SUPPLY CHAIN NETWORK EVOLUTION: DEMAND-BASED DRIVERS OF INTERFIRM GOVERNANCE EVOLUTION

Michael J. Gravier, B.A., M.S.

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APPROVED:

M. Theodore Farris II, Major Professor
Shailesh Kulkarni, Minor Professor
Nancy Spears, Committee Member
Terrance L. Pohlen, Committee Member
Kathleen Cooper, Dean of the College of Business Administration
Sandra L. Terrell, Dean of the Robert B. Toulouse School of Graduate Studies

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Which form of exchange governance performs better in a dynamic environment? This remains an unanswered question in the transaction cost analysis (TCA) and relational exchange literatures. Some researchers purport that transactional governance provides superior performance by providing firms the flexibility to change suppliers. Others suggest that relational governance leads to superior performance because of the willingness of both parties to adapt. Reviews of TCA have turned up ambivalent empirical findings with regard to the effects of uncertainty despite a track record of strong empirical support for other predictions.

Because most of TCA and relational exchange theories' predictions enjoy strong support, this research builds upon these theories to propose a theoretical modeling framework for a dynamic environment in a supply chain network (SCN) setting. This dissertation extends TCA and relational exchange to a dynamic, network environment. It uses the approach of building a simulation in order to study in detail the relationship between key exchange factors and the selection of transactional and relational exchange governance over time.

This research effort extended TCA theory with a complex adaptive model of supply chain network governance evolution that attempts to link environmental, network, production, firm and exchange factors in a continuously evolving loop. The proposed framework expands transaction cost analysis' explanatory power. Results partially support past scholarly proposal that uncertainty functions as an antecedent of asset specificity rather than as an independent construct affecting governance outcome dependent upon which form of uncertainty is being considered.

The successful simulation of supply chain networks as complex adaptive systems shift

the focus from deterministic, confirmatory models of exchange to an exploratory, positive model. Instead of exchange governance as an outcome, it is the catalyst of the evolutionary process.

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No phrase in English or Spanish expresses the acknowledgement owed by this man to his wife, Marta. Her father spoke true when he consented to my request for her hand in marriage: “Te llevas la perla de la casa.” My children also deserve acknowledgement as Marta, James, Vega, and Matthew have each provided morale support and demonstrated maturity beyond their years and even beyond that of some adults. I am a proud father—but they made me so.

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The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

> Transaction costs, and their reduction, lie at the heart of the interest in supply chain management.
>
> Jill E. Hobbs, 1996, *Supply Chain Management*

Which form of exchange governance performs better in a dynamic environment? This remains an unanswered question in the transaction cost analysis (TCA) and relational exchange literatures. Some researchers purport that transactional governance provides superior performance by providing firms the flexibility to change suppliers (Dyer, 1997; Dyer & Nobeoka, 2000; K. Kim, 2001); others suggest that relational governance leads to superior performance because of the willingness of both parties to adapt (Kathleen M. Eisenhardt & Schoonhoven, 1996; Jap, 1999; Klein *et al.*, 1990). At the heart of the issue is the firm-centered, static nature of TCA and relational exchange theory. While TCA and relational exchange provide a conceptually useful continuum of interfirm exchange governance (Heide, 1994), both are firm-centered and assume a static environment (Joshi & Campbell, 2003; A. Rindfleisch & Heide, 1997). As a result, reviews of TCA have turned up ambivalent empirical findings with regard to the effects of uncertainty despite a track record of strong empirical support for other predictions (David & Han, 2004).

Because most of TCA and relational exchange theories' predictions enjoy strong support, this research builds upon these theories to propose a theoretical modeling framework for a dynamic environment in a supply chain network (SCN) setting. To extend TCA and relational exchange to a dynamic, network environment, this dissertation uses the approach of building a simulation in order to study in detail the relationship between key exchange factors and the selection of transactional and relational exchange governance over time. This research interprets exchange governance as an adaptive mechanism subject to Darwinian selection. Under Darwinian selection, a population of organizational forms will organize itself in response to industry and market conditions in a way that certain network configurations dominate. The end market environment acts as a pressure cooker—firms will choose different forms of exchange in response to end market pressure in order to survive. Survival does not require being the best—simply just a little better than the best firm that didn't survive. The study of the dominant network configurations and the evolutionary process that develops them provides the insights needed to take a first step toward building a dynamic theory of interfirm governance in the setting of a supply chain network. This view finds support in Coase's (1937) original work in which he envisioned the embeddedness of the individual firm in a dynamic network, with firms continuously moving from one equilibrium state of relative prices and costs to another. As Coase states in his concluding paragraph (1937): "We thus have a theory of moving equilibrium."

The proposed simulation model serves two purposes. First, the simulation model is used to develop a theoretical framework that extends TCA's insights to the dynamic, network context. Second, it creates a theoretical framework and model that reproduces the evolution of the semiconductor industry. The semiconductor industry serves as a "fruit fly" example for the study of rapid evolution in a highly dynamic industry (Fine, 1998), and its study can provide insights for similar industries. By fulfilling these two purposes, the simulation model should answer the research question presented in the introductory paragraph in the context of the semiconductor environment. Specifically, this research question is: How does a dynamic network environment influence the evolution of transactional and relational exchange governance in a supply chain network? The end result is a framework of testable propositions for future research .

The use of simulation to build theory dates back to Forrester's (1958, 1961) system dynamics models. However, it is becoming increasingly significant as a methodology used for theory development in the organization and strategy literatures (Davis *et al.*, 2007). This use is not without controversy. According to the review and synthesis by Davis, Bingham, and Eisenhardt (Davis et al., 2007). This study's key differences from these past systems dynamics studies are its emphasis on historical relationships with a continuous spectrum from relational to transactional exchanges, verification against a high tech industry, and the emphasis on evolutionary changes in the supply chain network rather than industrial and network growth or distribution issues. It also differs from other past studies that studied the interplay of transaction costs and information technology such as the internet (Akkermans, 2001; Pathak, 2005).

The main purpose of this research dissertation is to argue theoretically that both firms and interfirm exchange governance adapt and evolve in response to production and environmental selection. This dissertation applies the three fundamental processes that underlie organizational evolution—variation, selection, and retention—to interorganizational evolution (Lin *et al.*, 2002).

The main purpose of this research dissertation is to argue theoretically that both firms and interfirm exchange governance adapt and evolve in response to production and environmental selection. This dissertation applies the three fundamental processes that underlie organizational evolution—variation, selection, and retention—to interorganizational evolution (Van De Ven & Poole, 1995). Although constructing an accurate model of supply chain network evolution is part of the process, the true objective of this dissertation is to build theory. This follows the example of the famous supply chain simulation known as the "beer game" that, although simplistic compared to reality, has provided an important stepping off point for extensions to logistics and supply chain theory applied to more realistic settings, such as the bullwhip effect (Lee *et al.*, 1997a, 1997b; Simchi-Levi *et al.*, 2004).

This research effort was able to successfully recreate the evolution of the supply chain network in the semiconductor industry. The ability of a complex adaptive system to reproduce a real-life, multifaceted supply chain network implies that markets have evolved into ecosystems. Ecosystems as much shape as they are shaped by their inhabitants; supply chain networks both respond to and shape consumer demand with new innovations and more efficient landed costs to the end consumer. These findings from the research shift the focus from deterministic, confirmatory models of exchange to an exploratory, positive model. Instead of exchange governance as an outcome, it is the selective force in the evolutionary process. And the exchange governance process continuously changes in order to best adapt interfirm relationships to current productions and end market conditions.

Although transaction cost analysis worked quite well as the governmental mechanism in this dissertation model, it required interaction with production and network factors to produce accurate results. These interactions demonstrate transaction cost's weaknesses as an essentially firm-centered and static theory.

This research resulted in two proposed theoretical extensions. One of the proposed extensions is a complex adaptive model of supply chain network governance evolution that links environmental, network, production, firm and exchange factors in a continuously evolving loop. The resulting proposed framework expands transaction cost analysis' explanatory power. This research also resulted in an insight into the transaction cost model itself—namely, that uncertainty as a construct embodies too many diverse concepts. The second proposed extension proposes that TCA's bounded rationality is an antecedent of asset specificity whereas behavioral uncertainty is an independent construct. The findings that support this proposed extension partially supports past scholarly suggestion that uncertainty functions as an antecedent of asset specificity rather than as an independent construct affecting governance outcome (Rangan *et al.*, 1993).

Two important production factors—economies of scale and rate of technological advance—demonstrated strong abilities to accurately influence accurate outcomes in the simulation model. These factors highlighted the importance of capacity to firm survivability and prosperity in a supply chain network. They also led to the apparent creation of modular networks, supporting past research into semiconductor industry structure that prompted the modular theory of the firm (Langlois, 2002). Other findings offer strategic insights for managerial decision-makers.

This dissertation is organized as follows. Chapter II lays the foundation for the simulation by presenting an overview of the use of simulation to build theory, then reviewing the literature on supply chain networks and TCA. It also reviews past modeling efforts, especially complex adaptive systems models, with a focus on the simulation method used in this study, as well as a justification for why another computational model is needed. It then integrates TCA, production processes, and complex adaptive systems in a conceptual model that forms the foundation for the simulation.

