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Simulating the Role of Inter-Firm Relations in Construction on the Productive Implementation of Innovations

By

John Taylor, Raymond Levitt, & Ashwin Mahalingam

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If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
Terman Engineering Center
Mail Code: 4020
Stanford, CA 94305-4020

SIMULATING THE ROLE OF INTER-FIRM RELATIONS IN CONSTRUCTION ON THE PRODUCTIVE IMPLEMENTATION OF INNOVATIONS[1] [2]

John E. Taylor[3], Raymond Levitt[4] & Ashwin Mahalingam[5]
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Abstract

In this paper we develop a multi-agent simulation model to explore the impact of inter-firm relations in construction industry interorganizational networks on the productive implementation of innovations. Though interorganizational network researchers generally agree that when firms form into networks they will gain access to new knowledge, the question of learning beyond the firm at the boundaries between firms or at the level of the network itself remain less explored. We simulate the impact of task interdependence and relational instability on learning in interorganizational networks comprised of multiple disparate specialist firms. We find that relational instability in networks slows learning and that task interdependence moderates the impact of increasing relational instability on network productivity rates. The findings have significant implications for interorganizational network theory and for the construction industry, which is highly fragmented with significant inter-firm relational instability. Furthermore, the simulation results provides insights into appropriate firm and network strategies for change.

Keywords: Coordination, Innovation, Interorganizational Networks, Relational Instability, Simulation, Task Interdependence

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[3] Assistant Professor, The University of Texas at Austin and Director, Project Organization Dynamics Lab
[4] Professor, Stanford University and Director, Collaboratory for Research on Global Projects
[5] Assistant Professor, The Indian Institute of Technology - Madras

INTRODUCTION: The Engineering and Theoretical Problem

In this paper we develop a multi-agent simulation model to explore the issue of learning in interorganizational networks. Interorganizational network scholars describe learning as an outcome of knowledge flowing (Appleyard 1996), transferring (Mowery, Oxley, & Silverman 1996), spilling over (Uzzi & Gillespie 2002), and diffusing (Zucker, et al. 1996) across network role interactions. Implicit in this view of learning in networks is the notion that learning occurs within firms. Knowledge becomes an object to be exchanged at the boundary between firm dyads for the edification of one firm, presumably to be reciprocated in later knowledge exchanges.

Though interorganizational network researchers generally agree that when firms form into networks they will gain access to new knowledge, the question of learning beyond the firm at the boundaries between firms or at the level of the network itself remains less explored. Mowery and his colleagues argue that "*the 'learning' that takes place within alliances (thus) appears to be more complex than most of the literature on this topic suggests, underlining the need for better definitions of learning in theoretical discussions of alliance activity*" (Mowery, Oxley, & Silverman 1996: 89). The perspective we adopt in our research is that the prevailing viewpoint of learning in interorganizational networks fails to capture the learning that occurs at the boundaries between firms in the network. In this paper we extend the current understanding of learning in networks through the development of a simple multi-agent simulation model (Burton & Obel 1995) to explore the dynamics of learning within and across firms in interorganizational networks.

Our research is particularly applicable and relevant to the construction industry. The construction industry consists of a large set of firms that are classified into various trades. A large number of these firms need to collaborate and coordinate in an orchestrated, interdependent fashion in order to complete a construction project. It is virtually impossible for a single firm to complete a project on its own. Thus, the construction industry is a network-based industry.

Several recent CIFE studies have shown the inability of the construction industry to improve its productivity over time. Lack of interorganizational learning could potentially lie at the foundation of this phenomenon. In this paper we introduce a formal explanation for why this is so, and also suggest some strategies in order to improve the current state of productivity in the construction industry.

POINT OF DEPARTURE I: Research on Interorganizational Networks

Firms are increasingly adopting network forms of organization both within (Barley, et al. 1992, Powell, et al. 2005) and across (Kanter 1991, Pekar & Allio 1994) industries. Over the last two decades a stream of research has emerged to explore the nature of these network forms of organization. In interorganizational networks, groups of two or more firms work together in the interdependent production of goods or services (Powell 1990). Interorganizational networks were first identified by Eccles (1981) where he observed relations between different specialist firms as being stable and continuous over fairly long periods of time.

