hybrid hierarchy, in which subgroups of individuals work under one manager. Regarding the tasks, the baseline was the decision-making task described in Carley (1992) with variations in the routiness of the tasks. The tasks also combined different decomposition schemes (Lin, 1994).

The following chapter describes in detail the model, including the implementation of the interactions, the representation of knowledge, and the model used for the tasks and for the organizational structures. Chapters 4 and 5 present the design of the first virtual experiment and the analysis of its results. Chapters 5 and 6 present the design of the second virtual experiment and the discussion of its results. Finally, chapter 7 presents the conclusion of this research study. In addition, the final chapter identifies the limitations of this study and suggests future research work as well.

Chapter 2: The Model

A schema of the components of the model implemented in this research project with their relationships is shown in Figure 1. As Argote (1999) indicated, knowledge is embedded in the individuals, the technology, and in the structure of an organization. Therefore, these three elements represent the basis for the proposed model.

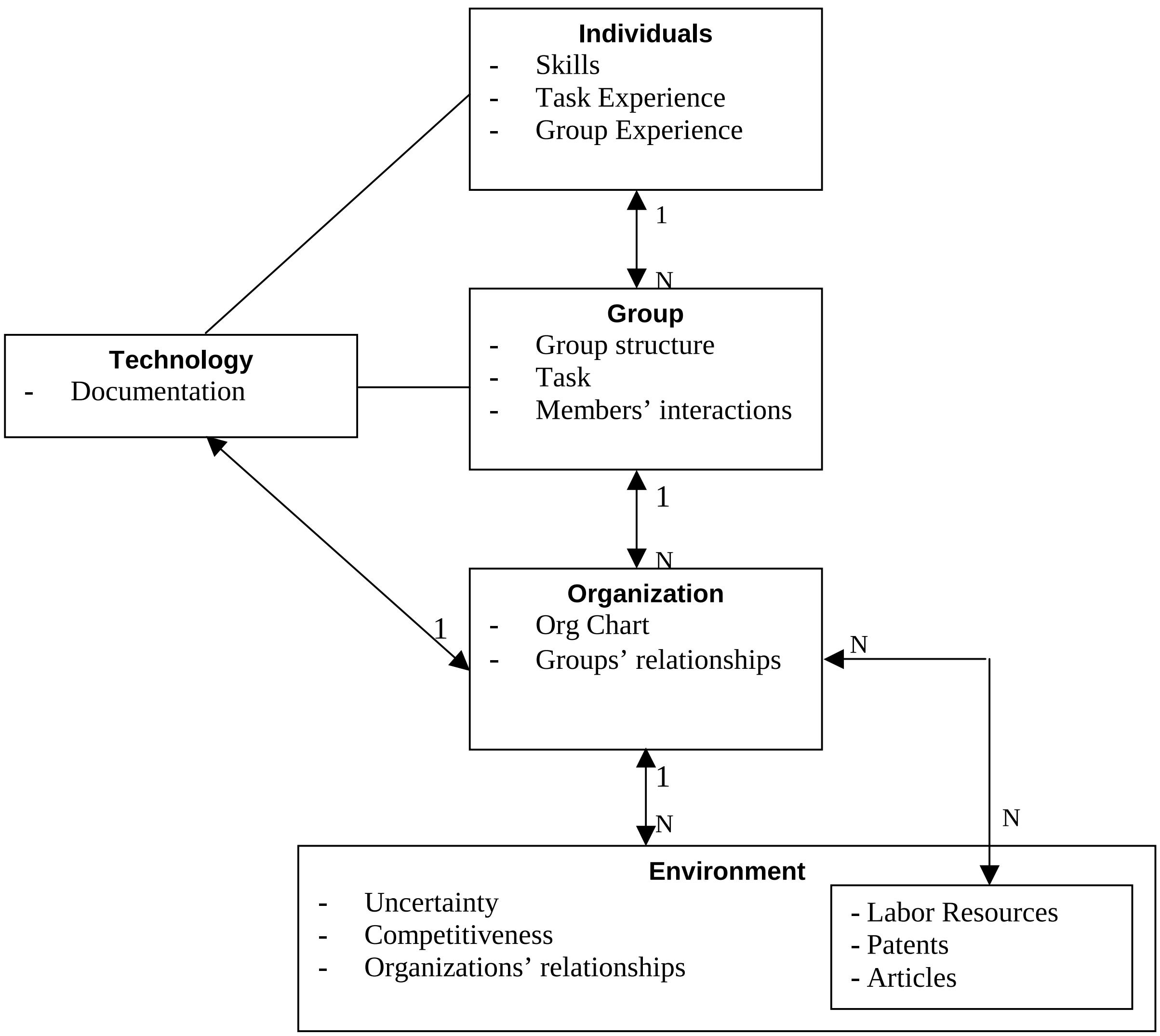

Figure 1: Component diagram of the model

The first component is the environment in which the organizations operate. The general characteristics of the environment are defined by two attributes: uncertainty and competitiveness. In addition, there is a collection of organizations with relationships among them, a representation of labor resources, and patents and articles repositories.

The second component is the organization. It consists of a collection of groups, an organizational structure, a relationship matrix that represents the opportunities of interaction among the groups, and a documentation system that the organization's members can access. If the organization has N groups, then the organization structure is an NxN matrix in which a one in the cell *ij* indicates that group *i* depends hierarchically from group *j*. Individuals might leave an organization or move among groups. Turnover is modeled using a Poisson process and the outgoing individuals are immediately replaced with new individuals with skills and experience consistent with corresponding experimental condition.

The third component is the group. A group is composed of a collection of individuals, a group structure, and a relationship matrix that represents the opportunities of interaction among the group members. If the group has N individuals, then the group structure is a NxN matrix in which a one in the cell *ij* indicates that the individual *i* depends hierarchically from the individual *j*. Groups perform one of three different types of tasks available in the model.

Finally, individuals are modeled as agents with a memory consisting of three different kinds of knowledge: general, task, and group knowledge. Knowledge is operationalized as a collection of pieces of information, consistent with the constructural theory (Carley, 1990, 1991). The memory is initialized accordingly to the experimental conditions to represent individuals with particular characteristics: general or specific skills, task experience or no task experience, and group experience or no group experience.

In this model, knowledge can be transferred through various mechanisms. At the organizational level, interactions among individuals, documentation, and transferring individuals among the groups serve as alternative knowledge transfer mechanisms. In the environment, knowledge transfer could occur by transferring individuals between two organizations and through generation or acquisition of articles and patents. In order to understand the effect of the independent variables on the knowledge transfer, various measures are collected. Examples of these measures are the total number of pieces of information shared, the total number of new pieces of information shared, and the total number of pieces of each type of knowledge shared. Research in groups has shown that, depending on the type of task, diversity of skills influences group performance (Cohen & Bailey, 1997), and sharing of unique information affects decision-making quality (Stasser, 1992). Therefore, the performance of the groups in the different tasks is also measured. The rest of this section describes the model in more detail.

The interactions

The organizational members interact with each other following a model of interaction based on constructural theory (Carley 1990, 1991). Each individual has a probability of interacting with another, denoted $P_{ij}(t)$. This is the probability that the individual *i* chooses *j* for interaction. The probability that individual *i* chooses to interact with individual *j* at time t, given that all individuals are available for interaction, is a function of both how much knowledge *i* shares with *j* at time t, denoted $SK_{ij}(t)$, and how many opportunities *i* has to contact *j* relative to *i*'s shared knowledge and contact opportunities with everyone else, denoted OC_{ij}. The probability of interaction is given by the following expression (Carley & Krackhardt, 1996):

$$P_{ij}(t) = \frac{OC_{ij}(1 + SK_{ij}(t))}{\sum_{k=1}^{I} OC_{ik}(1 + SK_{ik}(t))}$$

Shared knowledge affects the probability of interaction in a very simple way. The more knowledge that an individual shares with another relative to what he or she shares with everyone else, the more likely he or she is to choose to interact with that particular individual. Opportunities for contact affect the probability that one individual interacts with another in two ways. First, the opportunities for contact of an individual with another can engender a certain likelihood of interaction with another individual, regardless of how much information they initially share. Second, in pairs of individuals who share the same amount of information, those who have fewer contact opportunities are less likely to interact (Carley & Krackhardt, 1996).

Similarity of knowledge, $SK_{ij}(t)$, is the proportion of pieces of information that two individuals, *i* and *j*, have in common at time t. If an individual *i* has in his or her memory the piece of information *k*, the function $F_{ik}(t)$ will return 1, if not the function will return 0. The similarity of knowledge is given by the following expression (Carley & Krackhardt, 1996):

$$SK_{ij}(t) = \frac{\sum_{k=1}^{K} F_{ik}(t) \times F_{jk}(t)}{K}$$

where *K* is the total number of pieces of information in the knowledge base. As the formula shows, $SK_{ij}(t)$ is the percentage of pieces of information shared by a dyad relative to the entire knowledge base. As we increase the size of the knowledge base, the value $SK_{ij}(t)$ might decrease, suggesting that the individuals are less similar. However, it could also be argued that the similarity should be considered at a higher level instead of at the specific level of piece of information. Therefore, the model implemented in this study combined both ideas. Similarity of knowledge is a function of the number of pieces shared between two individuals, $SK_{ij}(t)$, and the similarity of the knowledge masks of the individuals, denoted $SKM_{ij}(t)$, and represented by a real number between 0 an 1. The mathematical expression of the similarity of knowledge is:

$$SK'_{ij}(t) = \frac{SK_{ij}(t) + SKM_{ij}(t)}{2}$$

The representation of knowledge

The individual's knowledge contains three different categories: task knowledge, group knowledge, and general knowledge. Task knowledge represents the knowledge that an individual has on a particular set of tasks, for example, the set of procedures or rules in order to perform a particular task. Group knowledge refers to knowledge about the other group members, knowledge about teamwork in a particular organizational and task settings as well as teamwork experience in general. Finally, the rest of the individual's knowledge is grouped under the general category.

Eight main experimental conditions (skill breadth x task experience x group experience) are manipulated by how many pieces of information an individual's memory contained and by how the breadth of knowledge was represented. The generalist/specialist condition in manipulated by representing the characteristics of the individual's skills in a knowledge mask, which is 64-bit array where the distribution of 1s and 0s models the breadth of knowledge. The more ones the mask contains, the more experience the individual will have represented in his or her memory. In addition, the closer the ones are from one another in the 64-bit array, the more specialized the individual will be. Thus, specialists are represented by a knowledge mask with clusters of ones. Table 1 shows different examples of knowledge masks.

	Knowledge mask	Description
A	0111100000011111111100111	Specialist knowledge with long experience
B	0000110111110000000000010	Specialist knowledge with short experience
C	0010011001001001010100 11	Generalist knowledge with long experience
D	1101000100010010101001 01	Generalist knowledge with long experience
E	0001000000001000100000100	Generalist knowledge with short experience

Table 1: Examples of Knowledge Masks

Example A shows a highly specialized individual with extensive experience because of the three clusters of ones and the number of ones in the mask, respectively. On the other hand, example B represents a specialist with shorter experience. If we compare the knowledge similarity of two individuals with the masks in examples A and B, the similarity will be low due to the minimal number of matching bits between the two masks. For instance, both individuals might be computer scientists but one is specialized in file systems while the other is an expert in computational theory. Examples C, D, and E represent generalists. All three categories of knowledge have a knowledge mask associated with each one of them.

The comparison of the knowledge mask is done at two levels. First, the number of matching bits is determined. Second, the mean and the standard deviation of the distribution of ones is calculated. The comparison mechanism can be explained with an example. In Table 1, mask C and D don't have many matching ones. However, the means and standard deviations of the distribution of ones will be relatively similar. This suggests that although at the specific bit level there is low matching rate, in general the two individuals have similar knowledge. Moreover, the adjacent positions are assumed to share some similarity of knowledge. Thus, the similarity between two knowledge masks is a function of number of ones that the masks have in the same position within the array and the comparison of means.

Cognitive psychology research has suggested that expert level of knowledge in a subject matter is reached over time and with an accumulation of 50000 organized chunks of information (Simon, 1991). Consistent with these results, task experience and group experience are modeled by manipulating the number of pieces of information of the corresponding type. The increasing number of pieces of information of a particular type, the more experienced the individual will be in that area. In addition, experience is represented in the number of ones that the knowledge mask has. Therefore, knowledge similarity is a function of the characteristics of the knowledge masks and the number of pieces of information that dyads share. From the implementation point of view, the initial amount of pieces of information to represent experience is random number between 500 and 1000, and to represent no experience is a random number between 0 and 500. Regarding the initialization of the knowledge mask, the number of ones to represent experience is a random number between 32 and 48, while no experience is represented by a random number of ones between 4 and 16.

The pieces of information are drawn from a knowledge base, which is initialized at the beginning of the simulation. The size of the knowledge base can be configured per type of information allowing the simulation of environments with varying complexities.

The tasks

In order to better understand the effects of organizational members on knowledge transfer and possible consequences on group performance, three different types of tasks were implemented. These are general tasks involving both pattern-matching and statistical relationships. For each problem, there is a true decision and a decision provided by the group members. Such a problem is divisible into a set of sub-problems, each of which is a 64-bit integer. Each group member has a distinct sub-problem, and given with that sub-problem, the group member decides - yes (represented as a boolean value true) or no (represented as the boolean value false). Based on the group structure, the group members will have different possibilities for discussing the sub-problem with other peers. Using the probabilities of interaction, the group members will randomly interact with other individuals sharing the sub-problems and the decisions. This sharing process might result in the regeneration of the group member decision about the sub-problem. Finally, the number of correct decisions reached over the total number of pieces of information that constituted the task yields the performance of the group in that particular task. The mean performance on each task is calculated per simulation run.

The main difference among them is the level of routiness, which is modeled by restricting the size of the pool of possible integers from where the tasks are drawn. The decision-making task is implemented as a sequence of 64-bit integers drawn from a set of 1000 possible values, randomly chosen at the beginning of the simulation. The group members infer the decision from their knowledge base contents. If the individuals do not have that piece of information in their memory, they will determine their decision by interpolating the relative quality of two closest pieces of information and affecting that interpolation by the relative distance of those pieces to the information not existent in the memory.

The rote task has a similar implementation as the decision-making task, however the 64-bit integers were drawn from a fix set of 50 possible numbers, randomly chosen at the beginning of the simulation. Finally, a guessing task was implemented as a decision-making task without adjustment of quality of the piece of information, thus, representing a highly unlikely event from which learning is minimal.

Tasks and Contents of Interactions

In the previous paragraphs, the models for the interaction among the individuals and for the various tasks have been described. However, these models do not explain which type of knowledge would be shared in each particular interaction. The work of Mintzberg on the nature of managerial work was the frame of reference used to solve this problem. Mintzberg, based on a five-week observation of managers, suggested that they spend their daily work on five different types of tasks: scheduled meetings, desk work, unscheduled meetings, telephone calls, and organizational tours (Mintzberg, 1973 - pp. 31-44). Each activity contains different degrees of interaction and the content of that interaction ranges from social conversations to task-related information. Table 2 shows the probabilities of interaction of each activity and the percentage of the type of content identified as general, task, and group.