Chapter III presents the methodology that operationalizes the simulation based on the conceptual model presented in Chapter II. Chapter III presents the research design and analysis methods. Chapter IV describes the verification of the computational representation and the results of the experiments, including insights and the presentation of a theoretical framework extending TCA to the dynamic supply chain network setting. Chapter IV also validates the new theoretical framework in the semiconductor setting. Chapter V summarizes the results and presents propositions for future research as well as implications both practical and theoretical.

CHAPTER II

LITERATURE REVIEW

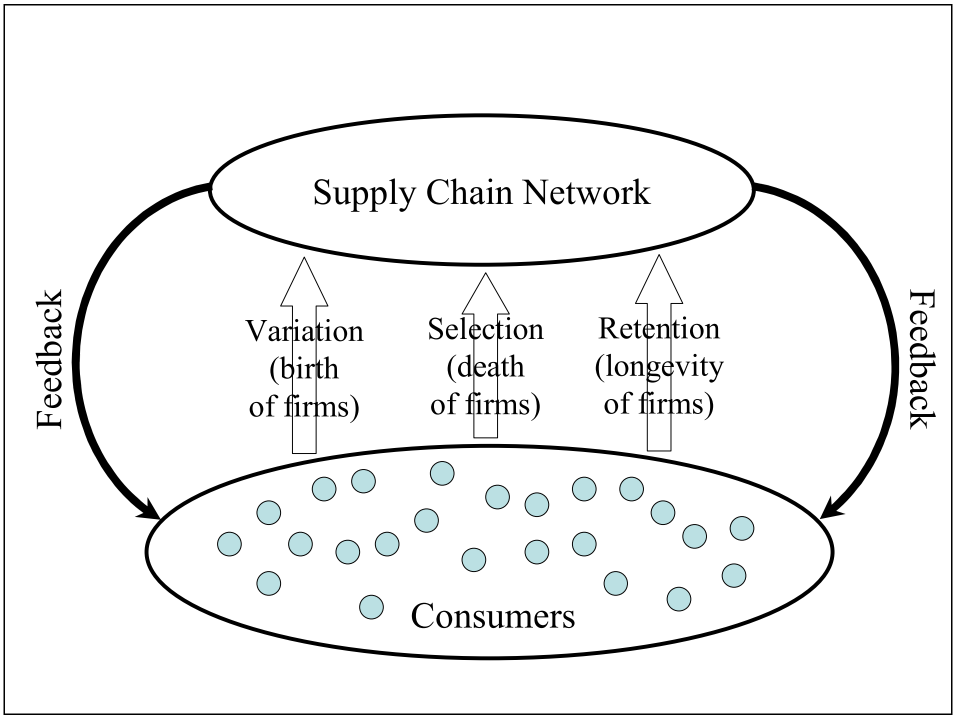
1. Introduction

This literature review begins by presenting the modeling framework. The modeling framework determines the structure and behavior of the simulation system. Each process in the modeling framework is described, including past research on dynamism and the demand environment, organizational evolution, complex adaptive systems, and transaction cost analysis. This chapter concludes with a brief history of the semiconductor industry that will form the basis for validating the simulation described in Chapter III.

2. Modeling Framework

Figure 2.1 presents the modeling framework for this dissertation. It presents each of the simple theories used to address the research question. In this modeling framework, the demand environment consists of consumer characteristics and such characteristics such as demand volume and technological change. The demand environment sets the threshold for survivability of the firm and, hence, influences evolution of the supply chain network. The demand environment exerts change on the supply chain network via three evolutionary processes (variation, selection, and retention). The products produced by the supply chain network in turn influence consumer expectations of the supply chain network in what is known in complex adaptive systems as a feedback loop. By incorporating complex adaptive system concepts such as the feedback loop, this research model allows the supply chain network to evolve based upon the interactions between firms in a bottom up fashion.

FIGURE 2.1
Modeling Framework



3. Demand Heterogeneity as the Supply Chain Network Environment

An important consideration when studying an evolutionary system is the environment. The environment both shapes and is shaped by the system under study (P. Anderson, 1999; Choi *et al.*, 2001; Morel & Ramanujam, 1999; Surana *et al.*, 2005). In the context of a supply chain network, the environment consists of the demand exerted by the end consumer market, other possible sources of supply not currently part of the supply chain network, and socio-cultural institutions that pervade the supply chain networks and its responses (Choi et al., 2001). In the scholarly literature, there are three principle views of the environment: 1) strategy view, 2) product life cycle view, and 3) a demand-based view.

The *strategy view* describes a top-down effect characterized by rational processes on the part of top management. Technological dynamism is either externally focused by a firms' suitability to enter an industry (Porter, 1980) or internally determined on matching firm capabilities and resources to environmental and market factors (Barney, 1992). Little is known about the effect of the demand environment or technological development on dynamism in the supply chain network.

The *product life cycle* view originated with Utterback and Abernathy (R. Adner, 2002, 2006a; Desarbo *et al.*, 2006) is a supply-side explanation of the technological life cycle based on product and process innovation. This view describes the early stages of a product life cycle where product innovation dominates. Product designs are changeable and many design variants exist. Product innovation focuses on improving product performance. Product innovation dominates the product life cycle until a dominant design emerges, at which point process innovation begins to take on increased importance. The emergence of a dominant design allows firms to concentrate on lowering costs through improved manufacturing process innovation.

An alternative to the top-down views of the strategy and product life cycle views of technological change is the *demand-based view*. This bottom-up view has found recent support in the strategy (R. Adner, 2002; R. Adner & Zemsky, 2006b; Desarbo et al., 2006) and marketing (J. L. Johnson *et al.*, 2003) literatures. This view premises itself on the importance of firms matching their decisions both proactively and reactively to a heterogeneous demand environment. It roots itself in the value-added business strategy work of Brandenburger and Stuart (1996) that attempts to incorporate demand side valuations of market offerings into strategy considerations.

Adner and Levinthal (2001) contributed to demand environment view by jointly assessing external market requirements with the development and evolution of technology. Specifically, they integrated the well-established notion of heterogeneous thresholds from the consumer choice and innovation diffusion literatures with Brandenburger and Stuart's willingness to pay construct. The notion of a functionality threshold indicates the minimum objective level of performance acceptable for a consumer to accept a product regardless of the price (Brandenburger & Stuart Jr., 1996).

While consumers may have a minimum requirement for a functionality threshold, there is no maximum level of utility that consumers find unacceptable. However, improvements in functionality beyond consumer needs should generate decreasing marginal utility (R. Adner & Levinthal, 1996). Of course, with all else equal, when confronted with two choices consumers will choose the superior product (R. Adner & Levinthal, 2001). With all else equal, when confronted with two choices consumers will choose the superior product (R. Adner & Levinthal, 2001).

Although Adner and Levinthal addressed the differential effects of demand heterogeneity on product and process innovation, they did not extend their analysis beyond the firm level. Macher (2006) used the knowledge-based view to assess firm-boundary decisions in the context of organizing for innovation. His findings indicate that integrated firms (those with interdependent actors) enjoyed distinct innovation advantages in the face of ill-structured and complex problems while specialized firms (those with independent actors) enjoyed advantages when innovating in the face of well-structured and simple problems. However, Macher used manufacturing measures as the outcome of his analysis and did not address the importance of market demand heterogeneity, nor did he explore in detail an entire supply chain. Furthermore, neither Macher nor Adner and Levinthal addressed the influence of customer feedback beyond price and functional criteria on technology development. The point at which these scholars left off has provided a ripe opportunity for further research.

4. Dynamism and Evolution

Markets and supply chain networks are dynamic systems. With reference to simulation models, a static model represents a snapshot in time for a system. In contrast, a dynamic model represents system evolution over time (Law & Kelton, 2000). In a system of cognitive actors, dynamism means incessantly accumulating experience and changing in response to other entities, the environment, past history, and current interactions.

Dynamism exists at several different levels. The consumer demand environment continuously changes. This dynamism results from fluid consumer preferences that the supply chain network attempts to satisfy by adapting its interactions and interdependencies, processes and resources. From a statistical perspective, the demand is stochastic (presenting random fluctuations) and non-stationary, particularly insofar as it results from a product life cycle with an early phase of rapid growth, a mature phase of slower growth with intense competition, and an end-of-life phase of slowly phasing out of production. The mechanism that triggers supply chain network adaptation is information. Entities incapable of effectively gathering and responding to information cannot adapt. The ability to seek information and create responses to it--whether it is an existing firm responding to conditions or a new firm deciding how to start out--makes supply chain network evolution possible. This perspective is rooted both in organizational evolutionary theory (Van De Ven & Poole, 1995) and the economics view of markets as complex adaptive systems (e.g., Markose, 2005).

Information may be ex post or ex ante. Ex post information flows up the supply chain network from the demand environment as in the case of information about demand response to market offerings. Ex ante information takes the form of creating a dialogue with consumers before producing a market offering, or information exchange amongst members of the supply chain network. Supply chain network members work together ex ante to adapt themselves in anticipation of changes to the demand environment. Supply chain members also exchange information amongst themselves ex post based upon changes both in the supply chain network and in the demand environment.

The exact manner and type of information exchanged depends on the type of interactions and interdependencies that exist between entities. The pertinence of this topic to this dissertation project is discussed in the section on *Governance*. At this point, it is important to note that information precipitates adaptation which may result in the phenomenon of supply chain network evolution.