This new mode of economic exchange has been the subject of a nascent but exponentially growing stream of research. Researchers primarily focus their investigations on interorganizational network partner selection strategies (Beckman, et al. 2004, Gulati & Gargiulo 1999, Powell, et al. 2005) and strategies for governance in networks (Jones, et al. 1997, Uzzi &

Gillespie 2002). These studies have contributed meaningfully to a fuller understanding of how firms select partners and how they adopt network governance strategies, however, literature on this topic has largely ignored the question of how networks of firms learn. A number of interorganizational network studies address the question of the distribution of knowledge (Appleyard 1996, Möller & Svahn 2004, Mowery, Oxley, & Silverman 1996, Uzzi & Gillespie 2002, Zucker, et al. 1996), however, these investigations explore the movement of knowledge contained in one firm to another firm and largely ignore the learning that can occur across interdependent tasks at the boundaries between firms and, hence, learning at the level of the network. Furthermore, although the network literature has focused on why and how firms come together into networks, scholars have failed to explore how the stability of these interorganizational network relationships may impact learning.

POINT OF DEPARTURE II: Learning in Interorganizational Networks

Studies of learning in interorganizational networks have resulted in conflicting findings. Powell and colleagues (1996) identified networks within the biotechnology industry as the loci for innovation. Their arguments were rooted in the fact that organizations do not contain all the knowledge that they need. Interorganizational networks provide access to relevant knowledge not available internally or externally for purchase. Therefore, organizing into interorganizational networks enables firms to share and exploit asymmetries in learning. Building and leveraging an inter-firm sharing of knowledge enabled firms in networks to build new capabilities and outperform firms that were not connected in networks. Ahuja (2000) confirmed the findings of Powell and his colleagues in the chemicals industry. He found that connectedness through direct and indirect ties into networks increased performance.

In two later papers about learning and innovation in biotechnology and pharmaceutical networks, Powell and his colleagues (Powell 1998, Powell, et al. 1999) caution about the difficulty of making learning portable in interorganizational networks. Zeller (2002) investigated the impact of developing research and development interorganizational networks in the Swiss pharmaceutical industry and observed a slowdown in the innovativeness of the firms related to tendencies toward the sharing of knowledge. In other industries, the impact on learning of adopting the interorganizational network form of organization has been found to have strong negative effects. Lampel and Shamsie (2003) found an evolutionary stagnation in the ability for firms in the motion picture industry to innovate due to issues with the accumulation of and sharing of knowledge. Gann and Salter (2000) and Taylor and Levitt (2004) both describe difficulties in orchestrating changes associated with innovation in construction industry interorganizational networks. There is clearly some question as to what impact the interorganizational network form of organization has on learning.

POINT OF DEPARTURE III: Task Interdependence in Interorganizational Networks

Most interorganizational network studies focus on firms that are bound by resource interdependencies. We explore settings where task interdependent firms must each learn how to implement a change internally and, in the process, mutually adjust to changes in interorganizational work practices. Thompson (1967: 55) defines the highest degree of interdependence, reciprocal interdependence, as the case where "*contingency is not merely potential, for the actions of each position in the set must be adjusted to the actions of one or more others in the set.*" We develop a simulation model that examines the impact of reciprocal task interdependence on learning occurring at the boundaries between firms and within each of the firms in the network to develop a more complete understanding of learning at the level of the interorganizational network.

POINT OF DEPARTURE IV: Relational Instability in Interorganizational Networks

Core to the concept of interorganizational networks is the notion of partner selection. Eccles (1981) first identified interorganizational networks in a study of the Massachusetts homebuilding industry where he observed interdependent firms with continuous and stable partner selection over time. Interorganizational researchers speculate that the stability of these relations impacts a network of firms' ability to respond to changes (Taylor & Levitt 2005), particularly when these changes occur in boundary objects that connect the disparate social worlds of specialist firms in a network (Taylor 2006). We therefore construct our simulation to explore the impact of stability in network partner selection on an interorganizational network's ability to learn. We simulate the learning in the context of productivity performance following a system-level change in the network. With these systemic changes, firms need to learn how to adapt to the change both internally and across the interdependent tasks that connect the organizations' work.