	No Interaction	General Knowledge	Task Knowledge	Group Knowledge
Scheduled Meetings (49%)	0.00	0.31	0.55	0.13[1]
Desk work (22%)	0.74	0.17	0.05	0.03
Scheduled Inter-group meetings (10%)	0.00	0.31	0.55	0.13[2]
Unscheduled Meetings (10%)	0.00	0.12	0.68	0.20
Telephone Calls (6%)	0.00	0.13	0.68	0.19
Tours (3%)	0.14	0.28	0.15	0.43

Table 2: Activities and content of interactions.[3]

[1] Sensitivity analysis indicated that the results are not affected for values in the interval [0, 0.30]
[2] Sensitivity analysis indicated that the results are not affected for values in the interval [0, 0.55]
[3] Based on Mintzberg's description of managerial work (Mintzberg, 1973).

Mintzberg showed that managers consume 59% of their time in scheduled meetings. Three main kinds of activities take place in these kinds of meetings: ceremony, strategy-making, and negotiation. In this study, ceremony is considered to contain general content, while the other two activities are primarily task and group content-based. In addition, the scheduled meetings activity was divided in two different activities: scheduled meetings per se, which involves intra-group tasks and interaction, and scheduled inter-group meetings, which involves meetings and interaction among individuals from different groups. The amount of time an individual spends in inter-group meetings was defined as 10% of the work day. This percentage might be considered high for a host of organizations, particularly those with more emphases on specialized positions. However, individuals in project-based organizations (e.g. consulting firms) might spend more time in inter-group meetings. Also, the percentage of time spent in inter-group meeting might vary depending on the level in the organizational structure at which the individual is positioned.

Desk work, is mainly an independent activity, in which the individuals perform a small number of interactions. In the case of manager, those interactions, mainly, take place with the secretary scheduling meetings (general content) and in a smaller proportion with peers or subordinates discussing work-related issues. Desk work has been separated from two other activities, unscheduled meetings and telephones calls, because of the difference in the nature of the contents of the interactions. Unscheduled meetings and telephones calls is the preferred medium for requests and solicitations of task and status information, representing an instant communication path also used as problems arose suddenly.

Finally, observational tours provide the managers with unique opportunities to interact with different members of the organization, maintain ties, schedule brief meetings, and get status information.

Using this group of six activities and based on the probabilities indicated in Table 2, the simulation model randomly selects six interactions per time period per individuals. For each of those interactions, the type of content is also randomly selected. A group task is performed if all group members have a scheduled-meeting kind of activity in that time period. If the group members agree more than once in a time period, the group task will be performed as many times as the number of group-level agreements with respect to scheduled meetings.

Turnover

In this model, turnover occurs under three different situations. First, an organizational member might be transferred between organizations. An inter-organizational turnover is a function of the attributes of the environment as well as the decisions of the organizations regarding what repositories of knowledge those organizations choose to use in each time period. Within an organization, turnover occurs when members are transferred between groups or when individuals leave the organization and are replaced by new personnel. When turnover takes place, the model uses a probability of 0.5 to randomly determine the type of turnover: inter-group or not. Intra-organizational turnover is implemented by having a group member leave and another immediately enters periodically over time as a Poisson process with parameter λ[4]. The individuals that leave the organization are selected randomly. The skill characteristics, task experience, and group experience of the new individuals are randomly generated based on the experimental conditions. In the case of inter-group turnover, the individual will be transferred to a randomly selected group. An individual of the recipient group is selected to leave the organization and is replaced by the transferred individuals. A new individual joins the donor group.

The Environment

The environment consists of a set of attributes and components that define the basic rules under which the different organizations interact among them. The general characteristics of the environment are defined by two main attributes: uncertainty and competitiveness. Uncertainty is defined as the level of uncertainty existent in the environment. For instance, in the high-tech industry might refer to the volatile success of a product due to factors such as constant offering of substitutes products or shortage in parts to satisfy the demand levels. In the aeronautics industry might represent the variability of the demand of airplanes. In the specifics of the model, uncertainty is implemented as the variance in the tasks that an organization performs. The degree of uncertainty varies on how spread apart the integers selected as subtasks are. Therefore, the higher the uncertainty, the lower the likelihood that the organizational members have encountered that piece of information before.

Competitiveness is defined as a function of the degree of knowledge scarcity, the size of labor resources in the environment, and of the ratio of patents over articles existing in the environmental repositories. Knowledge scarcity is defined as the proportion of overlap in the set of knowledge the different organizations require. The higher the degree of knowledge scarcity, the higher the overlap will be. Consequently, organizations will be more likely to

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[4] The parameter λ indicates that on average λ turnovers will occur every other time period

compete for the particular pieces of knowledge they need. In the model, tasks are represented as a collection of integers (subtasks). The higher the degree of knowledge scarcity, the higher the number of integers that will be equal in the tasks performed by two different organizations.

In addition, the environment contains three components: a labor resource, a repository of patents, and a repository of articles. Initially, organizations recruit individuals from the labor resource, which is a representation of the labor marketplace. Over time, they will recruit from other organizations as well as from the labor resource. The size of the labor pool represents a factor of competitiveness in the environment. The larger the pool of individuals is, the higher the number of unemployed individuals that will be available. Therefore, organizations can be more selective in their recruiting efforts. The implementation contemplates two selection factors. First, individuals who contain a set of pieces of information more similar to the requirements of the organization are more likely to be hire. Second, an organizational culture attribute is associated with the organizations. In addition, each individual has the preference of organizational culture assigned randomly. Therefore, those individuals with preferences aligned with the organization's culture will be more likely to be part of that particular organization.

The knowledge generated by the organizations is stored in their members' memory, in the organization's structure and technology, and in the environment. The patents and articles repositories are the environmental representations of the knowledge created by an organization that is stored outside the boundaries of the organization. Patents are pieces of information that organizations can look at but they cannot use them unless they pay a corresponding royalty fee. On the other hand, articles are freely available pieces of information. The ratio between the number of patents and articles available in the environment represents another factor of environmental competitiveness. If the environment promotes cooperation among organizations the number of articles produced should be higher than the number of patents produced. Therefore, the ratio between patents and articles should be small. Organizations decide to produce an article or a patent when the organizations' knowledge contains pieces of information with the associated quality coefficient larger than a randomly generated threshold, which is a function of the environmental attributes. The decision whether an article or a patent is produced is a function of the ratio between the number of patents and articles.

Interaction among organizations

Almeida and Kogut (1999), in their study of localization and knowledge transfer among semiconductor companies, found that geographical proximity and the migration of engineers from one company to another are significant factors in knowledge transfer. These factors, in particular geographical proximity, might not be significant in other industries. For instance, Darr (1994), in his examination of knowledge transfer in pizza franchise organizations, found that geographical proximity was not a significant factor affecting knowledge transfer between stores. Thus, these contrasting results call for more systematic research. The model proposed in this paper provides some of the necessary tools to explore how location proximity might affect knowledge transfer depending of various environmental and organizational attributes.

The model extends the constructural theory (Carley, 1900, 1991) to represent the interactions among actors in the environment. Each actor has a probability of interacting with another, denoted $P_{ij}(t)$. This is the probability that the actor i chooses j for interaction. The probability that actor *i* chooses to interact with actor *j* at time t is a function of both the similarity of knowledge that those two actors have at time t, denoted $SKO_{ij}(t)$, and how distant, geographically or virtually, *i* is from *j*, denoted GD_{ij}, relative to *i*'s knowledge similarity and location proximity with the rest of the actors. The relative weight of location proximity and similarity of knowledge between two organizations is controlled by the coefficients β and δ. The probability of interaction is given by the following expression:

$$Pij(t) = \beta \frac{GD_{ij}}{\max(GD_{ij})} + \delta \frac{SKO_{ij}(t)}{\sum_{k=1}^{I} SKO_{ik}(t)} \quad where \beta + \delta = 1$$

Similarity of knowledge between two organizations, $SKO_{ij}(t)$, is defined as the proportion of knowledge requirements, denoted $KR_{ij}(t)$, and knowledge production, denoted $KP_{ij}(t)$, that two organizations, *i* and *j*, have in common at time t. If an organization *i* requires in one of its task a piece of knowledge *k*, the function $F_{ik}(t)$ will return 1, if not the function will return 0. Then, the proportion of knowledge requirements is given by:

$$KR_{ij}(t) = \frac{\sum_{k=1}^{K} F_{ik}(t) \times F_{jk}(t)}{K}$$

The proportion of knowledge production refers to the number of pieces of knowledge developed by two organizations that are similar or related. That is, pieces of knowledge that belong to the same domain and constitutes complementary pieces. The same procedure described previously to compare knowledge masks is used to determine the similarity of knowledge production.

As in the case of organizations, the model allows the definition of an environment structure. However, the role of this structure is to define the location proximity of the participating actors. Using different distance values allows the manipulation of the degree of clustering among the actors and of the number of clusters that will operate in the environment.

Finally, the model assumes that organizations use a cost-minimizing strategy when searching for the pieces of information to satisfy their knowledge requirements. Therefore, first the actor *i* searches the articles repository. If the piece of knowledge is not found, the actor will search the patents repository. Then actor *i* will interact with actor *j*. If at this stage the search is successful, actor *i* compares the cost of acquiring the knowledge from actor *j* or transferring an organizational member from actor *j* with the cost of the patent, and acts rationally minimizing the costs of the transaction.

Measures

Various measures are collected at user-defined fix intervals. At the organizational level, the measures are the total cumulative knowledge transferred, the total cumulative new knowledge transferred, and the ratio of successful task performance relative to the total number of tasks performed.

At the environment level, the measures are the total number of articles produced, the total number of articles acquired, the total number of patents produced, the total number of patents acquired, the total number of individuals transferred between organizations, and the total number of transactions performed by the organizations.

Comparison with existing models

Over the last decade an important number of models that focus on one or more aspects of organizational studies have been developed. In order to compare the model presented in this paper with other existing models, it is necessary to perform the analysis along various dimensions such as organizational-level features, environmental-level features, measures, and learning and cognitive features.

Feature	Plural-Soar[5]	Carley (1992)	Lin (1994)	March (1991)	This Model
Organizational Attributes:					
- Structure					
Multiple structural forms		Yes	Yes		Yes
Multiple groups					Yes
- Tasks:					
Non-decomposable		Yes	Yes		
Decomposable	Yes	Yes	Yes		Yes
Set of activities	Yes				Yes
Complexity		Yes			Yes
Routiness					Yes
Cooperation					Yes
- Knowledge:					
Memory	Yes	Yes		Yes	Yes
Knowledge domains hierarchy					Yes
- Learning:					
By doing	Yes	Yes			Yes
By sharing				Yes	Yes
From experience					Yes
- Turnover:					
Experience manipulation		Yes	Yes	Yes	Yes
Position manipulation		Partial			
- Interaction among members:					
Due to formal structure		Yes			Yes
Due to similarity					Yes
Due to task activities	Yes				Yes
- Technology					
Documentation					Yes
Other repositories				Yes	
Environmental Attributes:					
- Uncertainty			Partial	Yes	Yes
- Competition:					
For knowledge				Yes	Yes
For labor					Yes
- Location:					
Actors Clustering					Yes
Proximity importance manipulation					Yes
- Search approach					
Cost-Minimizing					Yes
Benefit Maximizing					
Measures					
- Performance measures	Yes	Yes	Yes		Yes
- Organizational design					
Efficiency measures			Yes		
Structure measures			Yes		
Cost measures			Yes		

Table 3: Comparison of the model at the organizational level.

[5] Carley et al. (1992)

In addition, the comparison becomes more complex due to the different views used to operationalized concepts. As indicated in previous paragraphs, the model is based on constructural theory (Carley, 1990, 1991) and it also draws concepts and ideas from two previous simulation models (Carley, 1992, Lin, 1994).

Table 3 shows an extensive set of features and which of those features are implemented by the model presented in this paper as well as by Plural Soar (Carley et al, 1991), by Carley's (1992) model, by March's (1991) model, and by Lin's (1994). There two major contributions of the proposed model. The first contribution is the integration of a more complex knowledge representation, the organizational members' interactions, and new forms of learning into commonly used organizational design and task models. The second contribution is a model of the environmental properties not previously implemented such as a knowledge-based operationalization of competition and location of the actors within the environment.

The proposed model does not implement an elaboration of the human problem-solving or decision-making paradigms such as Soar (Laird et al., 1987) and to certain extent Plural-Soar (Carley et al., 1991). On the other hand, the model presented in this paper has a broader view of organizational learning and knowledge sharing compared to other models such as March's (1991) and Harrison and Carrol's (1991). March (1991) presented a more abstract model that examined the effects of socialization rate, turnover, and environmental turbulence (or uncertainty) on sharing of beliefs. March's model did not incorporate organizational features such as structure, tasks, and members' interactions. Harrison and Carrol (1991) developed a model that examined organizational culture diffusion. Although they looked at various organizational structures, their model did not include environmental parameters, tasks, or members’ interactions.

Chapter 3: Virtual Experiment I

Considering selection scheme, task experience, group experience, organizational structure, and task type, this virtual experiment presents a 2 X 2 X 2 X 3 X 3 factorial design. Table 3 shows the different parameters and their respective values used in the simulations. The simulation of the 72 cases was done over 400 time periods. However, data were collected every 40 periods. Thirty runs of each simulation case were performed. In order to randomly generate profiles of individuals with the appropriate skill characteristics, task experience, and group experience, a condition ratio of 1 to 9 was used. For instance, in the generalist skill condition, the memory of the individuals would be set up as a generalist with a probability of 0.9, which implies there is a probability of 0.1 that the individual would be expertise-specific.

Parameter	Values
Number of time periods	400
Number of runs	30
Measures collected at time period	40 / 80 / 120 / 160 / 200 / 240 / 280 / 320 / 360 / 400
Organizational structure	Hierarchical / Hybrid / Team (fully-connected)
Organization size	30 individuals
Number of groups	3
Group size	10 individuals
Group tasks	Decision-Making / Guessing / Rote
Probability of generalist skill	0.1 / 0.9
Probability of task experience	0.1 / 0.9
Probability of group experience	0.1 / 0.9
Knowledge base size	1000 (per knowledge type)
Turnover rate	0 / 0.5 individuals per time period
Inter-group turnover	No (in all cases) / Yes (in all Rote Task cases)

Table 4: Simulation parameters for Virtual Experiment I.

The organizations simulated in this study contained three groups of 10 individuals in each group. Three organizational structures were examined: the centralized hierarchy, team (fully-connected), and a hybrid structure that combined characteristics of hierarchy and team.