The concept of evolution seems so commonplace in modern society that a precise definition is required to distinguish the use of the word in a supply chain network setting from more common use of the word. In the organizational science context, perhaps the most cited[1] definition of organizational change is that of Van de Ven and Poole (1995), who define evolution as "...cumulative changes in structural forms of populations of organizational entities across communities" (p. 517-518). They further describe evolution as: "...evolution explains change as a recurrent, cumulative, and probabilistic progression of variation, selection, and retention of organizational entities" (Van De Ven & Poole, 1995).

This definition includes three primary processes for evolution: variation, selection, and retention. *Variation* is the creation of novel forms of organizations. *Selection* results from the

[1] Cited 394 times according to Google Scholar (as of September 5, 2006).

environment selecting amongst competitors for scarce resources. *Retention* is the perpetuation and maintenance of certain organizational forms. Any study of supply chain network evolution must include indicators that these three evolutionary processes are occurring.

With regard to the three processes of evolution (variation, selection, and retention), it should be noted at this point that retention is a counteracting force to variation and selection. Process indicators that indicate variation or selection will occur obviate the occurrence of retention, and vice versa.

Logically, the positive end result of the evolutionary processes is the survival of the entity. An entity that is adapted to one or more environmental niche will survive. In the case of supply chain networks, the demand marginal utility functions comprise the heterogeneous landscape; entities that fail to meet the minimum threshold, or are not supplying another entity that meets the minimum threshold, will die out. Entities that generate too much marginal utility are not efficient—they will also die out as they spend too much energy to survive.

The change in focus from the resource or industry-based view of competitive advantage found in much business literature to the issue of adaptation finds support from Williamson who called adaptation to the environment "the central problem of economic organization" (1991). Williamson's conceptualization of adaptation did not focus on a single firm, which "...would at best realize imperfect realignments and could operate at cross-purposes" (1991) and would thus create costs from "transactions that are maladapted to the environment" (1991).

Williamson's description of TCA demonstrates evolutionary implications—adaptation in the form of governance decision creates transaction costs that, in turn, are either well- or mal-adapted to environmental conditions. Although TCA has enjoyed much success at the firm and dyadic levels, scholarly research has yet to assess TCA's ability to predict the evolution of governance decisions of firms embedded in a dynamic network.

5. What is a Supply Chain Network?

5.1. Movement toward a Network Paradigm

Practitioners and researchers have increasingly moved toward a network paradigm of value creation. The shift from a focus on the firm to the realization of firm embeddedness in ever larger constellations of firms increasingly appears in diverse streams of literature, including marketing (Achrol, 1997; Sawhney & Zabin, 2002), strategy (Gulati, 1998; Jarillo, 1988), management (Borgatti & Foster, 2003), purchasing (Harland *et al.*, 2004), supply chain management (Golicic *et al.*, 2003), and operations management (Choi et al., 2001; Surana et al., 2005).

In marketing, the prominence of networks has been attributed to industrial restructuring—the traditional large, multi-divisional corporations have been largely superseded by leaner firms focused on a core competency and members of alliances and partnerships of suppliers, distributors and competitors (Achrol, 1997). This movement augured a change in the traditional marketing paradigm, which had been rooted in exchange from the firm's perspective (Kotler, 1972; Kotler & Levy, 1969). The perspective gradually shifted to the extra-firm level first in the channels literature where the focus remained on the firm but directed at the firm's interactions with other members in a channel (El-Ansary & Stern, 1972; S. D. Hunt & Nevin, 1974). This focus gradually incorporated a larger, extra-firm view in the dyadic perspectives expressed in the transaction cost (Heide & John, 1988; Monteverde & Teece, 1982; Williamson, 1975, 1986) and relational exchange (Dwyer *et al.*, 1987; MacNeil, 1974) literatures often cited by marketing scholars.

The 1990s proved a harbinger of change. Increasing international competition and government deregulation in the 1980s had created an environment where individual firms and dyads were no longer competitive (Farmer, 1997; Tan, 2001). Rather, networks of organizations governed increasingly by norms rather than contracts appeared (Dwyer et al., 1987; Heide & John, 1992). The 1990s saw the proliferation of supply chain management as a discipline. Supply chain management broadened the firm and dyadic perspectives to incorporate the flow of goods in a value chain from raw materials through manufacturing to the end consumer (Christopher, 1992; Houlihan, 1987). However, theory takes time to develop; as of yet, supply chain management still lacks a core theory (Hult *et al.*, 2004).

The trend of competition between larger groups of firms continued until scholars began to identify that interorganizational networks provide an increasingly prevalent alternative between open market and integration, especially at the international level (Granovetter, 1985; Thorelli, 1986). Early definitions of networks such as "two or more organizations involved in long-term relationships" (Thorelli, 1986) and "concrete personal relations and structures" (Granovetter, 1985) indicate a gestalt shift from neo-classical assumptions of perfect information to the importance of asymmetric information in the modern economy. Specifically, networks provide an improvement over open markets due to the accumulation of information from the firm's past dealings with other members of the network (Granovetter, 1985; Gulati, 1998). As the economy shifts increasingly to a knowledge base (Achrol & Kotler, 1999; Vargo & Lusch, 2004), networks provide an increasingly important font of knowledge due to not only the verifiability of information regarding other network member, but also the flexibility to change in response to environmental demands both at the inter- and intra-organizational levels (Dyer & Hatch, 2006; Dyer & Singh, 1998).

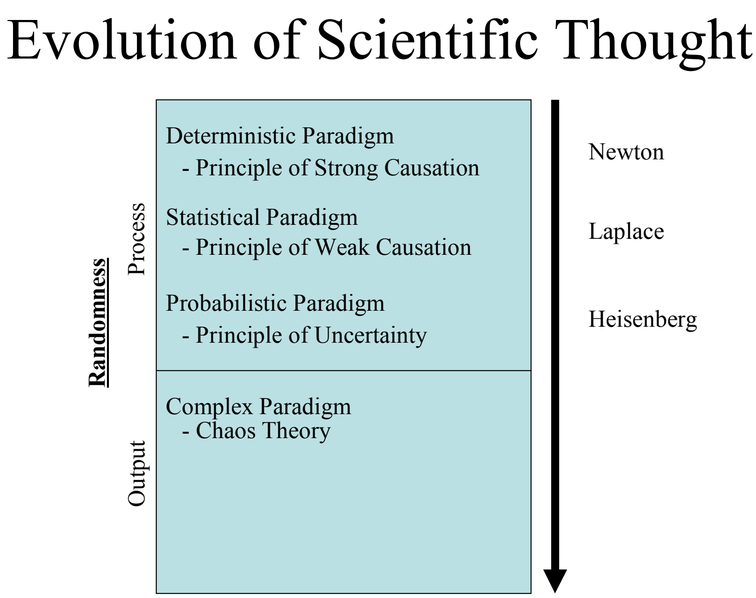
Despite empirical evidence that vindicates the belief that dyadic exchange relationships are embedded in a larger network of exchange relationships (J. C. Anderson *et al.*, 1994; Aric Rindfleisch & Moorman, 2001), thus far no comprehensive network theory of exchange has emerged. However, the development of complexity science in the physical sciences may provide a paradigm shift useful for the study of 21st century network phenomena.

5.2. Complex Adaptive Systems

Complexity science arose out of the study of open systems. In the organizational context, a system consists of interconnected components that interact; such systems are "open" because they exchange resources with the environment. When the members of a system have many interactions that result in a whole that is interdependent with the environment, they comprise a complex system (P. Anderson, 1999). In order to understand the difference between a complex system and a complex adaptive system, it is important to understand that complexity in the social sciences has developed in tandem with the shifts of the dominant scientific paradigm (see Figure 2.2).

Science initially developed under a deterministic paradigm characterized by the principle of strong causation (Mateos de Cabo et al., 2002). This view of the world assumed that linear laws governed phenomena, and complete knowledge of the initial conditions would enable absolutely accurate predictions. As science progressed, the increasing realization of the importance of environmental randomness shifted a purely deterministic view to a view that was still essentially deterministic, but with an appreciation for the lack of information known about the system. This prompted the incorporation of chance, or a statistical paradigm, wherein, operative laws approximated, on average, causes and effects. Heisenberg started to break up the co-existence of chance and determinism with his uncertainty principle wherein deterministic notions of cause and effect cease to exist; instead, probabilistic assessments are made.

FIGURE 2.2
Evolution of Scientific Thought (inspired by Mateos de Cabo *et al.*, 2002)



Although Heisenberg's probabilistic view of the universe marked a break with the previous deterministic-random duality views of the world, it still relied on the dichotomy for practical study of the world. The uncertainty principle shared the deterministic and statistical paradigms' focus on randomness in the process being studied. The appearance of chaos theory finds its roots in physical sciences studying dynamical, complex phenomena (Gharajedaghi, 1999). Although popular use of the word chaos implies a complete lack of order, chaos theory is the study of non-linear dynamical systems that exhibit randomness, but are deterministic in the sense of following rules. However, the outcomes in a chaotic system are difficult to predict due to the large number of interactions and constant dynamism (P. Anderson, 1999; Mateos de Cabo et al., 2002).