RESEARCH METHOD: Simulating Learning in Interorganizational Networks

We develop a simple simulation that explores the impact on learning over time when varying the interdependence between firms in a network and the stability of relations between firms in a network. In the simulation we assume that learning occurs both within the firm and at the task interdependent boundaries between firms in a network. We model the learning over time using the learning curve equation developed by Wright (1936) in a study of the production aircraft manufacture. The learning curve equation we use is as follows:

$$\text{Productivity at Trial Period} = \text{Productivity Modification Factor} * e^{-\text{(Learning Rate)} * \text{(Learning Trial Period)}}$$

***Assumed simulation values**: Learning Rate = 0.8 {industry values range from 0.7 to 0.9 (Oglesby et al.1988)} and Productivity Modification Factor = 1.5 {rate of productivity immediately following a change requiring learning}*

In each simulation trial period we measure the learning of each firm in the interorganizational network as well as the learning that occurs across each interdependent task in order to arrive at a total productivity for the network. In the simulation we assume that four different types of specialist firm roles exist in the interorganizational network (Role Type A, Type B, Type C, & Type D). We run the simulation both with the assumption that there is no task interdependence between the firms and with the assumption that there is a 50% task overlap. For each type of specialist firm, we vary the number of firms that are members of the network in order to simulate varying relational stability.

At its most stable, the network participants always work with the same set of firms [e.g., $A_1+B_1+C_1+D_1$ in all cases]. However, in a more relationally unstable scenario we assume two firms could fulfill each specialist role. In this case there would be an equal probability among sixteen alternative network compositions: $A_1+B_1+C_1+D_1$, $A_1+B_2+C_1+D_1$, $A_1+B_2+C_2+D_1$, $A_1+B_1+C_2+D_1$, $A_2+B_1+C_1+D_1$, $A_2+B_2+C_1+D_1$, $A_2+B_2+C_2+D_1$, $A_2+B_1+C_2+D_1$, $A_1+B_1+C_1+D_2$, $A_1+B_2+C_1+D_2$, $A_1+B_2+C_2+D_2$, $A_1+B_1+C_2+D_2$, $A_2+B_1+C_1+D_2$, $A_2+B_2+C_1+D_2$, $A_2+B_2+C_2+D_2$, and $A_2+B_1+C_2+D_2$. In the simulation we vary the relational stability from one firm fulfilling each specialist role (high relational stability) to nine firms fulfilling each specialist role (high relational instability). We advance the number of firms per role in increments of two (i.e., 1, 3, 5, 7 & 9) giving us five different variants of relational stability. The results of the simulation are illustrated in the following figures.