The *centralized hierarchy* is modeled as a 2-tier hierarchical relationship among the groups and as a 2-tier hierarchical structure within each group. The *team* structure is modeled as a fully connected graph, that is, each group might interact with the rest of the groups. The group structure is modeled in the same way. Finally, the *hybrid* form is modeled as a 2-tier hierarchical relationship among the groups and as a 2-tier hierarchical structure within each group. However, the hierarchical relationship within the groups is not between one manager and N-1 group members. Instead, there is a manager and J subgroups with N-1/J members each.

Two turnover conditions were used: no turnover and a turnover rate of 0.5 individuals per time period. Inter-group turnover and inter-group turnover with the same task were only examined for all the conditions of rote task at the 0.5 individuals per time period rate.

	No Interaction	General Knowledge	Task Knowledge	Group Knowledge
Service activities (75%)	0.80	0.03	0.10	0.07
Group meetings (10%)	0.00	0.10	0.60	0.30
Spare parts mgmt (10%)	0.00	0.05	0.80	0.15
Training (5%)	0.00	0.25	0.50	0.25

Table 5: Alternative set of activities and contents of interactions.[6]

In order to examine how the contents of interaction affect knowledge transfer, a different set of activities (*see Task and Contents of Interaction in the previous section*), based on the group task described in Wageman (1995), was defined. Wageman studied the effects of interdependence on group effectiveness in service technicians groups of Xerox Corporation. The group members were responsible for repairing copier machines and most of the time was spent in the customer site. However, there were various degrees of interaction

[6] Based on Wageman's description of field service work groups.

with other group members in activities such as group meetings, job assignments, spare parts management, and training. Table 4 shows the approximate probabilities of interaction of each activity and the percentage of the type of content identified as general, task, and group, defined from my analysis of the study.

Results

The results of the simulations are shown in Figures 2 through 8 in Appendix A and in Tables 7 through 15 in Appendix B. There was a significant effect of organizational structure on the amount of total knowledge transferred with and without turnover (Table 11), regardless of skill characteristics, task experience, and group experience. There was also a significant effect of organizational structure on the amount of total new knowledge transferred with and without turnover (Table 14), regardless of skill characteristics, task experience, and group experience. In particular, the fully-connected structure allowed the highest amount of total knowledge and total new knowledge transferred (Figures 2.a, 2.b, 2.c, and 2.d). The hierarchical structure was the most restrictive with respect to the possibilities to transfer knowledge.

There was no statistically significant effect of task type on the amount of total knowledge transferred either with or without turnover (Table 11). However, there was a significant effect of task type of the amount of total new knowledge transferred under turnover conditions and without turnover (Table 14). The comparison of the means (Figure 8) showed that the decision-making task promoted knowledge transfer more than the guessing task or the rote task. In particular, the amount of new knowledge transferred decreased over time when groups perform rote tasks because individuals are likely to learn most of the pieces of information (Figures 5.a, 5.b, and 5c) in fewer time periods than the ones needed to learn all the pieces of information of the other two tasks.

Skills characteristics (generalist or specialist) had a significant effect on the amount of total knowledge transferred without turnover (Table 10). There was also a significant effect of skills characteristics on the amount of total new knowledge transferred without turnover (Table 13). Organizations with a majority of generalist individuals exhibited higher levels of knowledge transferred than organizations with majority of specialist individuals (Figure 3.a and 3.b). Surprisingly, under turnover conditions, skills characteristics affected significantly the amount of total amount of total knowledge transferred with turnover (Table 9) and the total new knowledge transferred only during the first 320 time periods and 280 time periods (Table 12), respectively.

Task experience and group experience affected the amount of total knowledge transferred and the amount of total new knowledge transferred in interesting ways. As table 9 and table 12 show, under turnover conditions, there was a significant effect of task experience and group experience only in the last 160 time periods of the simulation, coincidentally as the effect of skill characteristics becomes not significant. There was also a strong task experience x group experience interaction effect. Figures 4.a and 4.b show that the highest amount of total knowledge transferred occurs when individuals have task and group experience with or without turnover. When there was no turnover, task experience and group experience did not produce any statistically significant effects (Table 10 and Table 13).

Tables 7 and 8 show that there was no significant direct effect of skill characteristics, task experience, and group experience on rate of learning performing the tasks. However, skill characteristics, task experience, and group experience, as well as organizational structure, affected the amount of knowledge transferred, which in turns affected the rate of learning. The higher the amount of knowledge transferred, the faster the groups learned about their tasks.

As figures 2.a, 2.b, 2.c, 2d, and 6 show, turnover affected the total amount of knowledge transferred and the total amount of new knowledge transferred. The higher the turnover, the more knowledge is transferred. This increase in knowledge transferred in turns affected the performance on the groups (Figures 5.a, 5.b, and 5.c). In decision-making tasks (Figure 5.a), there was a small difference in performance between the turnover conditions, with the no turnover groups performing slightly better than the turnover groups. However, the results are insignificant. For guessing tasks, as expected, there was no learning. Nevertheless, as the amount of knowledge transferred increases, there is a slightly faster convergence of the performance to 0.5 (Figures 5.a). Figures 5.c shows the group performance for rote tasks. Performance increased the lowest in the turnover condition. However, when some of the employees selected to leave the organization are transferred to another group (inter-group turnover condition), group performance increases at a slightly faster rate than in the no turnover condition. The best performance and learning rate occurs in the inter-groups turnover condition when groups perform the same task.

Finally, there was a strong statistically significant effect of the set of activities and content of interaction in the total amounts of general knowledge transferred, of task knowledge transferred, and of group knowledge transferred (Table 15). Group members performing the set of activities indicated in Table 5 will have a less interactive and more task-focused behavior than those performing the set of activities described in Table 2. As

Figure 7 shows, these differences impacted significantly the amount of knowledge transferred.

Chapter 4: Discussion of Virtual Experiment I

The results of this virtual experiment showed that skill characteristics, task experience, and group experience are important factors affecting how knowledge is transferred in an organization. Organizations in which the majority of members have generalist skills allowed more knowledge to be transferred than organizations with a majority of expertise-specific individuals. Since in this model generalist individuals were represented by knowledge masks with less skewed distributions of 1s (see *The representation of knowledge*) than specialist individuals, generalists might have had higher knowledge similarity with more individuals than specialists had which may have led to more possibilities of interaction. Under conditions of turnover, the effects of skill characteristics decreased over time and task and group experience became significant factors in determining how knowledge is transferred. In organizational terms, these results suggest that initially organizational members are not cognizant of what the other individuals know, and therefore since generalist individuals have a broader understanding of organizational issues or processes, generalists are more likely to have more interactions with other individuals than specialists have. Consequently, organizations with majority of generalists would allow more knowledge to be transferred. Over time, individuals learn about the organization and its environment and they accumulate experience. Task experience and group experience become more relevant factors in determining how interactions occur because individuals with the appropriate task and group experience represent important sources of knowledge. As a result, how much knowledge is shared will be affected by the patterns of interaction of experienced individuals rather than by the patterns of interaction of generalists.

The type of task affected the amount of new task knowledge transferred, mainly due to the manipulation of routiness. For instance, rote task consisted only of 50 different possible pieces of information. Once group members share all the pieces stability is reached. Therefore, there is no need to share more new knowledge, except under turnover conditions. However, this situation did not occur in the decision-making and guessing task because they consisted of much larger sets of pieces of information, and stability could not be reached during the 400 time periods of the simulations.

On the other hand, the type of task did not affect the total amount of knowledge transferred. One reason for this could be that the tasks implemented in this model have all the same characteristics except for the level of routiness. Job characteristics such as interdependence might be factors that affect how knowledge is transferred among individuals. Highly interdependent groups are more likely to have more opportunities for interaction and higher necessity to share information than groups with low interdependence. Therefore, we would expect to see larger amounts of knowledge transferred in highly interdependent groups than in group with low interdependence. Support for this explanation was provided by the comparison between two different sets of activities. As indicated in previous sections, a set of activities and the contents of the interaction (Table 2) were defined based on Mintzberg's (1973) description of the nature of managerial work. In addition, a second set of activities and content of interaction (Table 4) was defined based on Wageman's (1995) description of field service groups. These two kinds of tasks differ significantly in its nature, in particular, in the need to interact and in the need to share information among group members. When groups performed a rote task, those groups that interacted based on the activities from Table 2 showed a larger amount of knowledge transferred than the groups performing the activities in Table 4. However, this analysis was done only on one type of task. More systematic research is needed in order to achieve a better understanding of how job characteristics affect knowledge transfer.

The organizational structure is also another important element that moderates the amount of knowledge transferred in an organization. Hierarchical structures are the most restrictive in terms of knowledge transfer. In this case, the sharing of information between two group members occurs only through the manager. The role of the manager as an intermediary represents a bottleneck in the process of knowledge transfer. Therefore, the amount of knowledge that can be transferred is reduced. In the fully-connected structure, organizational members have more possibilities of communication which facilitates the sharing of knowledge. However, fully-connected organizational structures are unlikely to exist in their pure form. Characteristics of the environment, in which the organization exits, such as degree of ambiguity and uncertainty require that organizations achieve a balance between integration and differentiation in order to maintain and increase performance (Lawrence & Lorch, 1967), therefore, reducing the number of communication channels. In fact, fully-connected organizations might suffer from information overload which in turn affects the organization negatively (Galbraith, 1973). Thus, sharing knowledge might not be beneficial to the organization. The results of this study suggest the hybrid organizational structure as an interesting alternative to both the fully-connected and the hierarchical organizational structures. The hybrid structure allowed more knowledge to be transferred than the average between the other two organizational forms. Therefore, the hybrid structure is more suitable for sharing knowledge than the hierarchical form and it is less susceptible to information overloading than the fully-connected organization.

One of the objectives of transferring knowledge within the organization is to allow the different units or individuals to learn from the experiences or work of other organizational groups or members and as a consequence to improve organizational performance (Argote, 1999). The performance measures of groups working of rote tasks provided interesting insights to the benefits of knowledge sharing under varying conditions of turnover (Figure 5.c). When none of the organizational members leave, learning occurs and performance increases monotonically over time. Under conditions of turnover, knowledge and experience are lost when the individuals leave the organization because knowledge might be difficult to articulate and therefore is not possible to store it in mechanisms such as technology. Consequently, a certain level of organizational forgetting (Argote, 1999) occurs and, in this study, is reflected in a slower rate of performance increase.

Research has shown that transferring individuals between units or groups is an effective mechanism of knowledge transfer (Argote, 1999). This study provided additional evidence consistent with those findings. Transferring individuals among groups allowed the organization to overcome the negative effect of turnover, increasing performance over time to the levels of the no-turnover condition. This positive effect was further magnified in the case where the groups performed the same task because the information that the new group member was able to share was the same set of pieces of information used by the group. These results suggest that although the donor group's performance might suffer from the departure of a group member, this decrease is offset by the increase in performance of the recipient group. This situation might occur because the new member is experienced in the particular task or in situations relevant to the context of the task, therefore, the group members incorporate this new knowledge and group performance increases. An alternative explanation could be that the new individual brings access to resources that the other group members did not have. In this case, the improvement in performance stems from learning who knows what or who has what.

Chapter 5: Virtual Experiment II

Considering environmental uncertainty, environmental competitiveness, location clustering of organizations, location importance, breadth of skill, and organizational structure, this virtual experiment presents a 2 X 2 X 2 X 2 X 2 X 2 factorial design. Table 3 shows the different parameters and their respective values used in the simulations. The simulation of the 64 cases was done over 400 time periods. However, data were collected every 40 periods. Forty runs of each simulation case were performed.

Parameter	Values
Number of time periods	400
Number of runs	40
Measures collected at time period	40 / 80 / 120 / 160 / 200 / 240 / 280 / 320 / 360 / 400[7]
Environmental Uncertainty	0.1 / 0.9
Environmental Competitiveness	High / Low
Knowledge Scarcity	0.9 / 0.1
Ratio Articles/Patents	0.9 / 0.1
Labor Pool Size	100 / 200
Location proximity	1 cluster / 2 clusters
Location importance	0.1 / 0.5
Initial size of the repositories	450 pieces (in total)
Number of Organizations	3
Organizational structure	Hierarchical / Team (fully-connected)
Organization size	30 individuals
Number of groups	3
Group size	10 individuals
Group task	Rote
Probability of generalist skill	0.1 / 0.9
Probability of task experience	0.9
Probability of group experience	0.9
Knowledge base size	1000 (per knowledge type)
Turnover rate	0.5 individuals per time period
Inter-group turnover	Yes

Table 6: Simulation parameters for Virtual Experiment II.

The degree of competition is a function of knowledge scarcity, the ratio between the number of patents and the number of articles stored in the environmental repositories, and the size of the labor pool. The values indicated in Table 6 for those three factors gave a high competition condition with an approximate value of 0.7 and a low competition condition with an approximate value of 0.2. Regarding location proximity, two conditions were defined, one condition with all organizations clustered together and the second one with two organizations clustered and one distant organization. In addition, the importance of proximity was evaluated with the β factor equal to 0.1 and 0.5.

The environmental repositories were initialized with a total of 450 items. The proportion of articles and patents was determined based on the experimental conditions. Although organizations might be new in a particular environment, they have access to external expertise and knowledge that might be useful in their development. Therefore, the existence of pieces of knowledge in the environment at the beginning of the simulation intended to provide a more realistic setting by providing an external support for newly created organizations.

The organizations simulated in this study contained three groups of 10 individuals in each group. Two organizational structures were examined: the centralized hierarchy and team (fully-connected). The centralized hierarchy was modeled as a 2-tier hierarchical relationship among the groups and as a 2-tier hierarchical structure within each group. The team structure was modeled as a fully connected graph, that is, each group might interact with the rest of the groups. The group structure is modeled in the same way.

Dependent variables such as the number of articles published and retrieved, the number of articles published and retrieved, the number of people transferred between

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[7] The last 40 time periods were discarded from the analysis due to partial loss of data

organizations, the total amount of knowledge transferred directly between organizations, and the total number of transactions, were measured.

Parameters such as group task, inter-group turnover, probability of task experience, and probability of group experience were kept fixed at the values indicated in Table 6. The results of the first virtual experiment suggested that under those conditions knowledge transfer within the organization is highly facilitated.

Results

The results of the simulations are shown in Figures 9 through 27 in Appendix C and in Tables 16 through 24 in Appendix D. The two main attributes of the environment, uncertainty and competition, had a statistically significant effect on many of the dependent variables. First, uncertainty affected negatively the amount of articles published and retrieved as well as the amount of patents published and retrieved (Table 16, Figures 9, 10, 11, and 12). In addition, the higher the uncertainty, the lower the number of people transferred between organizations (Figure 13). However, this last result only reached statistical significance after 200 time periods (Table 16).

Second, environmental competitiveness affected the publication and retrieval of articles and patents in opposing ways. The number of articles published and retrieved was significantly smaller in the high competition condition than in the low competition condition (Table 17, Figures 14 and 15). Conversely, under high competition the number of patents published and retrieved was significantly higher than in the low competition condition (Table 17, Figures 16 and 17). The higher the competitiveness, the higher the number of people transferred between organizations (Figure 18). However, this last result only reached statistical significance after 240 time periods (Table 17). Competition also affected positively the total number of transactions (Table 17, Figure 19) performed among the different environmental actors.