The appearance of chaos theory precedes complex adaptive systems. The idea of *complex systems* goes back many years and the concept underlies Forrester's (1958, 1961) dynamic models now commonly used as the bases for studying the beer game or the bullwhip effect in supply chain analysis (Lee et al., 1997a, 1997b). *Complex adaptive systems* build on the idea that "adaptation builds complexity" (Holland, 1995). In a Complex Adaptive System (CAS), members of a system are called entities (Surana et al., 2005). Each entity communicates with other agents and the environment, accumulating experience (learning), continuously interacting, and changing its behavior and its own as well as the system's structures. Where a complex system is dynamic, a complex adaptive system goes a step further by incessantly accumulating experience and changing in response to other entities, the environment, past history, and current interactions. The CAS perspective has been applied successfully for many years to the study of socio-economical processes, to include economics (Holland & Miller, 1991; Limburg *et al.*, 2002; Markose, 2005), organizational learning (Chiva-Gomez, 2003; McElroy, 2000; Morel & Ramanujam, 1999), psychology (Dooley, 1997; Goldstone & Sakamoto, 2003), linguistics (Kirby, 2000), anthropology (Abel, 1998), military strategy (Ilachinski, 2000), innovation (K. Eisenhardt & Tabrizi, 1995), and strategy (Bettis & Prahalad, 1995).

Although attempts have already appeared in several conference proceedings and at least one journal article (Akkermans, 2001; Ishimatsu *et al.*, 2004; Parunak, 1998; Pathak *et al.*, 2003; Ren *et al.*, 2002), the realization of the appropriateness of treating a supply chain network as a complex adaptive system is relatively recent. Choi, Dooley, and Rungtusanatham (2001), note the increasing frustration of managers trying to follow the deterministic prescriptions of traditional supply chain scholars since the dynamism and complexity of real supply networks often lie outside their control. Drawing on Holland's (1995) work, Choi, Dooley, and Rungtusanatham (2001), define a complex adaptive system as "a system that emerges over time into a coherent form, and adapts and organizes itself without any singular entity deliberately managing or controlling it." In another call to treat supply chains as CAS, Surana, Kumara, Greaves, and Raghavan (2005), define CAS as a special category of complex systems to accommodate living beings "capable of changing themselves to adapt to changing environments."

Because a complex adaptive system is a natural system, complexity results from evolution. The system changes, adapting complex responses in order to make itself more robust to uncertainty in the environment and the actions of other members of the system (Surana et al., 2005). This shifts the focus from development of basic functionality to an interactive, co-evolutionary relationship between a system entity and its environment, as well as with other system entities. An interesting result of the evolutionarily-induced increase complexity is the concomitant increase in fragility--each new complexity adds fragility at the same time it creates robustness. This leads to a cycle of increasing complexity to compensate for the fragility, which may spiral until it induces a cascading system failure (Surana et al., 2005). A real-life example of a complexity that evolved in the computer supply chain is the reduction of the number of computer memory factories world-wide in order to achieve the economies of scale required to maintain competitiveness. The fragility that resulted from the reduction in sources of supply became evident during the 1999 Taiwan earthquake that rocked world-wide computer memory supplies (Papadakis, 2003).

An additional feature of complex adaptive systems is the importance of information flows. One perspective on CAS views it as “the physics of information” (Zurek, 1990). In this view, a CAS is an information processing system that accounts for how the system obtains information, how the system entities create mental models of their surroundings, and how the system entities make decisions (Lloyd & Slotine, 1996; Surana et al., 2005). Whether encoded as genetic information in a biological system or as rational action in an economic system, information processing implies a set of rules or some form of computational ability that generates a process that selects among variant responses and evolves accordingly (Kauffman, 1990).

5.3. Definition of a Supply Chain Network

The preceding background of complex adaptive systems highlights six characteristics when applied to supply chains. The first five are: 1) interactions, 2) interdependencies, 3) high non-linearity, 4) self-organization, and 5) evolution. Because a CAS is also a complex system, it is also characterized by a sixth characteristic: dynamism. Furthermore, information processing underlies the evolutionary mechanism in a CAS.

Table 2.1 reproduces the definitions of a supply chain from a more traditional view and from a complex adaptive systems perspective. Notably absent from these definitions is any mention of dynamism or information processing. The following is the proposed definition of a supply chain network that incorporates past work and compensates for their important deficiencies:

> A *supply chain network* can be defined as sets of supply chains, characterized by dynamic (continuously changing) interactions and inter-dependencies among different entities, processes and resources both within and between the supply chains, that describe

the flow of information, goods and services from original sources to end customers and the flow of information from end customers to original sources.

TABLE 2.1
Previously Published Definitions of Supply Chain Networks

Surana et al 2005 (*International Journal of Production Research*)	"A supply chain is a complex network with an overwhelming number of interactions and inter-dependencies among different entities, processes and resources. The network is highly nonlinear, shows complex multi-scale behaviour, has a structure spanning several scales, and evolves and self-organizes through a complex interplay of its structure and function."
Lamming, R., et al., 2000 (*International Journal of Operations and Production Management*)	"Supply networks can be defined as sets of supply chains, describing the flow of goods and services from original sources to end customers."

6. Supply Chain Network Links: Governance Theory

Supply chain networks consist of actors, the links between the actors, and the demand environment. To model the links between the actors, this dissertation draws on two dominant governance theories (Ferguson *et al.*, 2005): transaction cost analysis (Williamson, 1975, 1986) and relational exchange (MacNeil, 1974). Transaction cost analysis (TCA) has generated 250 to 500 citations annually since the early 1990s (David & Han, 2004). The transactional-relational continuum of exchange governance provides a conceptually useful typology of interfirm exchanges ranging from market to hierarchy to bilateral governance (Heide, 1994).

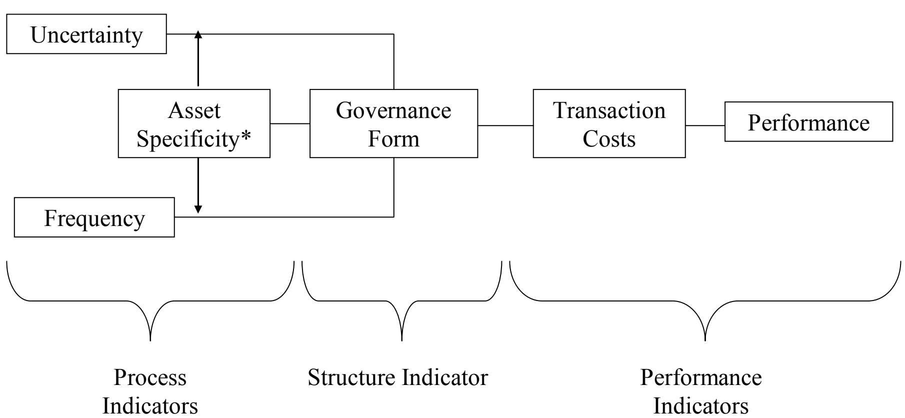
As already noted, Williamson (1991) calls adaptation to the environment "the central problem of economic organization" (1991). Williamson goes further to place the context of TCA governance decisions as coordinated response among all the players serving a particular market, particularly if the players want to survive a market disturbance. However, Williamson stops short of providing testable hypotheses for applying TCA to the network level of analysis.

This literature review briefly presents TCA. Several more complete reviews already exist in published research journals; this précis focuses on TCA's potential for pinpointing evolutionary process indicators in a supply chain network. As such, what follows is a brief description of each TCA construct and how it is hypothesized to relate to the evolution of a supply chain network.

TCA features a firm-centric, exchange-based theory that views the firm explicitly as a governance structure. Specifically, as initially set forth by Coase (1937), under certain conditions, the costs of conducting exchange on the market may exceed the costs of organizing the exchange internal to the firm. Analogous to the role of information in triggering adaptation in the evolutionary process, these costs include both ex ante costs of searching and drafting contracts as well as ex post costs such as monitoring and enforcing agreements. Williamson (1975, 1986) added precision to Coase's argument by identifying the types of exchanges more appropriately conducted internally versus externally to the firm. Part of Williamson's extension included the identification of transaction costs to include direct costs of managing relationships and opportunity costs of making inferior governance decisions. Extending Coase's insights, Williamson founded his theoretical framework on two primary assumptions of human behavior (bounded rationality and opportunism) and three dimensions of transactions (frequency, asset specificity and uncertainty). Depending on how the selected governance form functions in the face of these assumptions and dimensions, greater or lesser transaction costs result (see Figure 2.3). The assumption is that lower transaction costs are more efficient, leading to superior performance in a competitive environment.

The basic premise of TCA is that if adaptation, performance evaluation, and safeguarding costs are absent or low, economic actors favor market governance (A. Rindfleisch & Heide, 1997; Williamson, 1991). However, several gaps exist in the current body of scholarly research literature. The two primary gaps are 1) the lack of research considering the time dimension and 2) the lack of research addressing phenomena at the network level (A. Rindfleisch & Heide, 1997). The time dimension has important implications within a relationship for how an individual transaction is governed because of the past history of interorganizational relations or the incentive structure created by the expectation of future transactions. A network level perspective reveals important insights regarding how governance of a particular transaction may be influenced by other actors within an interorganizational network (directly and indirectly).

FIGURE 2.3
Basic TCA Model



* Asset specificity moderates the relationship between both uncertainty and frequency

Extensive empirical research has supported much of Williamson's work while returning mixed results for other areas (David & Han, 2004; A. Rindfleisch & Heide, 1997). What follows is a description of each of TCA's constructs, the extent of its empirical support in past research, and inferences for how the construct can be used to pinpoint process indicators for supply chain network evolution.