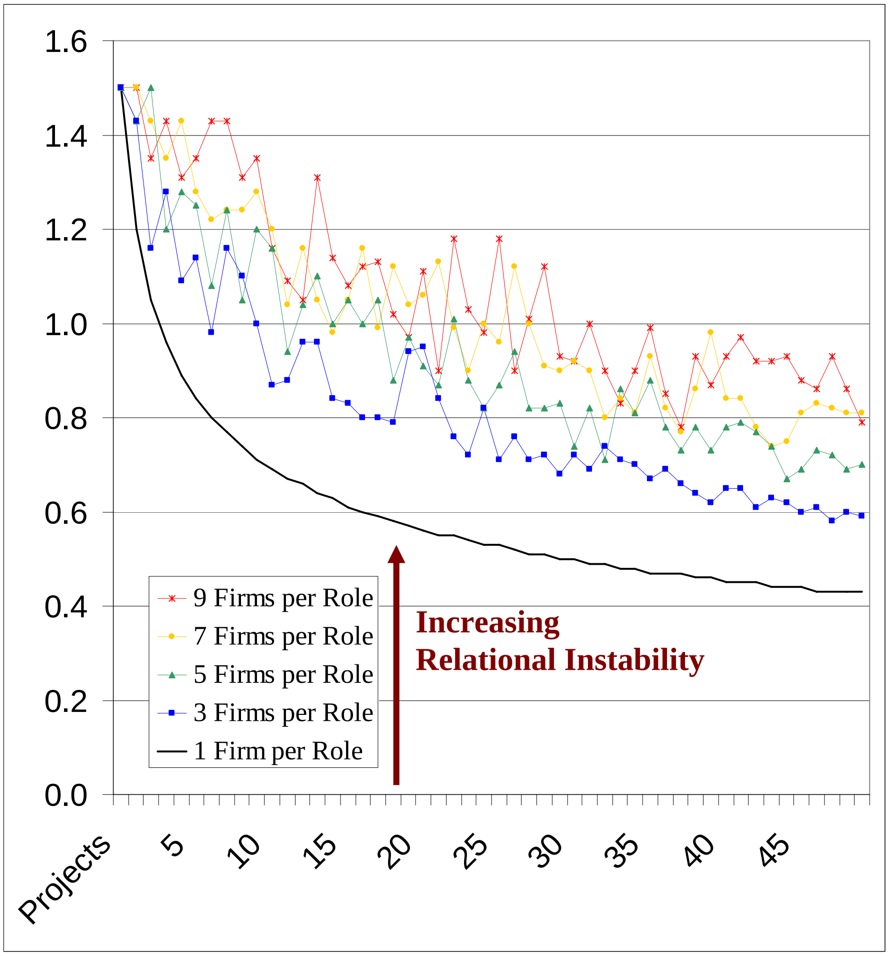

Fig. 1. Interorganizational network simulated learning outcomes with interdependent task overlap = 0%

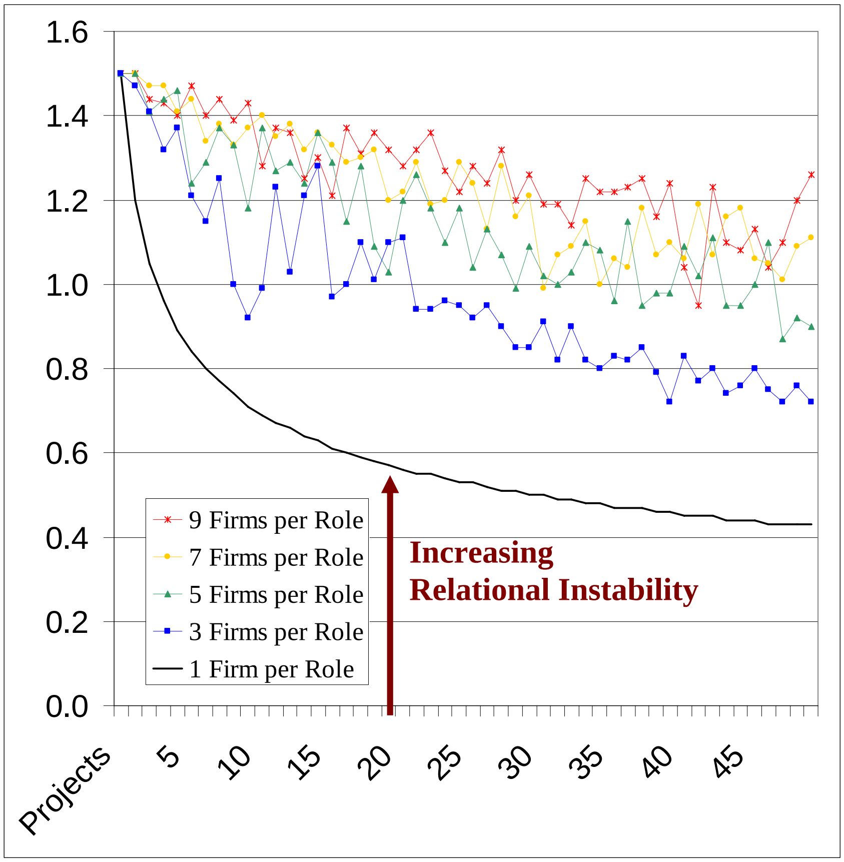

Fig. 2. Interorganizational network simulated learning outcomes with interdependent task overlap = 50%