The results showed a significant uncertainty by environmental competitiveness interaction effect on the total number of transactions (Table 18). Figure 26 shows the comparison of the average number of transactions. Under high uncertainty and high competition the organizations generated the most transactions while under low uncertainty and low competition, the organizations produced the lowest number of transactions.

Breadth of skill had a negative statistically significant effect on the number of articles and patents retrieved (Table 23). Organizations with generalist individuals retrieved more articles from the environment than organizations with specialists (Figure 22). Conversely, organizations with mostly generalist members retrieved less patents from the environment that organizations with specialists (Figure 23). In addition, organizations with generalist individuals transferred a fewer number of people (Table 23, Figure 24) and produced a lower number of transactions (Table 23, Figure 26) than organizations with mostly specialist individuals. The results showed no uncertainty by competition by breadth of skill interaction effects (Table 24).

Organizational structure was introduced in the model in order to examine how it might affect the various measures. However, the results showed no statistically significant effect on any of the dependent variables (Table 19).

This model implemented the concept of location importance as a factor for determining interaction probabilities among the environmental actors. The results showed no significant effects of location importance (Table 20), of the number of clusters of organizations in the environment (Table 21), and no location importance by number of clusters interaction effects (Table 22) on any of the measures. However, a detailed analysis of the data revealed an effect of location importance and number of clusters in the number of interactions between organizations (Figure 27). In the high location importance and two clusters condition, organizations 1 and 2 interact mostly between themselves while organization 3, which it is equally distant from the other organizations, interact equally with organization 1 and 2.

Finally, an examination of Figures 9 through 12, and Figures 14 through 17 shows that the number of articles and patents retrieved from the environment is larger than the number of pieces published. The articles and patents repositories had an initial combined size of 450 pieces and this condition allowed a number of retrieved items higher that the number of published items. In addition, having patents or articles available in the environment at the beginning of the simulation eliminates the possibility of obscured effects due to the lack of sufficient pieces of knowledge in the environment.

Chapter 6: Discussion of Virtual Experiment II

This second virtual experiment had two objectives. First, it looked at how the attributes of the environment facilitate or hinder the capabilities of organizations to share knowledge among themselves. Second, it explored if individuals' and structural characteristics affect knowledge transfer at the environmental level. The results suggested that uncertainty, environmental competitiveness, and breadth of skill are important factors affecting how knowledge is transferred among organizations. In addition, location of the organization emerged as a factor that potentially might have an effect on knowledge transfer at the environmental level.

Organizations operating in a highly uncertain environment published and retrieved fewer articles and patents than when those organizations were part of an environment with a low level of uncertainty. In addition, the higher the uncertainty, the lower the number of people transferred between organizations. In the model, as individuals perform their tasks, the quality of the pieces of information they have in their memories increases, consequently, the higher the likelihood of selecting those pieces of information to be published as either articles or patents. Moreover, uncertainty was implemented as the variance in the tasks that an organization performs. Therefore, under high uncertainty conditions, organizations are less likely to find in the environment articles or patents that satisfy their knowledge requirements. The same explanation applies to the difference in the number of people transferred between organizations. Since individuals learn from performing the task, in highly uncertain environments organizations are less likely to find a member of another organization that fit their knowledge and skills needs. Researchers have suggested that organizations that are top performers are the ones that fit the better with their environment

(Argote, 1982; Lawrence & Lorch, 1969; Schoonhoven, 1981). Transporting this idea into the context of knowledge transfer, the results of this experiment suggest a low fit between the organizations and their environment. However, the model did not implement any adaptation mechanism to allow organization to evolve their interpretation of the environment. Therefore, the results should be taken cautiously.

Environmental competitiveness affected the publication and retrieval of articles and patents in different ways. In a highly competitive environment, organizations published and retrieved fewer articles than when they operated in a cooperative environment. Conversely, under high competition the number of patents published and retrieved was significantly higher than in the low competition condition. In this model, competition is a function of the degree of knowledge scarcity, the size of labor resources in the environment, and of the ratio of patents over articles existing in the environmental repositories. This last factor determines whether a piece of knowledge will be published as an article or as a patent. Since the ratio of patents over articles is high in a competitive environment, organizations will be more likely to publish patents than articles, which explains the opposite behaviors regarding publication of articles and patents. In addition, it implies that organizations will be more likely to find the pieces of knowledge they need in patents rather than in articles. Consequently, more patents will be retrieved under high competition than in a cooperative environment, however, the reciprocal situation occurs in the case of articles.

In addition, the higher the competitiveness, the higher the number of people transferred between organizations and the higher the number of transactions performed among the different environmental actors. Competition is also a function of knowledge scarcity defined as the proportion of overlap in the set of knowledge the different organizations require. The higher the degree of knowledge scarcity, the higher the overlap will be. Therefore, in highly competitive environments organizations are more likely to find members of other organizations that have knowledge that might be beneficial to those organizations. Consequently, more individuals are transferred among organizations under high competition than in cooperative environments.

Regarding the effect of competition on the number of transactions, this model implemented a cost-minimizing strategy, which followed a set of steps beginning with a search in the articles repository and the patent repository. The third step was to interact with a particular organization and determine whether that organization contained the piece of knowledge needed. If this last search was successful, then the organization determined whether the piece of information was available in an individual's memory or in the documentation. In a highly competitive environment, organizations were more likely to go through all the previous steps than in a cooperative environment for two reasons. First, in an environment with low levels of competition the article repository contains a substantially larger number of pieces than in a highly competitive environment. Second, in cooperative environments knowledge scarcity is low, therefore, organizations are less likely to have knowledge that might be useful to other organizations. Consequently, the last steps of the search strategy are less likely to occur. A possible interpretation of these results is that in competitive environments, organizations face a higher cost of searching for and transferring knowledge than in cooperative environments.

An interesting uncertainty by environmental competitiveness interaction effect on the total number of transactions was shown by the results. Under high uncertainty and high competition the organizations generated the most transactions, while under low uncertainty and low competition, the organizations produced the lowest number of transactions. At the model level, organizations operating in a highly competitive environment were more likely to go through all the steps of the cost-minimizing strategy described in previous paragraphs, consequently, increasing the number of transactions. Since under high uncertainty conditions organizations are less likely to find their knowledge requirements in other organizations, this increases the number of steps of the cost-minimizing strategy organizations go through, therefore, the number of transactions increases. This explains the uncertainty by competition interaction effect was shown by the results.

If we consider the semiconductor industry as a highly competitive one, the results described in the previous paragraphs are somewhat consistent with Almeida and Kogut's (1999) finding that the number of patents used by an organization is associated with the number of people transferred from other organizations. The analysis of the results did not look at the correlation between people transferred and patents retrieved from the environment. However, the data show that, in competitive environments, the number of people transferred and the number of patents retrieved increase over time.

Von Krogh and Roos (1996), in a research project that looked at knowledge management within organizations and in cooperative strategies, emphasize the complexities of understanding how knowledge is transferred in cooperative and competitive environments. Many different strategies can be used to facilitate and promote knowledge transfer, such as imitation, and interaction (e.g. partnerships, joint-ventures, or technology transfer agreements). However, the decision regarding which approach is the most appropriate depends on the characteristics of the industry or industries where the organization participates. Since the model of the environment presented in this paper is static in nature, the interpretation of the results from the environmental standpoint is difficult. Therefore, the suggested effects of competition on how knowledge is transferred should be considered with caution and the representation of the environment should be enhanced.

Organizations with generalist individuals retrieved more articles from the environment than organizations composed of specialists. However, organizations with mostly generalist members retrieved fewer patents from the environment that organizations with specialists. In addition, organizations with generalist individuals transferred fewer number of people. On the one hand, these results suggest that when the cost of specific knowledge existent in the environment is low (in this model articles are for free), organizations with mostly generalist individuals are likely to incorporate that knowledge as a complement to their generalist-skilled work force. On the other hand, when the required knowledge is highly costly, organizations with mostly generalist individuals tend to rely on their members' generalist skills instead of acquiring that new knowledge. Moreover, the results regarding transferring individuals between organizations might be interpreted as a protection mechanism organizations use because their generalist individuals represent a cost-effective trade-off between acquiring new knowledge from the environment and the time for the individuals to develop the new skills.

Organizational structure was introduced in the model in order to examine how it might affect the various measures. However, the results showed no statistically significant effect on any of the dependent variables. There are two possible explanations to this result. First, the model makes no distinction about which member is allowed to publish an article or patent. Therefore, the structural effects on how much knowledge is shared in the interactions between individuals performing a task are not reflected at the environmental level. Second, when a turnover occurs the individual is chosen randomly, consequently, the weakness of the hierarchical structure, such as loosing a manager, is less likely to surface.

Finally, this model implemented the concept of location importance as a factor for determining interaction probabilities among the environmental actors. However, the results showed no significant effects of location importance, of the number of clusters of organizations in the environment, and no location importance by number of clusters interaction effects on any of the measures. The possible reason for these results is the design of the experiment. Only three organizations were simulated, which led to only two clusters: one with two organizations and a single-organization cluster. This situation did not generate enough differentiation in terms of the knowledge they acquired over time, in particular for the organization that was separated from the two-organization cluster because it was still interacting with the other two organizations. Duplicating the number of simulated organizations will provide a much better scenario to explore the effects of location importance and location proximity. First, two very distinct clusters can be formed. Second, a higher number of articles, patents, and individuals in the system might allow a better examination of all the potential effects of the various independent variables.

Chapter 7: Conclusions

The results of this research project showed two main findings. First, organizations mostly composed of generalist individuals shared more knowledge than those organizations with mostly specialist members. However, over time the effects of breadth of skills diminished while task and group experience took active roles in how knowledge is transferred. The more task and group experience the individuals had, the higher the number of pieces of information that were shared. Second, the data suggested that organizations with mostly generalist individuals retrieved more articles from the environment than organizations with specialists. Conversely, organizations with mostly generalist individuals were more likely to retrieve fewer patents from the environment than organizations with mostly specialists.

In addition, some other interesting findings should be highlighted. First, organizational structure had a strong effect on the amount of total knowledge transferred with and without turnover, with the fully-connected structure as the most beneficial for knowledge transfer, while the hierarchical structure was the most restrictive. Second, the best group performance and learning rate occurred in the inter-groups turnover condition when groups perform the same task. Third, the results showed that the set of activities performed within a task and the content of interactions are important factors that determine how much general knowledge, task knowledge, and group knowledge is transferred. Finally, environmental attributes such as uncertainty and competition had a strong negative effect on how much knowledge is shared among organizations.

The study presented in this paper has two types of limitations. First, the virtual experiments presented a partial exploration of the parameter space. For instance, the number of organizations simulated in the second virtual experiment was too small, consequently, the possibilities to examine the effects of location importance and the number of clusters in the environment was limited. In addition, the experiments did not consider more heterogeneous conditions such as organizations with groups performing different types of tasks or organizations with different ratios of generalists versus specialists operating in the same environment.

The model presented a number of design limitations as well. First, the simulation model did not implement knowledge depreciation (Argote, Beckman, & Epple, 1990). For instance, once an individual learned a piece of information, it would be in the individual's memory forever. Although organizational forgetting effects can be partially modeled through turnover, knowledge depreciation could alter the results in a negative way. Second, the model did not consider group experience as an element in the design of the task. If group members would have been able to interpret the pieces of information related to group experience, those individuals might have been able to develop a group mental model, changing their patterns of interaction and that could have led to variations in their performance (Klimoski & Mohammed, 1994). Another limitation of the study is the way sharing occurs. When two individuals interact and share a piece of information, this newly acquired knowledge is instantaneously "available" to be used by the recipient. However, this might not necessarily be realistic, in particular with tacit knowledge such as problem solving in software development. Although a quality coefficient is associated with each piece of information, in this model after sharing that knowledge both individuals have the same quality value for that particular piece of information. This is more likely to occur with certain types of knowledge such as rules or particular procedures than with more difficult to articulate knowledge such as how to develop a successful business strategy. Fourth, the representation of the environment as well as the representation of the organizational procedures was limited. Different industries or multinational organizations might have diverse competition rules or search strategies other than the cost-minimizing one implemented in this model. Therefore, different patterns of knowledge sharing might emerge. Fifth, the model did not implement any feedback loops such as patent expiration, or dynamic change of environmental conditions. The lack of this feature might explain the monotonic behavior shown in many of the figures of appendix A and C. Finally, the model does not contemplate variations in the demographics. For instance, the labor pool maintains the same size over time and individuals do not change their skill set.

Although the study has limitations, the results provide valuable information as a starting point in the quest for deeper understanding of how individual's characteristics affect the knowledge transfer process in organizations. In addition, the limitations suggest various paths for future work. First, the results obtained in this study need to be contrasted with results from empirical studies in order to validate the model. Second, more comprehensive experiments need to be performed. The conditions studied by the virtual experiments presented in this paper represent a small subset of all the possible combinations of parameters. The examination of new conditions will allow us to better understand, for instance, the effects of location and structural characteristics on knowledge transfer. Finally, a number of improvements should be made to the model. A better environmental representation will permit us look closer at questions such as how the characteristics of a particular industry affect knowledge transfer among organizations? And how knowledge is shared among subunits of large organizations? The addition of dynamic changes in the environment as well as in the characteristics of the individuals will provide more realistic longitudinal results. In addition, the model should support new communication technologies such as e-mail because they might represent a significant change in the patterns of interaction among individuals, and therefore, in how knowledge is shared.