6.1. Asset Specificity

Asset specificity describes the degree that the assets used to facilitate a transaction can be reassigned to other uses without loss in productivity (Williamson, 1991). Higher asset specificity leads to increased interdependence, which in turn increases vulnerability. TCA predicts that higher levels of asset specificity will push toward hierarchical rather than market governance. Intermediate levels of asset specificity result in hybrid forms (Williamson, 1991).

Empirical studies regarding asset specificity provide strong support of TCA's predictive ability (David & Han, 2004; Leiblein, 2003). Asset specificity is perhaps the most studied variable in TCA research (David & Han, 2004). High levels of asset specificity have a strong correlation with more hierarchical and integrated government forms characterized by long-term relationships. Recent TCA work suggests that firms can safeguard specific assets through diverse hybrid governance mechanisms (A. Rindfleisch & Heide, 1997). Hybrid governance mechanisms fall into two categories (Heide, 1994): unilateral (governance relying on contractual authority) and bilateral (relational governance fostering close ties between exchange partners). In the context of this study, relational exchanges imply dependence on and existence of high asset specificity; this is in contrast with purely contractual, transactional exchanges.

With regard to the three processes of evolution (variation, selection, and retention), it should be noted again that retention is the counteracting force to variation and selection. Process indicators that indicate variation or selection will occur obviate the occurrence of retention, vice versa.

In terms of TCA's ability to predict variation based on asset specificity, high asset specificity implies a decreased ability to change suppliers and/or buyers, which could be a detriment when serving highly dynamic and heterogeneous markets. At the same time, high asset specificity implies improved ability to generate product change for end consumers that desire product innovation. Because a heterogeneous market means the existence of both types of end consumers, supply chain networks characterized by increased variation in asset specificity will be better adapted to serving markets characterized by high demand heterogeneity.

With regard to using TCA theory to predict selection based on asset specificity, asset specificity may lead to internal organization by decreasing the costs of internal organization rather than increasing the costs of market exchange as TCA suggests (A. Rindfleisch & Heide, 1997). If this is true, supply chain network relationships characterized by high asset specificity will tend to be selected at those points higher up the supply chain where more value added activity occurs, especially since costs tend to be magnified as products and services disseminate downward. This trend would tend to occur at point of the product life cycle where product performance levels begin to appeal to a wide audience and rapid market expansion occurs.

6.2. Frequency

The effect of frequency of transactions on governance form depends on their asset specificity (Williamson, 1986). Transactions that occur frequently and are asset specific engender constant monitoring; this type of situation favors the movement from a market to a hierarchical form of governance in order to lower monitoring costs. In contrast, asset specific transactions that occur only occasionally can be carried out on the market as their low frequency does not justify the creation of additional bureaucracy within the firm to monitor them.

Empirical support for TCA's predictions regarding frequency seem to enjoy strong empirical support, with one review finding 69% of studies supported this relationship with none finding results the opposite of TCA's predictions (David & Han, 2004). When one considers that many empirical studies that include frequency do not consider its differential effects due to asset specificity, this seems to indicate especially strong support for TCA's predictions regarding frequency.

With regard to applying these predictions to the supply chain network context, frequency of transactions should have variable effects on variation, selection, and retention depending on the extent of demand heterogeneity. With regard to variation in markets of highly heterogeneous demand, the different market segments should favor the existence of increased variation of governance structures to support highly frequent transactions. However, highly frequent transactions are much more efficient with high asset specificity. Furthermore, to a certain extent, high frequency of transactions will increase interfirm exchange of information, resulting in increased opportunities to adapt. In this situation, since more adaptation requires less commitment to a single set of relationships and more reliance on the ability to reconfigure rapidly to meet diverse market demands, supply chain networks characterized by increased variation in frequency of transactions with high asset specificity should be better adapted to serving markets characterized by homogeneous demand. Conversely, supply chain networks characterized by increased variation in frequency of transactions with low asset specificity will be better adapted to serving markets characterized by heterogeneous demand.

In terms of selection, frequency of transactions depends on asset specificity and market heterogeneity. When asset specificity is high and frequency is high, transaction costs would be lowered while the ability to adapt to changing market conditions would be diminished. In the face of a highly homogenous market, selection should favor high asset specificity in order to minimize process costs. On the other hand, in order to serve highly heterogeneous markets, the ability to change suppliers/buyers probably outweighs the opportunity cost of saving money on transaction costs with asset specificity. This reasoning implies selection in favor of supply chain network structures that reduce asset specificity. In sum, supply chain networks will be selected for high frequency of transactions with high asset specificity in response to highly homogeneous markets; supply chain networks will be selected for low asset specificity regardless of frequency in order to adapt to highly heterogeneous markets.

6.3. Uncertainty

Uncertainty embodies any unanticipated change to the circumstances surrounding an exchange (A. Rindfleisch & Heide, 1997). Uncertainty includes behavioral uncertainty and bounded rationality. Behavioral uncertainty primarily involves the problem of performance evaluation, resulting in either screening and selection costs ex ante or measurement costs ex post. Bounded rationality refers to the cognitive limits of managers who try to anticipate every contingency in a market exchange (Leiblein, 2003). Important aspects of uncertainty would include unanticipated variations in volume and technology. According to TCA, high environmental uncertainty increases transaction costs of due to the need to adapt contractual agreements.

The effects of uncertainty depend on the presence of asset specificity. In fact, uncertainty and asset specificity may be sequential rather than independent constructs (Rangan et al., 1993). This supports one possible path for evolution--asset specificity would tend to diminish following encounters with high uncertainty. Conversely, low levels of uncertainty would tend to motivate increased asset specificity in order to reduce transaction costs with little risk.

Empirical evidence demonstrates mixed results regarding TCA's predictions of the effects of uncertainty, probably largely due to the difficulty of measuring the construct (David & Han, 2004; A. Rindfleisch & Heide, 1997). It is the position of this author that since uncertainty is a multidimensional construct, it is best studied via longitudinal or dynamic methods such as the current study that take into account factors such as environmental dynamism, environmental heterogeneity, and innovation. Any insights gathered with regard to uncertainty would be an important contribution.

In terms of predictive ability, TCA claims that firms employ vertical integration as a means of easing the burden of performance evaluation. This follows from TCA's assertion that evaluation problems give rise to measurement costs. However, Ouchi (1979) provides an alternate view that measurement costs are incurred in order to distribute rewards across parties in an equitable fashion. If equitable distribution does not occur, an individual firm may eventually reduce its individual efforts, incurring opportunity costs resulting from the productivity losses. If Ouchi is correct, vertical integration will occur when equitable distribution becomes difficult--such as when margins are low for a highly commoditized item (implying highly homogenous demand). Additionally, uncertainty may also lead to more market-based exchanges due to the increased flexibility in partner-selection (A. Rindfleisch & Heide, 1997).

In terms of evolutionary process indicators, a homogeneous demand environment would compel the development of high asset specificity with variation in uncertainty throughout the supply chain. Variation in uncertainty throughout the supply chain with low asset specificity would enable the ability to switch partners as required to serve different market segments, thus rendering the supply chain better adapted to a heterogeneous demand environment. In other words, variation in uncertainty and high asset specificity throughout the supply chain would be better adapted to a homogeneous demand environment, whereas variation in uncertainty with low asset specificity throughout the supply chain would be better adapted to a heterogeneous demand environment.

Uncertainty would tend to be a strong evolutionary process indicator for selection. High uncertainty and high asset specificity would indicate an adaptation for a product toward the very early stages of the product life cycle where a dominant design has yet to be determined and competition occurs by rapid product innovation. Alternatively, low uncertainty and high asset specificity would be supply chain adaptations when low costs dominate after the product has become a commodity later in the product life cycle.

6.4. Market vs. Hierarchy vs. Hybrid Governance

The different governance forms embody the adaptation selected by the firms in a supply chain network. In simplest terms, TCA's primary theoretical prediction is that of "discriminating alignment" (Leiblein, 2003). Simple exchanges require simple forms of governance, and complex exchanges require complex forms of governance. Failure to select the optimal form of governance leads to inefficiencies which, in turn, result in the possibility that the firm(s) will be driven to extinction by firms involved in more inefficient governance arrangements.

The two basic governance forms proposed by Williamson (1975) were markets and hierarchies. Markets embody arm's length contractual relations whereas hierarchies involve fully internally organizing a function. Market governance is anonymous and limit dependencies and well-suited for simple transactions. Hierarchies are adaptive and allow control over complex transactions, but are expensive to upkeep. Hybrid governance forms were introduced later (Heide, 1994; Williamson, 1991) and imply autonomy on the part of both parties, but with the creation of some sort of interdependence that allows adaptability within a certain window.

Empirical evidence for TCA's ability to predict the proper governance form has mixed success. In predicting the "make or buy" decision or the degree of integration between buyers and suppliers, TCA has been fairly successful (David & Han, 2004). However, in studies involving prediction of hybrid governance forms, TCA has demonstrated a poor track record (David & Han, 2004; A. Rindfleisch & Heide, 1997). Furthermore, whereas TCA predicts vertical integration is more efficient, many current industries such as semiconductors are replete with interdependent companies that compete successfully (Browning *et al.*, 1995; Sturgeon, 2002). Finally, Hunt and Morgan (1995) have charged that TCA fails to distinguish firm-level decisions since all competing firms in a market face the same levels of exogenous variables.