Figures 1 and 2 above illustrate the results of the simulation using the assumed factor values and ranges. We ran the simulation for a total of 50 projects for each of the five relational stability variants mentioned above. For each run in the simulation, we selected a configuration of four firms – one from each of the four types. All firms of a given type had an equal probability of being selected in each of our simulations. Each project trial period provided a learning opportunity for each firm selected to participate in the project instantiation of the network. The reported values in the figures above were based on the total productivity for all firms participating in the project and then normalized to 1.0 in order to make the simulation results comparable. We plot the results of the simulation on two separate charts; one for no task interdependence (Figure 1) and one for 50% task interdependent overlap between firms (Figure 2). We observe that the scenario of stable networks in the presence or absence of task interdependence produces the fastest learning rates for the network. Networks with or without interdependent tasks achieved pre-change productivity rates by the fourth project. This network learning curve is consistent with normal firm-level learning curves and is illustrated in both Figure 1 and 2 as a black, smoothly curving line.

When relational instability increases, the network learns more slowly as is evidenced by learning curves in both Figures 1 and 2. In the absence of task interdependence (in Figure 1), selecting from among three firms per role delayed achievement of pre-change productivity from four to eleven projects. In relationally unstable networks where firms are selected from among nine firms per role, the network does not achieve its pre-change productivity until the thirty-third project. If each project is three months in duration –an extremely short duration for a drug development, building development, or software development project– and projects are completed sequentially, it will take the network over eight years to achieve its pre-change productivity rate. This far exceeds the reasonable duration most firms, and presumably networks of firms, would be willing to wait for a productivity improvement after investing in a technological change.

When the relational instability is combined with task interdependence, networks of firms produce even slower learning curves. These two factors combine to produce a synergistic negative effect on productivity. Because the presence or lack of task interdependence has no impact on productivity rates in relationally stable networks, task interdependence can be said to moderate the impact of relational instability on learning rates. The effect of increasing relational instability in the presence of task interdependence significantly worsens learning curve performance. In the case of networks comprised of three firms per role, the time required to reach pre-change productivity extends from eleven projects to twenty-two projects. In the cases of networks comprised of seven firms per role and nine firms per role, the productivity never achieves pre-change productivity over the course of the fifty simulated projects.

MODEL VALIDATION

According to Burton and Obel (1995), the degree of validation required is determined by the degree of realism of the model and the model's purpose. The purpose of our simulation was to extend interorganizational network learning theory using a simple intellective simulation model with a small number of parameters. According to Carley (1996), the lack of detail increases the generalizability of the simulation and is therefore fit with our purpose of extending interorganizational learning theory and is simultaneously a balanced approach (Burton & Obel 1995). The simple model is sufficent to demonstrate; (1) that existing theories of interorganizational learning are incomplete since they don't consider the impact of task interdependence and relational instability on interorganizational learning and (2) that task interdependence and relational instability have an insidious impact on learning at the level of the interorganizational network.

We grounded our simulation (Carley 1996) in established learning curve theory, thereby increasing the internal validity of the simulation. We did extend the way learning curve formulas are typically used from the individual or organizational level to the interorganizational level and, in doing so, made assumptions that the learning that occurs in interdependent tasks at the boundaries between firms occurs at the same rate as learning would occur within an individual or firm. With regards to external validity of the simulation model, we identified in previous empirical research how systemic changes resulted in more rapid productivity gains in relationally stable interorganizational networks than relationally unstable networks (Taylor & Levitt 2004, Taylor & Levitt 2005). The simulation does not reproduce/emulate (Thomsen, et al. 2003) the changes observed in the two aforementioned empirical investigations. However, the simulation does achieve face and pattern validity (Carley, 1996) since in both empirical investigations relational instability lead to slower productivity gains, more difficult implementation, and slower diffusion for innovations requiring systemic changes to the network. These findings were empirically observed in structural building material innovations among carpenters, plumbers, electricians, mechanical contractors (Taylor & Levitt 2004) and three-dimensional computer-aided design tool innovations among architects, structural engineers, contractors, and fabricators (Taylor & Levitt 2005).