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Appendix A: Figures for Virtual Experiment I

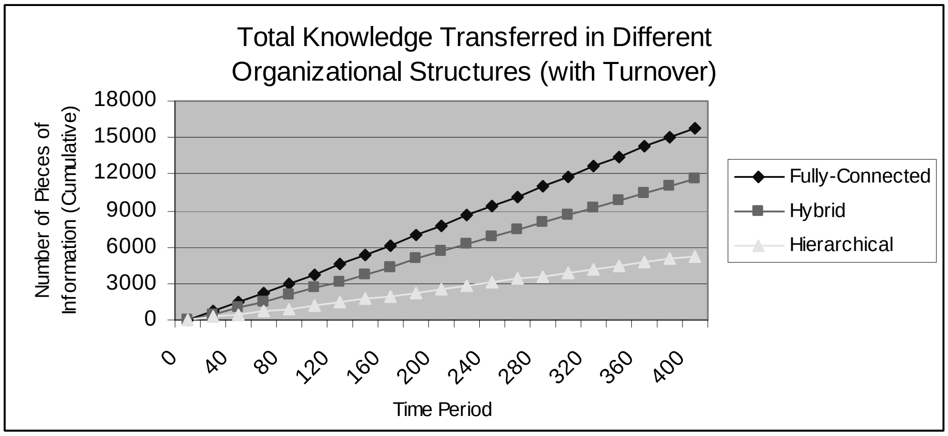

Figure 2a: Total Knowledge Transferred in Different Organizational Structures

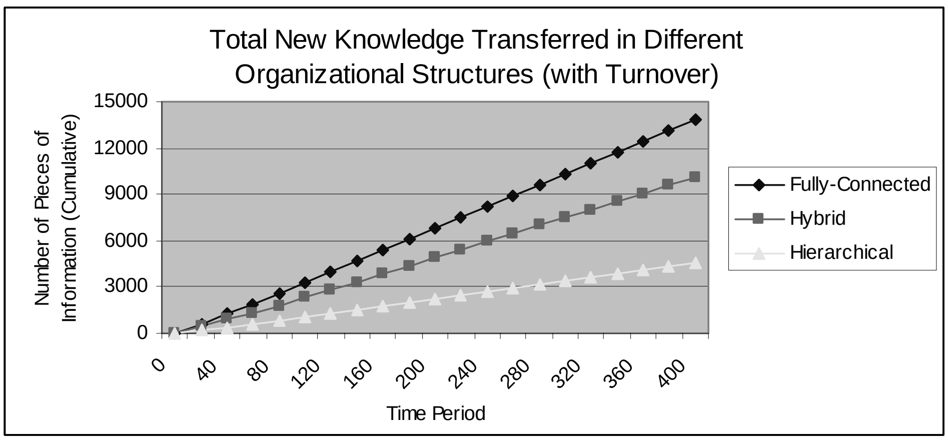

Figure 2b: Total New Knowledge Transferred in Different Organizational Structures

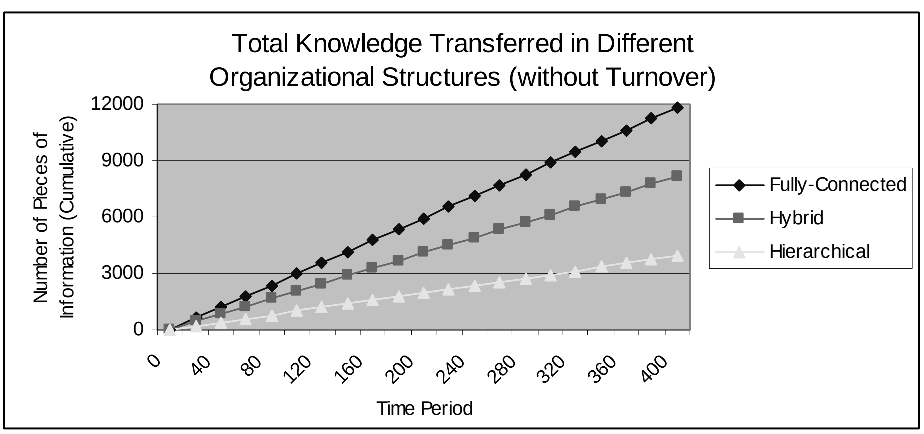

Figure 2c: Total Knowledge Transferred in Different Organizational Structures without Turnover

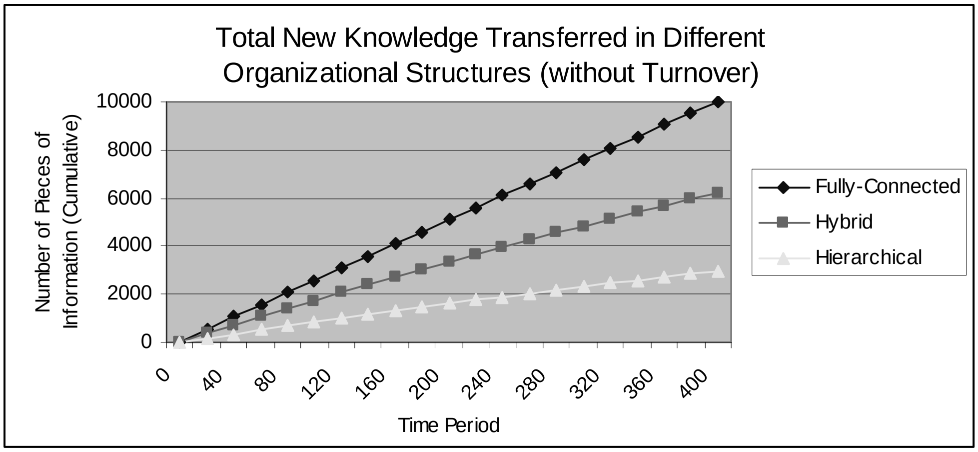

Figure 2d: Total Knowledge Transferred in Different Organizational Structures without Turnover

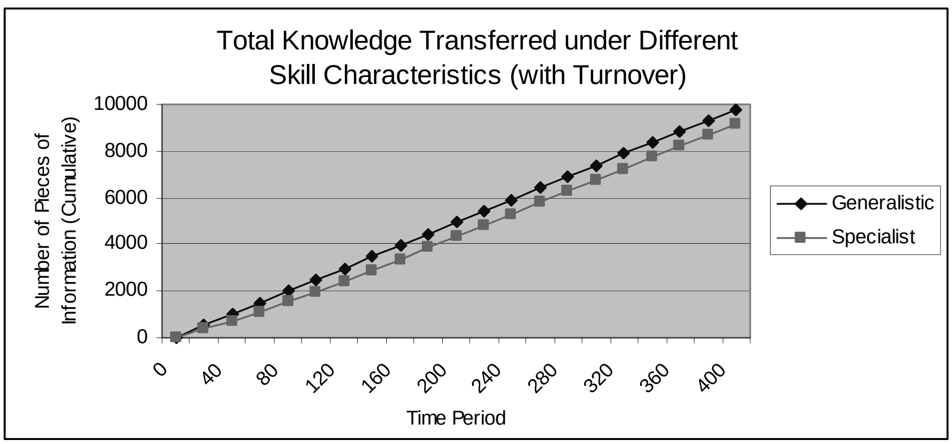

Figure 3a: Total Knowledge Transferred under Different Breadths of Skill

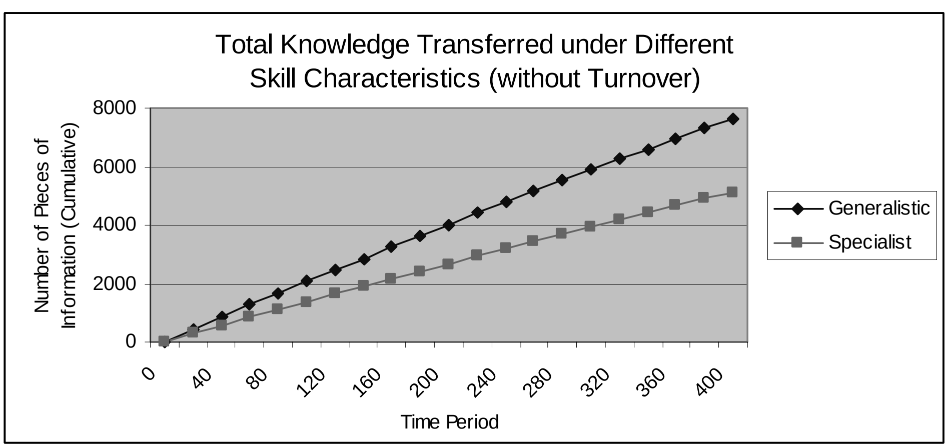

Figure 3b: Total Knowledge Transferred under Different Breadths of Skill without Turnover

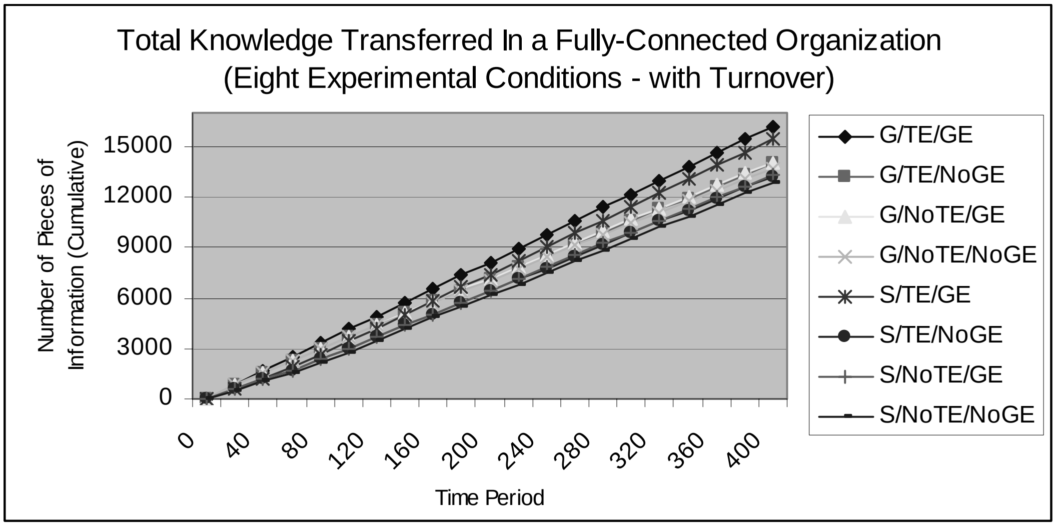

Figure 4a: Total Knowledge Transferred under Different Experimental Conditions

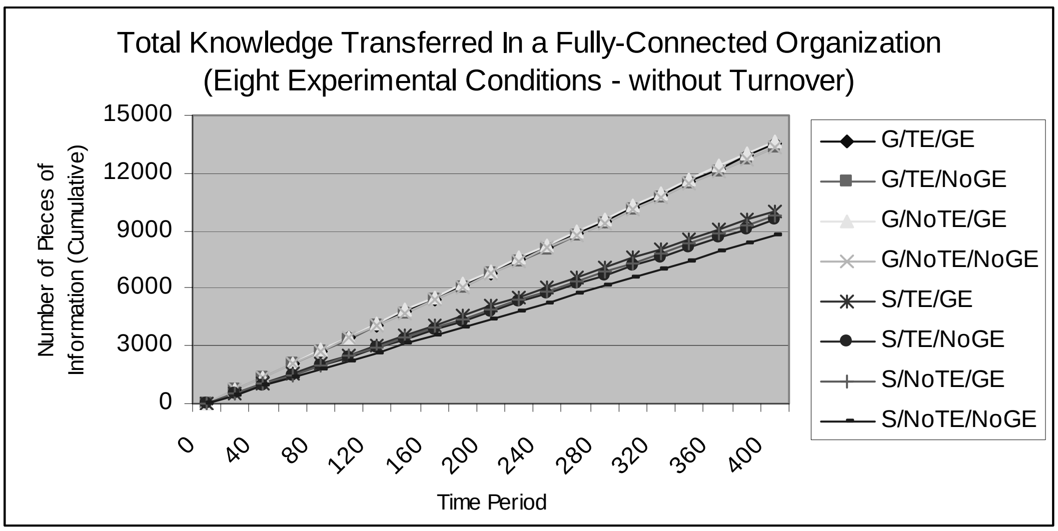

Figure 4a: Total Knowledge Transferred under Different Experimental Conditions without Turnover