In terms of the effect of the demand environment on interorganizational governance decisions, extant TCA studies provide ambivalent empirical results (Joshi & Campbell, 2003). Some researchers contend that market governance is better suited to highly dynamic environments since it provides firms with the freedom to change suppliers (Dyer, 1997; Dyer & Nobeoka, 2000; K. Kim, 2001). Other researchers have found evidence that relational governance performs better in dynamic environment by fomenting relationships with suppliers that are more adaptable to demand conditions (Kathleen M. Eisenhardt & Schoonhoven, 1996; Jap, 1999; Klein et al., 1990).

It is hoped that taking into account the demand environment and the network context can clarify some of these ambiguous findings (Table 2.2 summarizes the following discussion). With regard to process indicators of evolutionary variation, TCA implies that variation in governance forms would be a successful adaptation to a heterogeneous demand environment, particularly in the early stages of the product life cycle when lack of a dominant design requires generation of more innovation (and gathering and processing of more information). Conversely, a homogeneous demand environment will lead to supply chain network evolution that stabilizes with low variation.

TCA's predictions regarding process indicators of evolutionary selection for governance forms follow from the following reasoning. Hierarchical governance and vertical networks will be favored in circumstances of extremely new products with a focus on product improvement due to the requirement to both share the risk and innovate in cooperation with suppliers; this situation most commonly occurs when the demand environment is highly heterogeneous. Market governance and horizontal networks will also be favored when the product is commodity-like and focus is on low cost and process improvement due to existence of a de facto standard. This implies horizontal networks as competitors collaborate not only to maintain standards but also to pool capacity and increase economies of scale. Hybrid governance will tend to be favored at intermediate levels of the product life cycle when competition for both product and process innovations are fierce.

The case of homogenous demand and low innovation presents a sort of baseline case for studying supply chain networks. This describes a commodity type of product that is almost the antithesis of the semiconductor industry. The low level of innovativeness among consumers and lack of value for product differentiation creates an environment well suited to strong process innovation in order to reduce costs as much as possible higher up the supply stream in order to prevent their magnification as they go through additional value added services. At the assembler-retail level, transactional exchanges are preferred since they allow retailers to switch quickly to the lowest cost product.

TABLE 2.2
Interaction of Market Heterogeneity, Product Life Cycle and Supply Chain Structure

Demand	Market Characterization	Production - Assembly	Retail Dissemination
Homogenous	Low Innovativeness	Relational - small number of producers and assemblers - process innovation	Transactional - moderate number of retailers - process innovation
	High innovativeness	Relational - small number of producers and assemblers - product innovation	Relational - small number of retailers - product innovation
Heterogeneous	Early/mature stages of PLC	Transactional - many producers and assemblers - both process and product innovation	Transactional - many retailers - process innovation
	Late (declining) stage of PLC	Transactional - fewer producers with higher volumes - process innovation	Relational - small number of retailers, diminishing customer base - product innovation

Homogenous markets of highly innovative consumers create an environment that provides strong incentives for competition based on product innovation. In such an environment, a high willingness to pay for high performance leads to the appearance of product innovation at both the production and retail dissemination echelons of the supply chain network. In such an environment, a small number of producers with relational exchanges as well as a small number of assemblers and retailers with relational exchanges focus on product innovation.

Heterogeneous markets present a mix of consumers who desire high as well as low performance standards. In the early stages of the product life cycle where product performance is still improving in order to satisfy an increasing share of the market, the market environment will favor many producers and assemblers working to improve both process and product innovation. The heterogeneous environment provides opportunities for both low cost and high performance products, and assemblers able to switch producers will enjoy the benefit of being able to follow the profits as products gradually progress through improvements to both performance and price. However, at this stage, the incentive to expand market share will present enough of a downward influence on price that price savings are likely to be a favorable adaptation at the level of retail dissemination (i.e., the assembler-retailer exchanges).

Heterogeneous markets in the declining stage of the product life cycle are served by a supply chain network that has had time to develop the performance characteristics of a product to a high enough level to meet the needs of most consumers. Competition has shifted to cost, creating a strong incentive for a diminishing number of independent producers at the top of the supply chain network to specialize in cost reductions. Customers still exhibit varying levels of willingness to pay, and this provides opportunity for the retailer to add value through product innovation. In order to minimize costs in the value chain, smaller numbers of retailers form relational exchanges with assemblers.

7. Evolution of the Semiconductor Manufacturing Industry

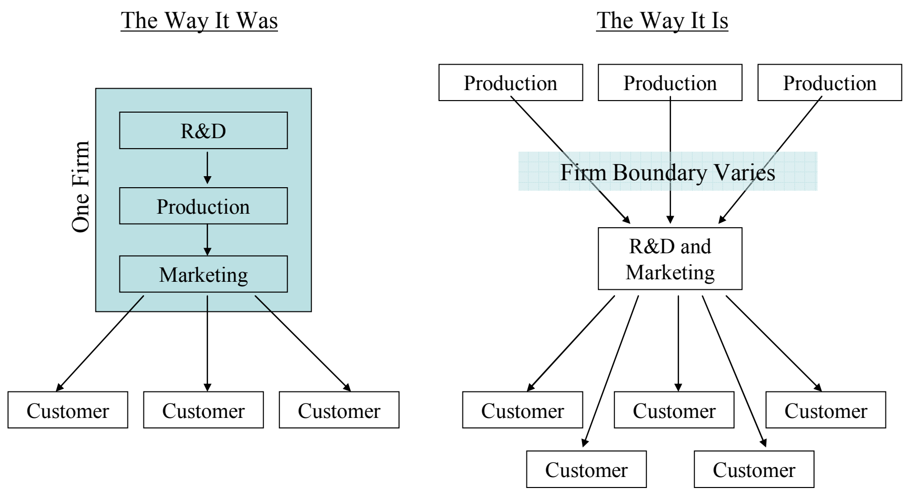
With a topical overview of some of the basic plant network literature, a primer on the evolution of the semiconductor manufacturing industry becomes more instructive. The history of the US semiconductor industry records a large transmogrification from the traditional American industry structure of the 1960s and 1970s to a far more innovative, competitive structure. In the process, American companies fell to all-time lows, then re-captured market leadership. What follows is a précis of “The Way It Was” and “The Way It Is.” The successful methods illustrate key factors that shed light on the nature of semiconductor manufacture and market competitiveness, insights that may prove valuable in a variety of high tech industries.

7.1. The Way It Was (Until 1985)

For most of the early history of the semiconductor industry, from the invention of the integrated circuit in 1959 until 1985, American semiconductor manufacturers dominated the market (Macher *et al.*, 1998). The picture of a typical American semiconductor manufacturer's network appears in Figure 2.4. Semiconductor firms characterized by vertical integration designed, manufactured, and marketed all within the company (Ernst, 1997; Sturgeon, 1997, 2002). Semiconductor firms like Intel and IBM produced advanced semiconductors in support of targeting distinct high-value market segments with different product offerings based upon proprietary designs (Ernst, 1997). It is important to note that up to this point, the personal computer comprised a negligible market, and although IBM first started selling personal computers in 1975 (Semiconductor Industry Association, 2005), Intel microprocessors did not debut in IBM personal computers until 1978 (Intel Corporation, 2005).

Interestingly, during this time, the seeds of the downfall of American semiconductor manufacturing were also planted. IBM elected to outsource all major components and software for what was then a small personal computer market, thus helping spawn the firms that would later successfully compete against them, most notably Intel and Microsoft (Chesbrough & Teece, 1996), though at the time a typical wafer fabrication plant cost just $10 million (Tewary & Wang, 2005). The American style of dedicated, small, highly innovative firms contrasted starkly with European and Japanese firms that were typically subsidiaries of large electrical equipment firms (Macher et al., 1998).

FIGURE 2.4
Evolution of Semiconductor Networks



For the microprocessor, from its introduction in 1971 until 1981, two interesting trends appeared that would in large measure dictate the current industry structure: product concentration and agglomeration economies (Swann, 1985). Microprocessor manufacturers divided into a small group that produced their own designs and a much larger group (about two thirds of manufacturers) that manufactured others' designs. The designs of 85% of microprocessors manufactured by other than the company came from five firms (Intel, Texas Instruments, Motorola, Mostek and Zilog). Increasing product design concentration gave rise to agglomeration economies, or geographically co-located bundles of related plants and resources that trade low transportation costs for internal economies of scale (a more detailed discussion of agglomeration economies appears later in this paper).

The "DRAM wars" constitute the watershed event for American semiconductor manufacturers. Direct Random Access Memory (DRAM) comprised a key product for US manufacturing firms (Macher et al., 1998). In the 1980s, American firms found themselves short on cash due to prevailing economic conditions (Ernst, 1997). Fierce competition forced margins to decrease rapidly, shifting competitive advantage to depend increasingly on economies of scale in manufacturing. The previous American model of specialized market segmentation and vertical integration proved inappropriate to keep up with rapidly shrinking margins on memory products, whereas the larger Japanese firms were able to invest huge amounts into capital buildup. Japanese firms drove most US firms out of the DRAM market and further more dominated the electronics and semiconductor manufacturing industries by 1985 (Borrus, 1997).