LIMITATIONS

The computational simulation model developed for this research was necessarily simple. However, future research using the simulation model should address several important limitations. In the simulation, only one project can be executed at any given time. As a result, firms that are not working on a simulated project do not have the opportunity to learn on other projects. In reality, multiple projects would occur simultaneously and lead to issues of allocation (e.g., firms may have limited resources to participate on multiple projects) and hold-up (e.g., firms might take advantage of relational stability in the network to increase pricing due to relationship-specific investments in learning). Including these issues in future iterations of the simulation will increase the richness of the output. An important limitation of our simulation is that it focuses uniquely on task learning and does not allow firms to exploit knowledge assymetries across organizations (as identified by Powell and his colleagues (1996) and Ahuja (2000)). Future developments of this simulation model should include the possibility for firms to learn new approaches from each other.

DISCUSSION

Our simulation demonstrates how firms in an interorganizational network adapt to the introduction of changes in work both within and across task interdependent organizations. In doing so we confirm the finding by Mowery and his colleagues that "*the 'learning' that takes place within alliances (thus) appears to be more complex than most of the literature on this topic suggests*" (1996: 89). When interdependent firms in interorganizational networks are faced with the challenge of learning at the level of the network, our simulation suggests that they should identify ways to decrease task interdependencies (e.g., modularize tasks) and develop more stable partnerships in the network. Networks of firms failing to reduce task interdependencies and stabilize partnerships will be faced with protracted learning curves as a result. If a network or industry that adopts the network form of organization is faced with changes and can not change interdependencies or partnership strategies as a result (e.g., due to regulations, external decision authorities, or inertia), then our simulation suggests that it may be a wise decision for those networks to avoid change. This provides some explanation as to why some interorganizational network scholars find certain mature industries to be experiencing an "evolutionary stagnation" (Lampel & Shamsie 2003: 2206).

Our simulation model improves the current theoretical understanding of learning in interorganizational networks. We identify a bipartite negagive impact on system-level learning when network role relations are unstable and task interdependence exists between firms. Furthermore, we conclude that task interdependence moderates the impact of relational instability on productivity performance. The results of this simulation provide some resolution to an on-going debate in the literature on interorganizational networks regarding learning performance. This study suggests that the learning performance of a network of firms depends on the interdependence of tasks and the relational stability of the network. Scholars identifying networks as being favorable toward learning tend to investigate resource interdependent, relationally stable networks (e.g., biotechnology (Powell 1996) and chemicals (Ahuja 2000)). Whereas scholars identifying networks as being a liability to learning tend to investigate task interdependent, relationally unstable networks (e.g., motion picture (Lampel & Shamsie 2003) and construction (Gann & Salter 2000, Taylor & Levitt 2004, Taylor & Levitt 2005)). The simulation model elaborated in this paper accommodates these divergent perspectives for network learning. The degree to which adopting a network form of organization enhances or detracts from learning depends on task interdependent learning and the effects of relational instability.

CONCLUSIONS

The construction industry suffers from a large amount of relational instability – several different firms exist in any given trade (firm type). In addition, the industry is characterized by a high degree of task interdependence, since coordination requirements between trades on a jobsite are quite high. Given this combination of factors, our simulation suggests that the rate at which productivity will improve for the construction industry after the adoption of an innovation is likely to be protracted and inefficient. Consequently, our recommendations are for firms in the construction industry to revisit Eccles' (1981) concept of the "quasi-firm" and reduce relational instability by entering into longer term partnerships with firms of various types, trades and backgrounds. This strategy in addition to work-procedure modifications that reduce the amount of overlap or interdependence between trades, can lead to significant performance improvements when innovations are implemented in the construction industry.

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