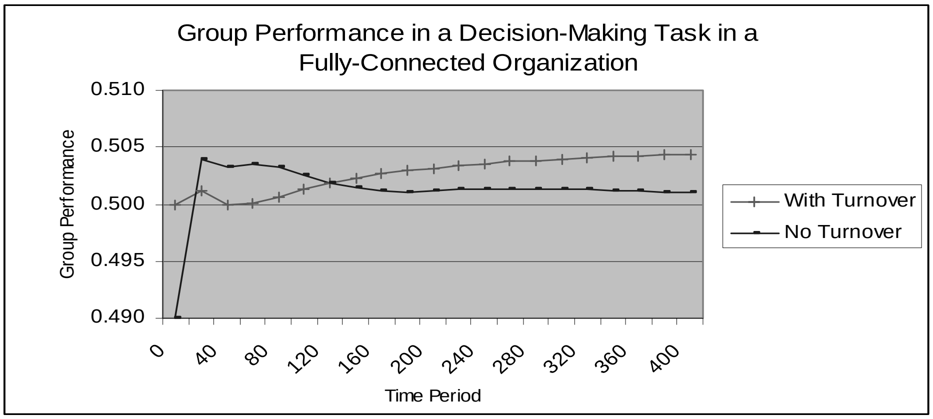

Figure 5a: Group Performance in Decision-Making Task

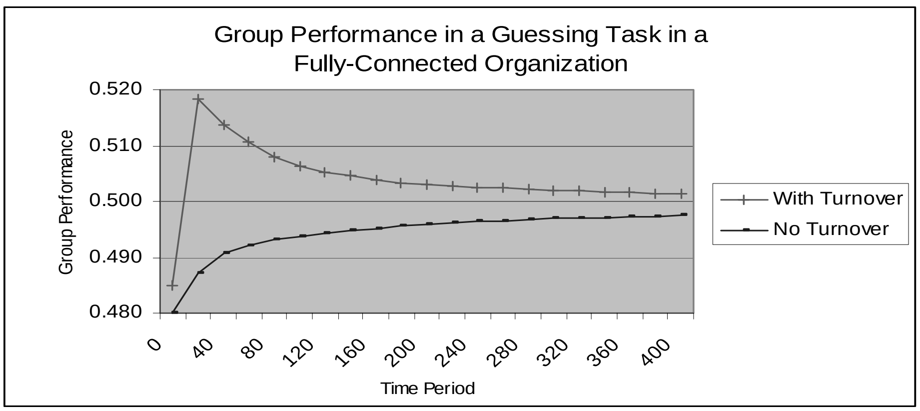

Figure 5b: Group Performance in Guessing Task

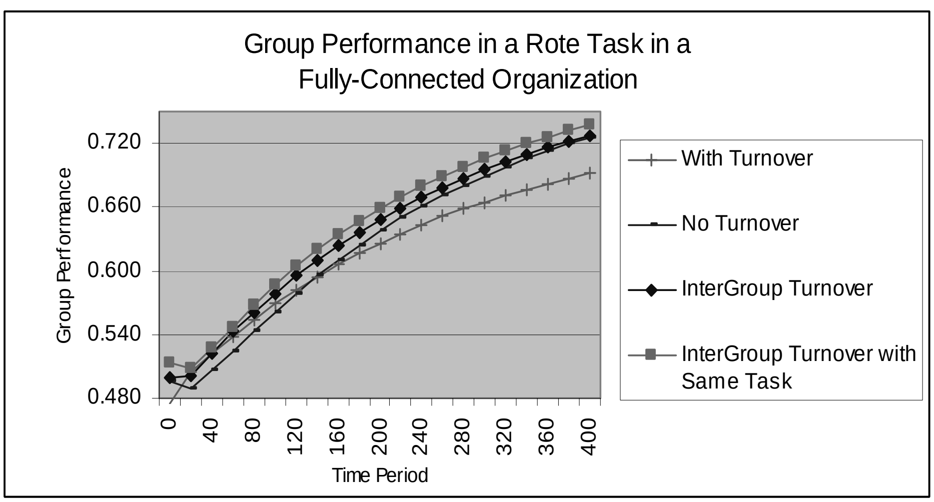

Figure 5c: Group Performance in Rote Task

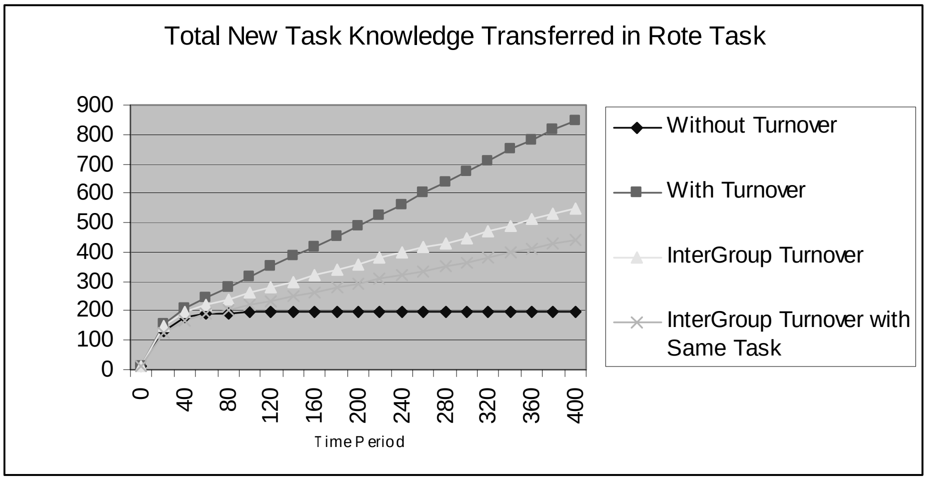

Figure 6: Total New Knowledge Transferred in Rote Task

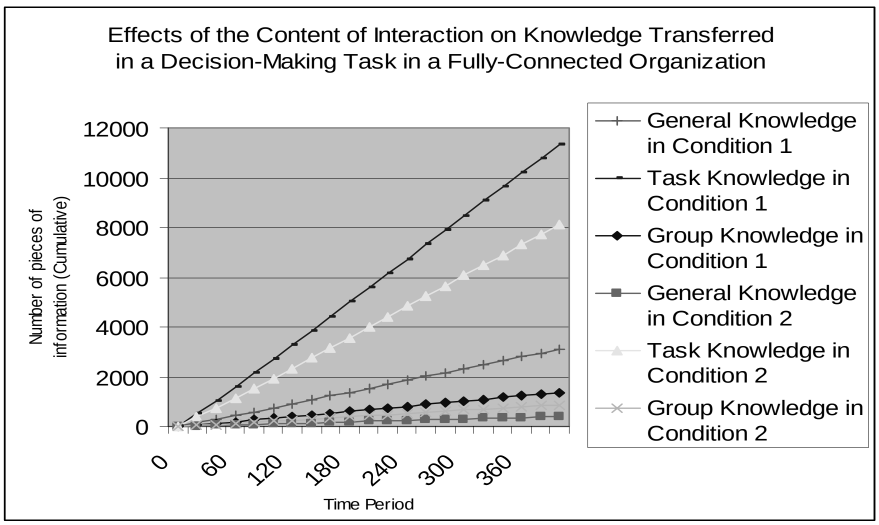

Figure 7: Task Activities and Content of Interaction (Mintzberg vs. Wageman)

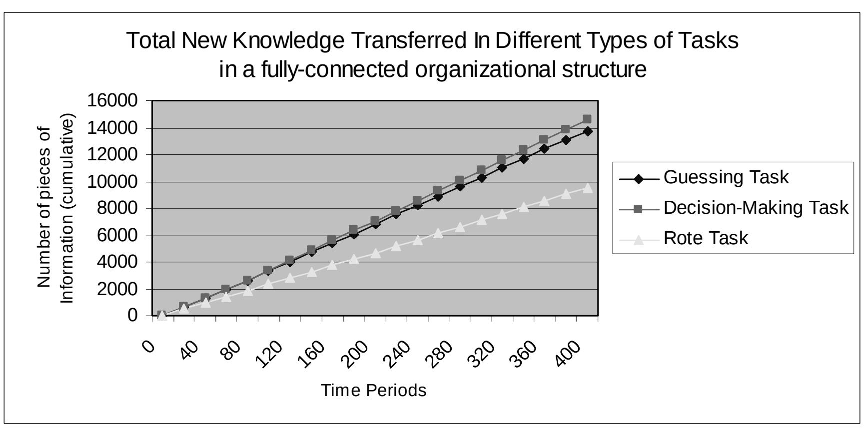

Figure 8: Total New Knowledge Transferred in Different Task Types

Appendix B: Tables for Virtual Experiment I

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task Experience - F(1,238)	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Group experience - F(1,238)	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 7: Effects of skill breadth, task and group experience on Rate of Learning (with turnover).

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.10
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task Experience - F(1,238)	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.08
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Group experience - F(1,238)	0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.06
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 8: Effects of skill breadth, task and group experience on Rate of Learning (without turnover).

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	12.93	12.39	10.92	8.22	6.72	5.44	4.70	4.16	3.51	3.13
p	<.001	<.001	<.005	<.01	<.025	<.05	<.05	<.05	n.s.	n.s.
Task Experience - F(1,238)	0.49	1.20	2.12	2.70	3.61	4.22	4.99	6.24	7.11	7.91
p	n.s.	n.s.	n.s.	n.s.	n.s.	<.05	<.05	<.025	<.025	.025
Group experience - F(1,238)	0.57	1.16	1.97	2.96	3.90	4.82	5.94	7.18	7.97	8.74
p	n.s.	n.s.	n.s.	n.s.	n.s.	<.05	<.025	<.025	<.025	<0.01
Task Experience x Group experience - F(2,236)	52.29	63.12	95.32	118.8	143	161.1	185.4	217.3	235.4	256.2
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 9: Effects of skill breadth, task and group experience on Total Knowledge Transferred (with turnover).

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	8.05	9.78	10.30	10.39	10.46	10.73	10.56	10.50	10.52	10.61
p	<.01	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Task Experience - F(1,238)	0.05	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Group experience - F(1,238)	0.12	0.13	0.16	0.13	0.15	0.16	0.17	0.17	0.17	0.17
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task Experience x Group experience - F(2,236)	30.67	37.17	38.88	39.45	39.49	40.11	39.80	39.59	39.75	40.09
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 10: Effects of skill breadth, task and group experience on Total Knowledge Transferred (without turnover).

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Task Type - with turnover - F(2, 717)	0.04	0.15	0.54	0.77	0.92	1.08	1.18	1.29	1.46	1.65
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Org. Structure - with turnover - F(2,717)	100.7	133.9	189.9	236.6	276.6	308.5	350.2	392.2	423.2	459.5
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Task Type - no turnover - F(1,717)	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Org. Structure - no turnover - F(2,717)	55.52	63.13	65.56	67.49	67.39	68.42	68.67	68.43	68.65	69.06
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 11: Effects of task type and organizational structure on Total Knowledge Transferred.

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	11.39	10.96	9.71	7.42	5.88	4.64	4.70	3.94	3.51	3.13
p	<.001	<.001	<.005	<.01	<.025	<.05	<.05	n.s.	n.s.	n.s.
Task Experience - F(1,238)	0.06	0.46	1.10	1.69	2.55	3.23	4.04	5.26	6.21	7.10
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	<.05	<.05	<.025	.025
Group experience - F(1,238)	0.44	0.97	1.72	2.70	3.59	4.41	5.42	6.53	7.32	8.00
p	n.s.	n.s.	n.s.	n.s.	n.s.	<.05	<.025	<.025	<.025	<0.01
Task Experience x Group experience - F(2,236)	48.67	59.69	90.23	113.9	133.1	147.6	168.2	194.1	210.0	227.7
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 12: Effects of skill breadth, task and group experience on Total New Knowledge Transferred (with turnover).

Variable \Time Period	40	80	120	160	200	240	280	320	360	400
Skill Characteristics - F(1,238)	7.60	9.12	9.57	9.71	9.78	10.01	9.89	9.88	9.88	9.94
p	<.01	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Task Experience - F(1,238)	0.06	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Group experience - F(1,238)	0.07	0.09	0.10	0.10	0.11	0.10	0.11	0.11	0.11	0.11
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task Experience x Group experience - F(2,236)	31.57	37.77	39.51	40.27	40.41	40.99	40.82	40.83	40.96	41.25
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 13: Effects of skill breadth, task and group experience on Total New Knowledge Transferred (without turnover).

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Task Type - with turnover - F(2, 717)	10.82	24.50	45.38	66.54	85.28	104.4	122.9	144.5	162.1	181.3
p	<.005	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Org. Structure - with turnover - F(2,717)	93.03	128.7	188.7	242.7	288.6	324.4	370.6	418.6	448.8	486.8
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Task Type - no turnover - F(1,717)	7.66	14.82	18.68	20.71	21.90	23.02	23.40	23.68	24.15	24.51
p	<.005	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Org. Structure - no turnover - F(2,717)	54.28	62.67	66.60	70.27	71.91	74.64	76.47	78.01	79.62	81.67
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 14: Effects of task type and organizational structure on Total New Knowledge Transferred.

Variable \ Time Period	40	80	120	160	200	240	280	320	360	400
Total General Knowledge - F(2, 717)	92.84	170.5	252.9	336.8	470.1	519.9	791.6	902.2	1045	1246
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Total Task Knowledge - F(2,717)	12.78	24.95	39.19	51.73	65.92	69.34	86.97	107.4	121.0	134.7
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Total Group Knowledge - F(1,717)	6.67	11.68	18.36	22.97	26.04	33.84	40.00	49.87	57.11	65.96
p	<.025	<.005	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 15: Effects of the two different sets of activities on Knowledge Transferred.

Appendix C: Figures for Virtual Experiment II

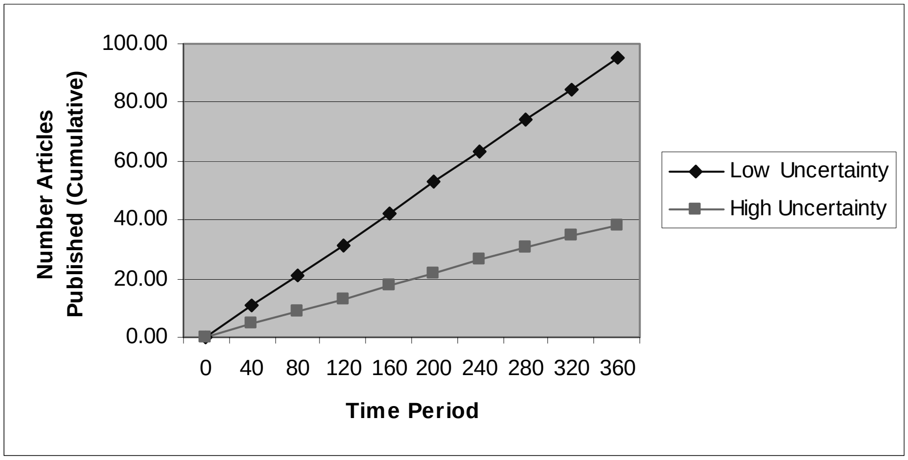

Figure 9: Effect of Uncertainty on the Number of Articles Published Over Time.

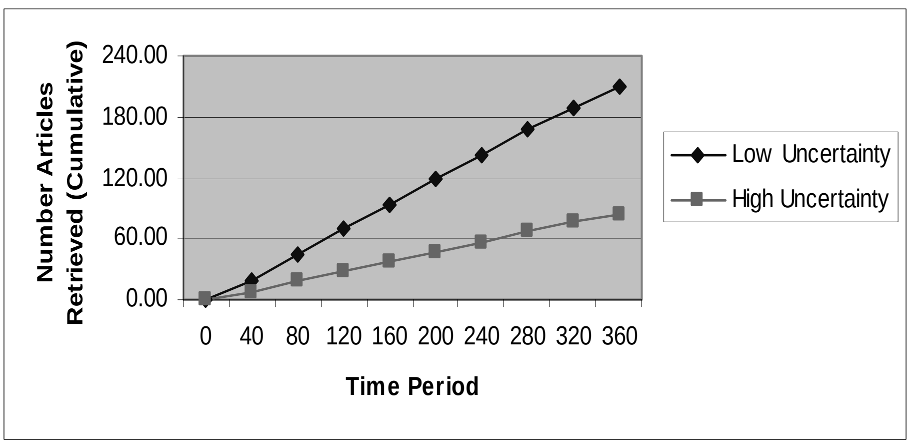

Figure 10: Effect of Uncertainty on the Number of Articles Retrieved Over Time.

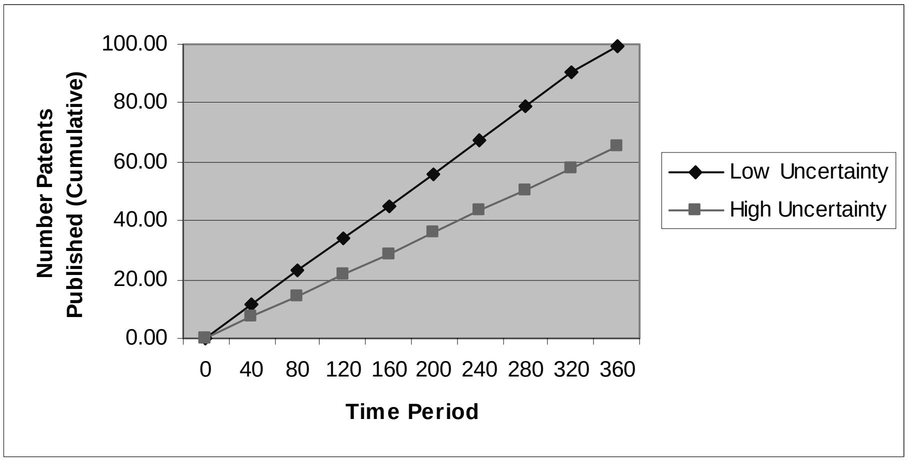

Figure 11: Effect of Uncertainty on the Number of Patents Published Over Time.

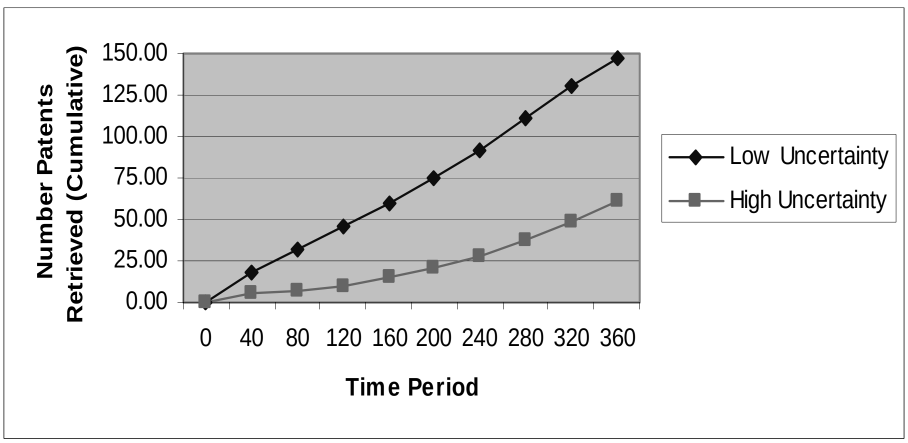

Figure 12: Effect of Uncertainty on the Number of Patents Retrieved Over Time.