7.2. The Way it is Now (Post-1980)

By 1990, Japanese firms dominated 98% of worldwide DRAM sales (Macher et al., 1998). However, by 1997 US firms had regained market dominance by leveraging superior innovation capabilities and switching production from volatile and low-margin DRAM to logic devices, mixed signal, and digital signal processors (Macher et al., 1998). As product designs increasingly concentrated in a few manufacturers, agglomeration economies became quite important (Swann, 1985). Agglomeration economies provide improved economies of scale due to the clustering of capabilities. Geographic proximity of “feeder” nodes result in low unit transportation costs that partially make up for lost internal economies of scale by not producing everything under one roof. Agglomeration economies derive from infrastructure and information externalities. Infrastructure advantages consist of general purpose support devices, software and components usable by any microprocessor that abides by certain design conventions. Informational externalities appear in response to the exchange of information by producers as they learn to produce the same products. Manufacturers located near clusters of other manufacturers that produce the same or similar products also reduce their risk by taking advantage of the locally available labor pool skill sets that facilitate such information exchanges. In the large group of manufacturers producing others' designs, five reasons account for the increasing importance of agglomeration economies:

- Ability to economize on large design and development costs
- Reduced risk in the form of lower technical uncertainty since the designing firms have already demonstrated the product's technical feasibility
- Reduced risk from market uncertainty due to being able to observe demand for the product
- Increasing product standardization makes it possible to leverage externalities such as software and support devices produced by other companies

Interestingly, agglomeration economies do not seem as important to firms that produce their own designs. Indeed, producing others' designs seems particularly appropriate to the risk adverse firm. Firms producing their own designs essentially find rewards in their ability to innovate in isolation (Swann, 1985).

Contemporaneous with the appearance of agglomeration economies, the semiconductor industry has demonstrated an increasing trend toward "value chain modularity" (Sturgeon, 2002, 2003). The hitherto more prevalent relational networks model attempts to lower transaction costs via close relationships such as alliances and collaborative partners, resulting in networks dependent on social ties and, most commonly, nationally specific (Sturgeon, 2003). These networks have resulted in a fragmented industry structure that has provided American industries with a competitive advantage in the global economy due to its flexibility (see Figure 1 again).

However, several trends render such networks insufficient for many industries. Increasing capital requirements to produce certain key products or subassemblies, such as the $3 billion cost for a new wafer fabrication plant, create large barriers to entry for many innovative companies that characterize industries with short product lives and who tend to be small and entrepreneurial (Sturgeon, 2003). Even where capital requirements do not prove a deterrent, exacting production and integration requirements create hurdles that distract companies from unrelated core competencies such as innovativeness and design. As the result of economic conditions, during the 1970s and 1980s many large companies that manufactured complex products, such as computer chips and automobiles, found themselves lacking capital to internalize new and complex production techniques. Increasingly they found themselves investing in outside contract manufacturers to provide production capacity, freeing companies to concentrate on innovation, design, and market focus (Sturgeon, 2002).

Outsourcing on such a grand scale created an interesting new phenomenon: the turn-key supplier. Increasingly as the companies grew, related industries cropped up nearby, resulting in bundles or modules of industrial capability. In order to reduce their risk of dependency on any one company, these contract manufacturers expanded their services in order to develop a generic manufacturing capability (Sturgeon, 2002). While most of these companies locate themselves in the US, they generally locate their production capacity overseas to take advantage of cheaper labor or other advantageous production factors (Sturgeon, 2003).

As a result, turn-key suppliers increasingly shifted production capability from proprietary and firm-specific to generic and codified, taking advantage of the bundles of overseas production capability built up over two decades to integrate low cost overseas production capacities with high cost domestic capacities. This model takes more complete advantage of the global economy and new information technology than the traditional relational model (Sturgeon, 2003).

To put the evolution of the semiconductor industry into TCA terms, the early history of the semiconductor supply chain networks was dominated by vertical integration and exclusive relationships. Asset specificity and frequency were very high, as was uncertainty in this nascent technology. The 1980s saw the industry divide into two principle groups: 1) large mass producers of standard designs, and 2) small producers of proprietary designs. The use of standard designs by large mass producers meant reduced asset specificity and frequency, although proliferation of mass producers was initially limited by demand that remained relatively low.

Skyrocketing demand starting in the late 1980s provided the impetus for a shift to large scale manufacturing in order to capture a more price sensitive end consumer market. Market domination by vertically integrated American supply chain networks comes to an end as large Japanese firms come to dominate. American companies eventually regain their leadership in the profitable custom and high end design markets, but cannot compete with the economies of scale that foreign competitors are able to attain. This paints the picture of a heterogeneous end market that sustains primarily two types of supply chains: 1) large scale manufacturers with the strategy of aggregating demand from many buyers and 2) smaller, more innovative manufacturers producing for a shrinking market for highly innovative products. The large scale manufacturers initially exhibit greatly decreased asset specificity and frequency of exchange with their buyers, but with the rising industry concentration since 2001 exchanges frequency has risen as they occur among increasingly fewer players. The smaller, more innovative manufacturers face increasing uncertainty both in terms of advancing technology beyond the mass producers and a shrinking pool of buyers. The smaller manufacturers continue to exhibit higher asset specificity and frequency of exchanges with a small number of partners as close relationships are an important key to success for their more complex product development processes.

8. Conclusion

This chapter has presented a brief review of the literature in order to present a framework for modeling the dynamic interplay between governance and supply chain network requirements. The next chapter implements the modeling framework in order to operationalize the study the evolution of TCA in a dynamic supply chain network.

CHAPTER III

METHOD

1. Introduction

This chapter discusses the appropriateness of simulation for conducting this research dissertation, including a brief précis on building theory with simulation. It then describes the selected simulation approach, the model structure and the important model variables. Lastly this chapter presents an experimental design and guidance for verification and empirical validation of the simulation model and it concludes with a brief summary.

2. Building Theory with Simulation

Simulation has been defined as, "Using a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model" (Law & Kelton, 2000). In terms of research design, simulation provides a means of conducting experiments using a computer to describe behavior of a complex system over periods of time (Banks *et al.*, 1999; Law & Kelton, 2000; Maisel & Gnugnoli, 1972).

Despite its ability to evaluate causality via experimentation and its increasing significance as a methodology for developing theory, theory building via simulation has prompted controversy. Although such use is common in the management science and production literatures (e.g., Levitt *et al.*, 1999; Steckel *et al.*, 2004), simulation in the organization and strategy literatures is largely a more recent occurrence that coincides with rapid advances in computing power. Davis, Bingham and Eisenhardt (2007) describe the strengths and weaknesses as well as the controversy surrounding the use of simulation to build theory in the organizational and strategy contexts.

As Davis, et al. (2007), explicate, much of the controversy stems from the lack of realism in simulations. Specifically, unrealistic assumptions and lack of fidelity to empirical phenomena are cited as reasons that simulations cannot provide useful insight into theory. Such complaints against experimental methods are not new to social science scholarship and repeated calls to reduce bias against experimental methods have been made (Berkowitz & Donnerstein, 1982; Fromkin & Steufert, 1976; Ilgen, 1986; Taylor III *et al.*, 2003). The complex and sometimes indeterminate results of simulations exacerbate concerns regarding their capability to provide accurate theoretical insights (Davis et al., 2007).

The position taken in this dissertation follows that of Davis, Bingham, and Eisenhardt (2007), who describe simulation's role in theory building as "the exploration, elaboration, and extension of simple theories." Simulation serves as a springboard to elaborate "simple theory"—consisting of well-understood basic processes or vaguely understood longitudinal processes—into more powerful theory. In this role, simulation occupies a position on the research design spectrum between theory creating and theory testing. The underlying processes and theories represented in the simulation should enjoy strong empirical support, enabling their accurate computational representation. In such a scenario, the researcher may garner insights into the interactions in the processes being modeled through the experimentation that simulation enables. Such insights require additional empirical validation that may not be attainable through any other method. Simulation is particularly attractive when empirical data is difficult to obtain, or longitudinal interactions must be studied, or complex and non-linear systems must be studied (Banks et al., 1999; Davis et al., 2007; Law & Kelton, 2000).

The methodological roadmap provided by Davis, et al. (2007), while analogous to roadmaps provided in other simulation texts (Banks et al., 1999; Law & Kelton, 2000; Maisel & Gnugnoli, 1972), is tailored to the application of simulation to theory building and extension. Table 3.1 shows which chapter in this dissertation addresses each step of the roadmap published by Davis, et al (2007).

Step 1 of the theory building roadmap appears in Chapter I which stated the research question: “How does a dynamic network environment influence selection of transactional and relational exchange governance in a semiconductor supply chain network?” Step 2, identification of “simple theory,” appeared in Chapter II which presented transaction cost analysis and relational exchange, complex adaptive systems, and several insights from the production and operations research literature. Steps 3 and 4 appear in this chapter with the selection of a simulation approach that embeds the modeling framework presented in Chapter II, and the research design for verification, experimentation and validation. Chapter IV presents the “verification” of the computational representation, the results of the experiments to build novel theory, and validation with empirical data from the semiconductor industry.