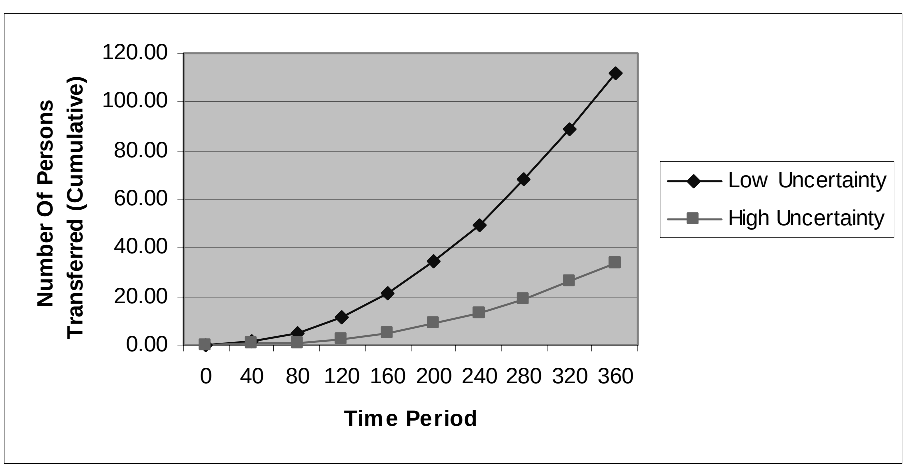

Figure 13: Effect of Uncertainty on the Number of Persons Transferred Over Time.

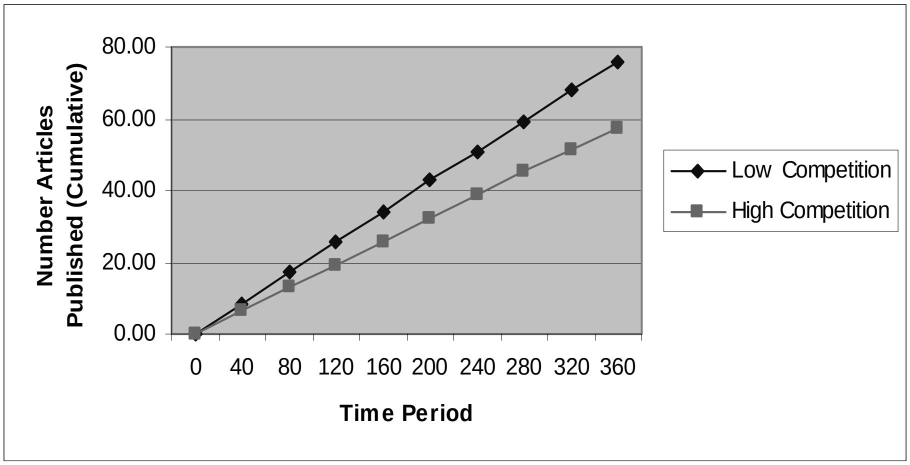

Figure 14: Effect of Competition on the Number of Articles Published Over Time.

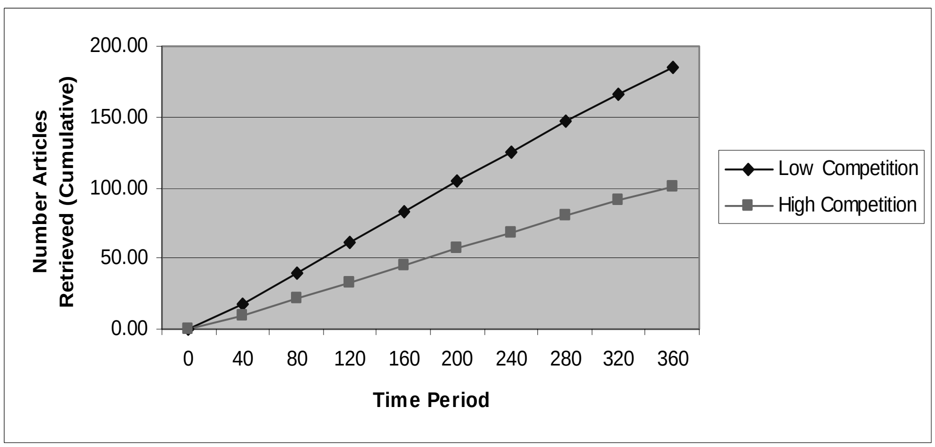

Figure 15: Effect of Competition on the Number of Articles Retrieved Over Time.

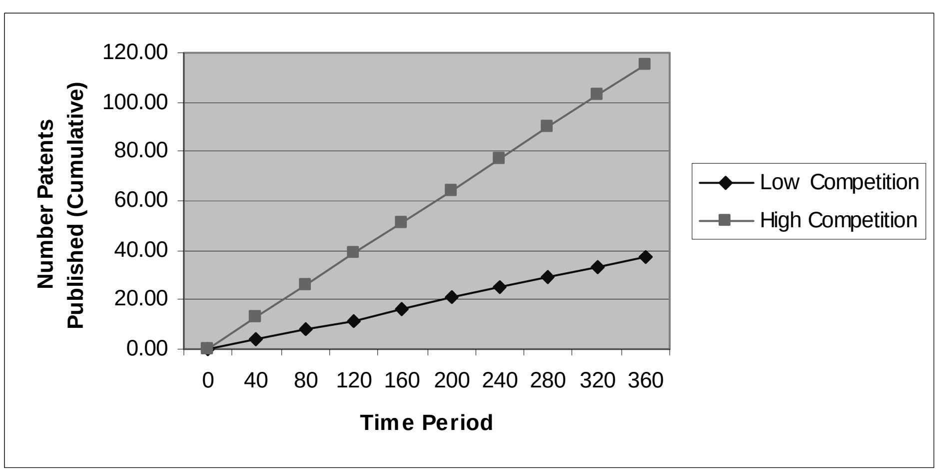

Figure 16: Effect of Competition on the Number of Patents Published Over Time.

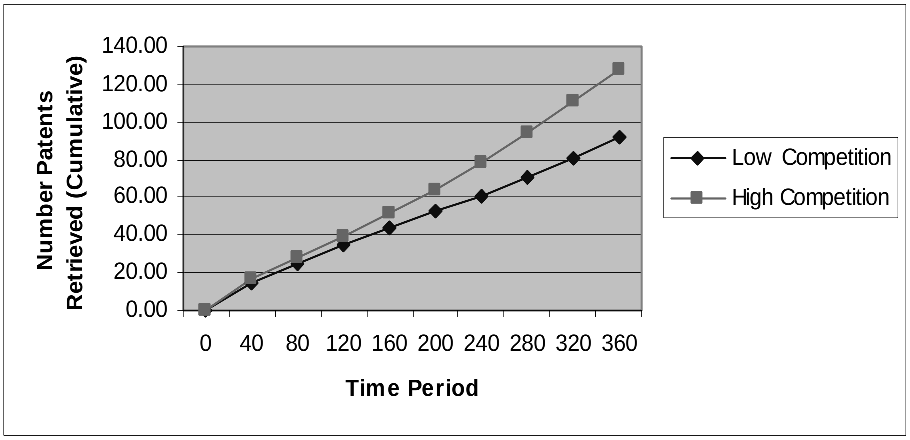

Figure 17: Effect of Competition on the Number of Patents Retrieved Over Time.

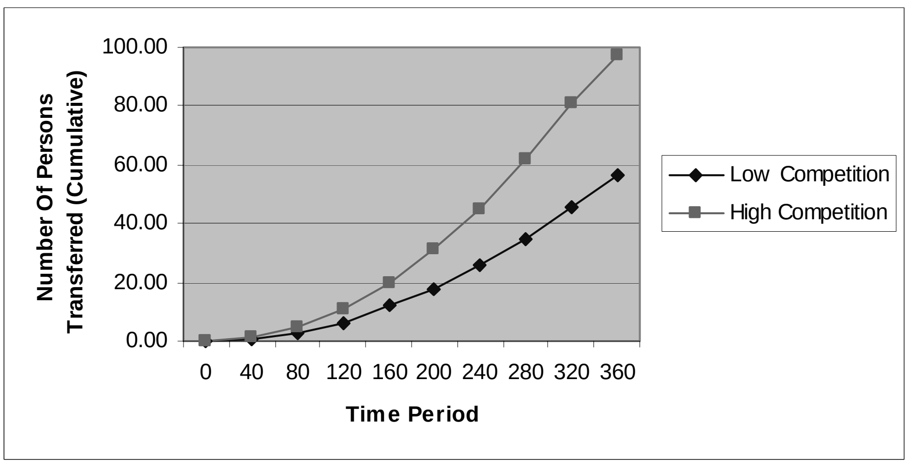

Figure 18: Effect of Competition on the Number of People Transferred Over Time.

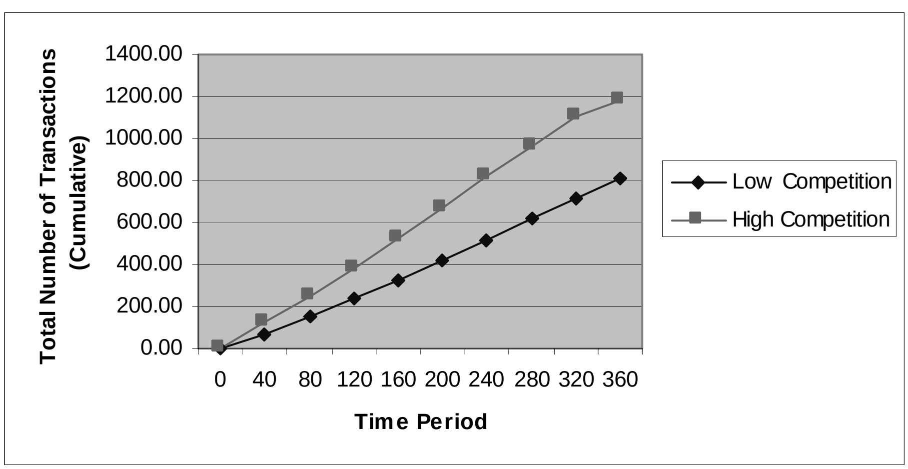

Figure 19: Effect of Competition on the Total Number of Transactions Over Time.

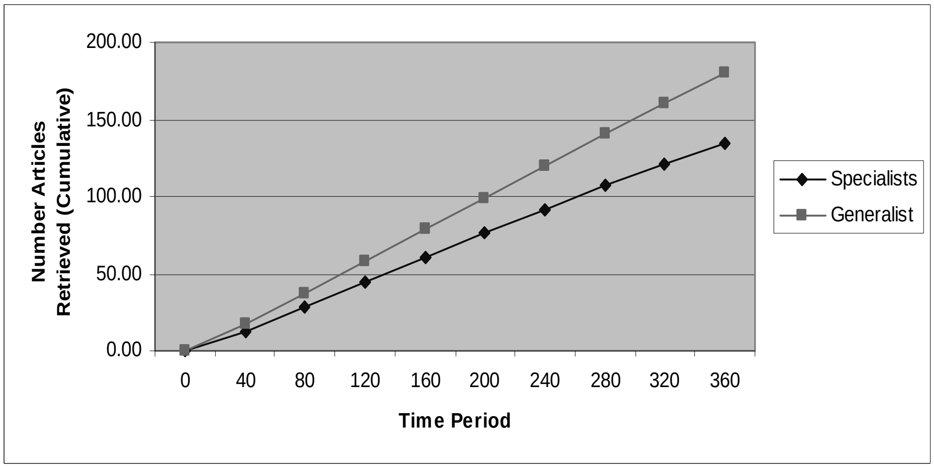

Figure 22: Effect of Breadth of Skill on the Number of Articles Retrieved Over Time.

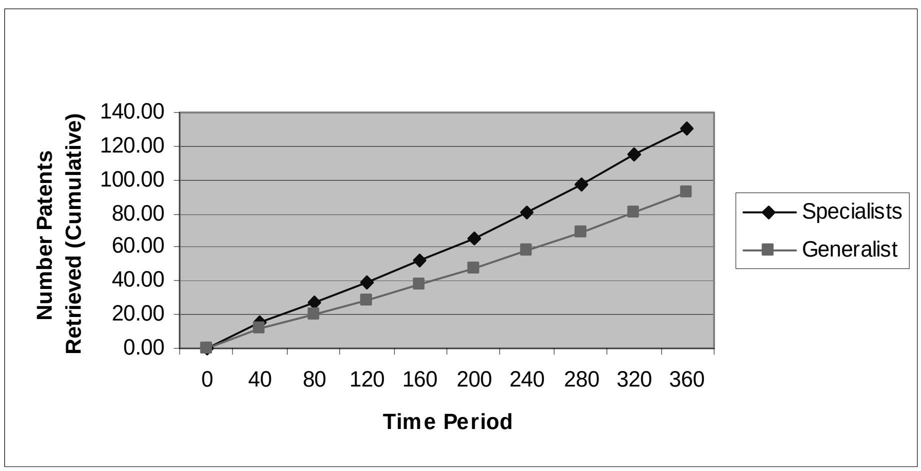

Figure 23: Effect of Breadth of Skill on the Number of Patents Retrieved Over Time.

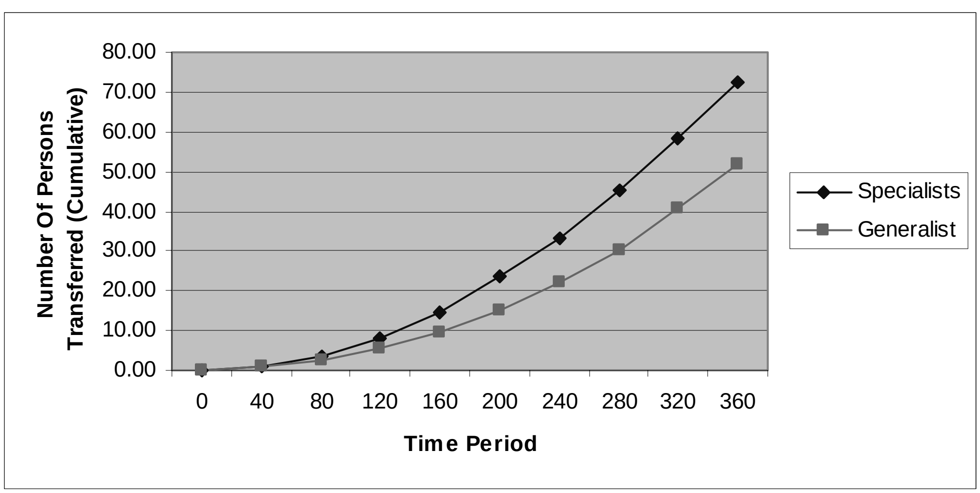

Figure 24: Effect of Breadth of Skill on the Number of Persons Transferred Over Time.

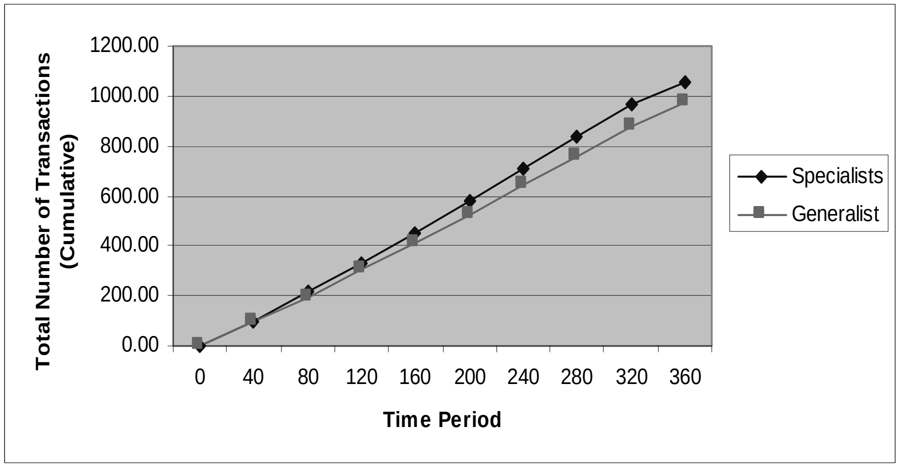

Figure 25: Effect of Breadth of Skill on the Number of Transactions Over Time.

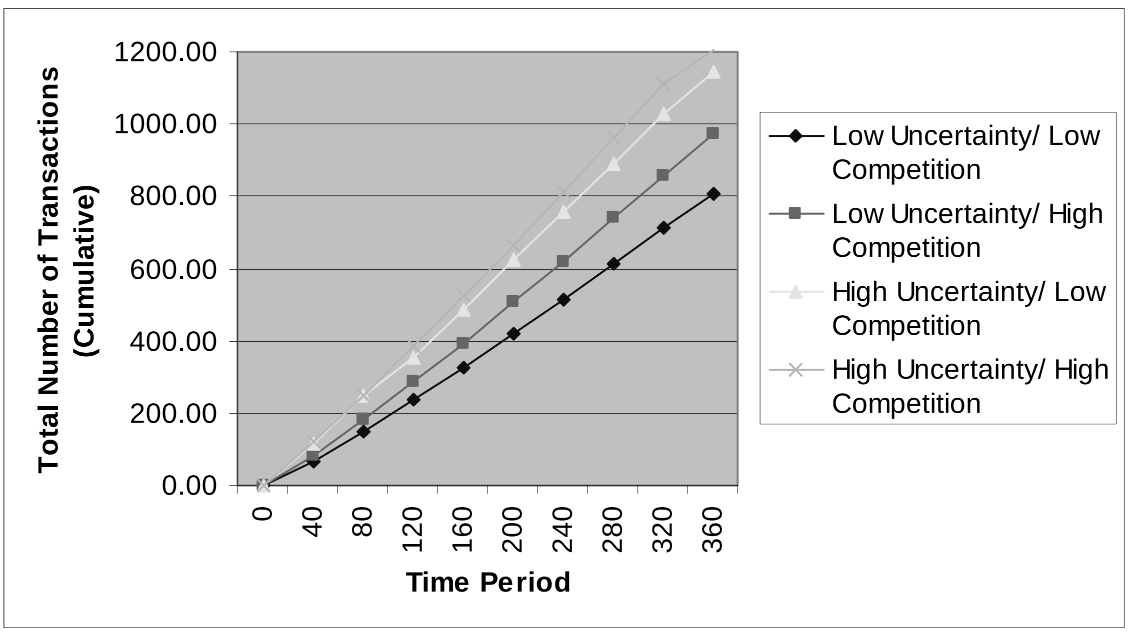

Figure 26: Uncertainty X Competition Interaction Effect on the Number of Transactions Over Time.

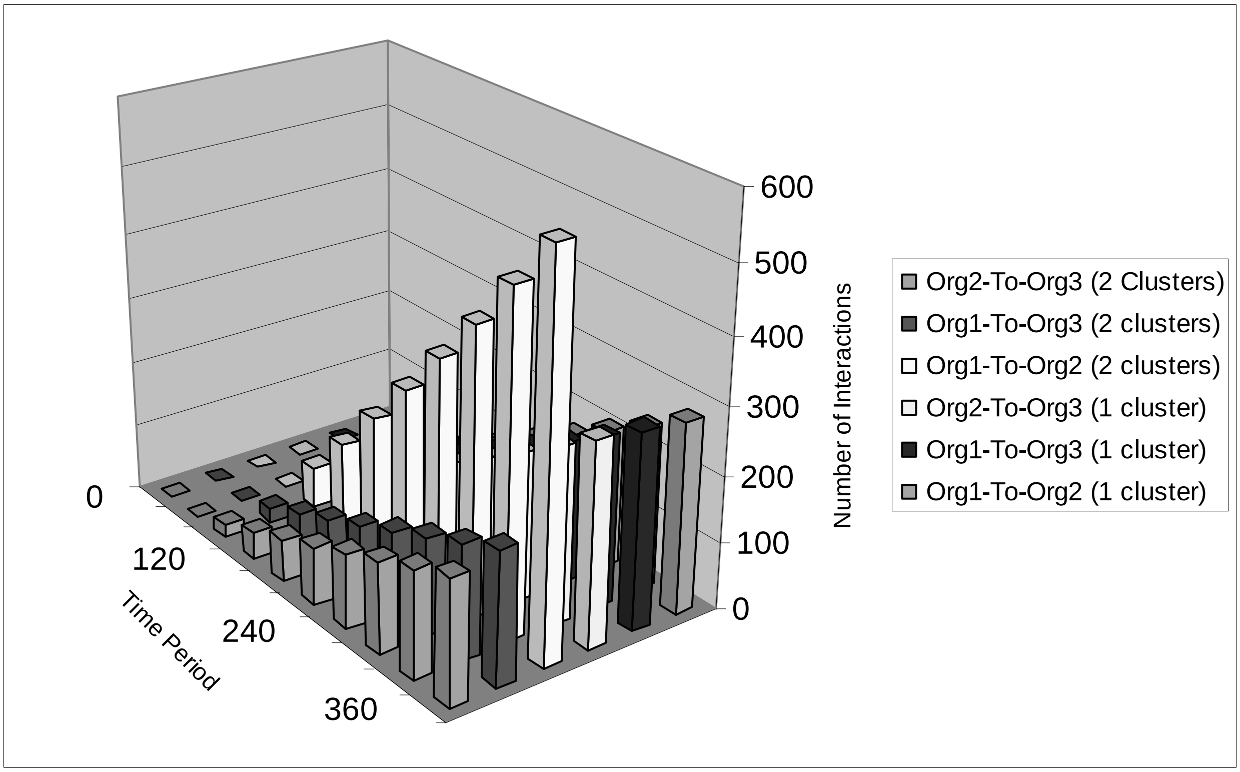

Figure 27: Number of Interactions Among Organizations with High Location Importance and One or Two Clusters Organizations.

Appendix D: Tables for Virtual Experiment II

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	3.68	9.32	16.14	23.22	30.56	38.07	46.99	56.92	66.92
p	n.s.	< .005	< .001	< .001	< .001	< .001	< .001	< .001	< .001
On Articles Retrieved - F(1,1241)	7.37	21.97	39.12	58.49	84.61	113.79	141.98	171.30	200.51
p	< .01	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
On Patents Published - F(1,1241)	0.45	1.39	2.35	3.61	4.73	6.00	7.31	8.34	9.68
p	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .01	< .005	< .005
On Patents Retrieved - F(1,1241)	3.22	8.29	15.93	25.93	40.50	48.03	59.78	69.48	81.01
p	n.s.	< .005	< .001	< .001	< .001	< .001	< .001	< .001	< .001
On Num. People Transf. From Orgs. - F(1,1241)	0.02	0.14	0.47	1.27	3.96	4.57	4.67	5.13	7.19
p	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .05	< .05	< .01
On Knowledge Transf. Org-To-Org - F(1,1241)	0.14	0.41	0.53	0.73	0.84	1.00	1.15	1.35	1.51
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 16: Effects of Uncertainty on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	2.58	6.91	9.41	11.21	14.83	17.51	18.21	21.83	23.79
P	n.s.	< .01	< .005	< .005	< .001	< .001	< .001	< .001	< .001
On Articles Retrieved - F(1,1241)	5.99	9.87	13.06	19.78	26.49	43.32	57.56	59.41	67.64
P	< .01	< .005	< .001	< .001	< .001	< .001	< .001	< .001	< .001
On Patents Published - F(1,1241)	10.51	24.56	39.44	56.61	87.93	90.80	108.88	125.73	127.83
P	< .005	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
On Patents Retrieved - F(1,1241)	2.06	3.40	4.79	8.41	8.82	9.56	15.07	15.90	28.68
P	n.s.	n.s.	< .05	< .01	< .01	< .005	< .001	< .001	< .001
On Num. People Transf. From Orgs. - F(1,1241)	0.04	0.24	0.81	1.18	3.07	4.09	4.75	6.02	6.83
P	n.s.	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .025	< .025
On Knowledge Transf. Org-To-Org - F(1,1241)	0.18	0.40	0.51	0.67	0.76	0.90	0.99	1.10	1.13
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	3.92	6.26	9.05	11.21	13.79	14.24	21.21	27.91	29.57
P	< .05	< .01	< .005	< .005	< .001	< .001	< .001	< .001	< .001

Table 17: Effects of Environmental Competitiveness on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.00	0.00	0.01	0.00	0.02	0.02	0.01	0.02	0.06
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.06	0.04	0.18	0.12	0.22	0.30	0.47	0.58	0.69
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Published - F(1,1241)	0.07	0.13	0.35	0.19	0.89	0.67	1.12	0.33	0.18
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.60	0.74	0.80	0.87	0.98	0.99	1.08	1.38	1.46
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.02	0.03	0.03	0.02	0.02	0.02	0.04	0.05	0.08
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	2.73	3.93	5.68	9.16	12.75	13.27	18.68	21.20	24.01
P	n.s.	< .05	< .05	< .005	< .001	< .001	< .001	< .001	< .001

Table 18: Uncertainty X Competition Interaction Effect.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.25	0.20	0.18	0.19	0.20	0.16	0.16	0.15	0.14
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.20	0.14	0.13	0.10	0.10	0.12	0.15	0.22	0.32
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Published - F(1,1241)	2.09	2.25	1.86	1.93	2.29	1.88	1.92	1.77	1.62
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.34	0.26	0.25	0.29	0.39	0.59	0.84	1.28	1.85
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.01	0.02	0.05	0.06	0.6	0.03	0.02	0.01	0.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.27	0.29	0.61	0.80	1.08	1.20	1.61	1.77	1.86
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.26	0.19	0.17	0.18	0.18	0.18	0.14	0.13	0.15
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 19: Effects of Organizational Structure on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.06	0.06	0.00	0.01	0.16	0.38	0.23	0.02	0.08
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.57	0.13	0.43	0.42	1.19	1.20	1.83	2.76	5.00
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	< .05
On Patents Published - F(1,1241)	0.01	0.00	0.02	0.06	0.03	0.08	0.11	0.40	0.27
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	1.70	2.57	3.00	1.90	1.73	1.68	2.18	2.75	3.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.06
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.14	0.24	0.10	0.19	0.15	0.13	0.06	0.14	0.08
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 20: Effects of Location Importance on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.27	0.07	0.05	0.07	0.45	0.69	1.11	1.11	1.23
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.73	0.07	0.29	0.25	0.30	0.26	0.06	0.02	0.47
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Published - F(1,1241)	0.07	0.03	0.05	0.01	0.07	0.13	0.02	0.00	0.02
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.60	1.04	2.43	0.91	0.46	0.89	1.13	1.31	0.54
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.01	0.01	0.01	0.02	0.04	0.04	0.05	0.04	0.04
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.04	0.05	0.11	0.08	0.10	0.11	0.28	0.28	0.23
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.02
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 21: Effects of Number of Clusters on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.06	0.03	0.02	0.02	0.08	0.13	0.20	0.22	0.22
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.19	0.03	0.11	0.13	0.20	0.29	0.44	0.73	1.48
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Published - F(1,1241)	0.02	0.01	0.01	0.02	0.06	0.08	0.08	0.13	0.13
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.32	0.62	1.20	0.79	0.64	1.08	1.21	1.10	1.25
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.01	0.02	0.02	0.03	0.02	0.06	0.03	0.04	0.02
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.07	0.10	0.11	0.15	0.14	0.21	0.28	0.32	0.28
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 22: Location Importance X Number of Clusters Interaction Effect.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.43	0.83	0.44	0.55	0.32	0.45	0.59	0.42	0.44
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.63	0.10	0.65	2.15	3.99	5.02	6.17	8.34	7.57
P	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .05	< .025	< .025
On Patents Published - F(1,1241)	0.02	0.20	0.03	0.03	0.08	0.08	0.00	0.01	0.01
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.17	0.33	1.23	2.78	3.94	5.87	7.16	7.56	7.91
P	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .01	< .01	< .01
On Num. People Transf. From Orgs. - F(1,1241)	0.21	0.45	1.56	2.89	4.12	5.64	6.98	7.87	9.82
P	n.s.	n.s.	n.s.	n.s.	< .05	< .05	< .01	< .01	< .005
On Knowledge Transf. Org-To-Org - F(1,1241)	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.01
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.95	0.03	1.16	5.03	7.63	8.12	9.53	14.52	13.57
P	n.s.	n.s.	n.s.	< .05	< .005	< .005	< .005	< .001	< .001

Table 23: Effects of Breadth of Skill on Dependent Variables.

Depend. Var. \ Time Period	40	80	120	160	200	240	280	320	360
On Articles Published - F(1,1241)	0.01	0.02	0.02	0.02	0.03	0.03	0.4	0.04	0.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Articles Retrieved - F(1,1241)	0.09	0.10	0.23	0.37	0.41	0.29	0.22	0.19	0.07
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Published - F(1,1241)	0.01	0.02	0.02	0.02	0.03	0.03	0.4	0.04	0.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Patents Retrieved - F(1,1241)	0.0‘	0.02	0.02	0.02	0.03	0.04	0.04	0.03	0.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Num. People Transf. From Orgs. - F(1,1241)	0.01	0.02	0.02	0.02	0.03	0.03	0.4	0.04	0.03
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Knowledge Transf. Org-To-Org - F(1,1241)	0.02	0.05	0.07	0.10	0.15	0.15	0.15	0.13	0.16
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
On Number of Transactions - F(1,1241)	0.04	0.09	0.12	0.08	0.11	0.11	0.09	0.12	0.09
P	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 24: Uncertainty X Competition X Breadth of Skill Interaction Effect.