TABLE 3.1
Theory Building Roadmap

Step	*Explicated in Dissertation Chapter*
1. Begin with a research question	I
2. Identify simple theory	II
3. Choose a simulation approach	III
4. Create computational representation	III
5. Verify computational representation	IV
6. Experiment to build novel theory	IV
7. Validate with empirical data	IV

3. Systems Dynamics

3.1. Systems Dynamics Modeling Steps

The systems dynamics approach to simulation is used for this modeling effort. The systems dynamics approach is useful when research focuses on the influence of causal relationships among constructs on the behavior of the system (Davis et al., 2007). The systems dynamics approach allows the researcher to specify several simple processes with circular causality—such as lower price leading to higher sales, which provides positive feedback to lower price again. These processes of circular causality also intersect with other constructs. For example, lower prices may result from increased economies of scale. The simple theories underlying the modeling framework dictate the sources of stochasticity in the modeled system.

Several past examples of simulation models have studied supply chains as complex adaptive systems using the systems dynamics approach (Akkermans, 2001; S. W. Kim, 2003; Lin et al., 2002; Parunak, 1998; Pathak, 2005). Past researchers have used an agent-based approach to study how markets consisting of semi-autonomous entities self-organize in a way that characterizes complex adaptive systems .

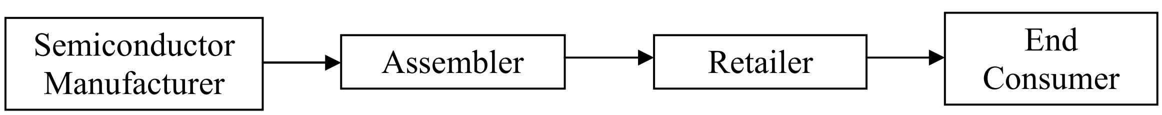
The systems dynamics approach of model building consists of six basic steps (Limburg & Wichmann, 2003).

The systems dynamics approach of model building consists of six basic steps (Mayo & Wichmann, 2003): 1) map cause and effect relationships, 2) formulate equations to represent the cause-effect relationships, 3) create the model in the computer, 4) generate output, 5) analyze output, and 6) make any needed changes to the cause and effect relationships and start again at step one. The first two steps are detailed hereafter; although a discussion of the outputs and appropriate analysis techniques were discussed earlier in this chapter, the results of steps three through six are detailed in Chapter IV.

3.1.2. System Dynamics Modeling Step 1) Map cause and effect relationships

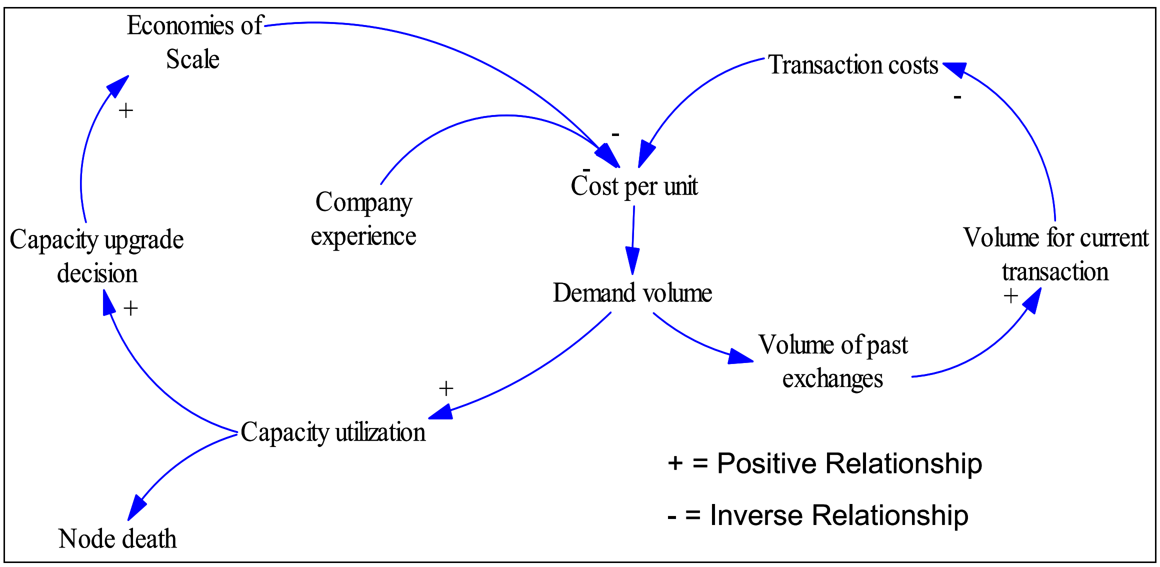
The conceptual supply chain model consists of four basic components: a semiconductor manufacturer, an assembler, a retailer, and a market demand environment comprised of end consumers (see Figure 3.1). Products must flow through the value chain as indicated in Figure 3.1. This model forms the basis for a supply chain network of multiple firms at each level serving a pool of end consumers. Each firm has similar cause-and-effect relationships, with minor differences depending on its role.

FIGURE 3.1
Basic Semiconductor Supply Chain



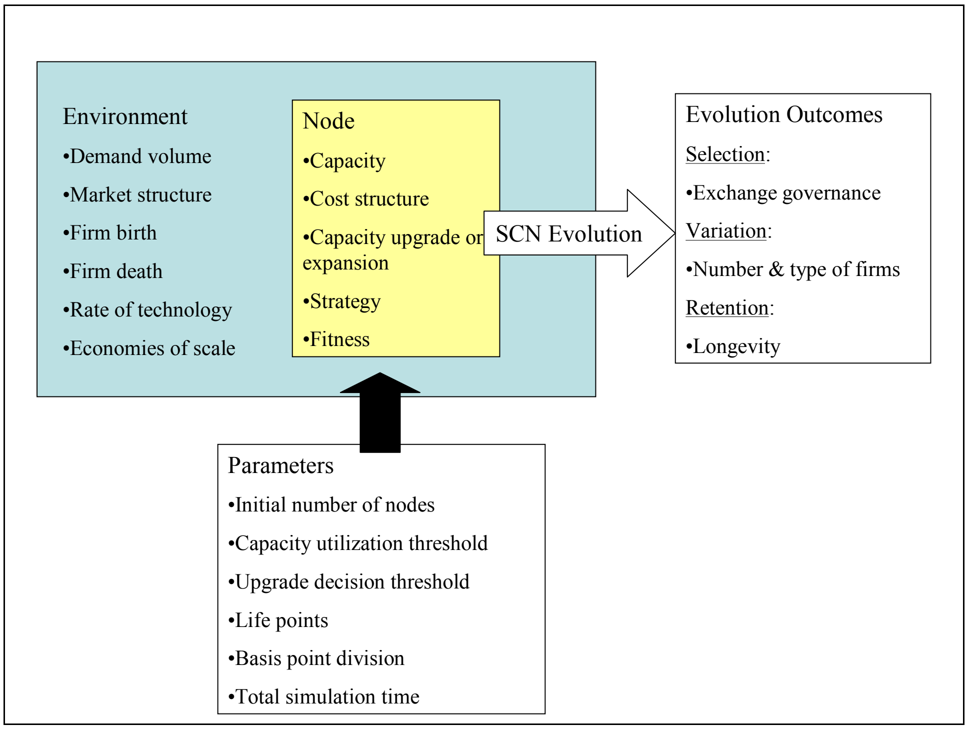
A basic causal loop diagram for exchange between two companies appears in Figure 3.2. Demand volume for the company's output determines the capacity utilization of the company, which in turn influences the decision to upgrade capacity. Economies of scale reflect the ability of a company to reduce the cost per unit based on more efficient production operations. The causal loop on the right half of the diagram describes the transaction costs for the exchange between two companies. Transaction costs diminish with frequency and magnitude, as reflected by the total volume of past exchanges and the volume of the most recent exchange. Companies select a supplier based on the lowest total production and transaction costs. The retailer is missing the transaction costs loop since this research is interested in the supply chain network evolution. This model assumes that all retailers conduct open market exchanges either with different customers or a significant period of time elapses before customers return to market. Figure 3.3 provides a conceptual diagram of how the rules interrelate. Figure 3.4 shows the flow chart for the computer program.

FIGURE 3.2
Basic Causal Loop Diagram for Manufacturers and Assemblers



Per unit cost is determined by economies of scale and the transaction cost. Nodes that do not efficiently use their capacity eventually die off. Nodes with high capacity utilization have the opportunity to improve their health and increase capacity. Health is reflected as life points assigned to the firm. Life points can increase in the case of exceptional capacity utilization. Companies with high capacity utilization are also likely to increase capacity. On the other hand, low capacity utilization reduces the likelihood of increasing capacity and also reduces life points. Once life points reach zero, the company “dies,” or is marked inactive. Company experience also contributes to lowering cost per unit and is reflected by reduced production costs based on the company's age.

FIGURE 3.3
Model Rules Framework



Other cause-and-effect relationships include the environmental factors of demand and market structure, firm birth, rate of technological change, and growth of economies of scale. Demand is distributed based on consumer price sensitivity. In a heterogeneous market, some consumers are more price sensitive and will select lower cost product; high cost products depend on the less price sensitive consumer. Markets can also be homogeneous, with consumers characterized by price sensitivity that is either high or low. An example of a homogeneous market with high price sensitivity would be a commodity such as sugar, whereas an example of a homogeneous market with low price sensitivity would be luxury goods such as jewelry or health care.

The process of firm birth starts when there is unfulfilled demand. When there is enough unfulfilled demand to support a new firm, a new firm appears. Since this simulation effort uses a demand curve with early rapid growth, there will be many births early in the simulation. New firms start at the average capacity of other firms of the same type.

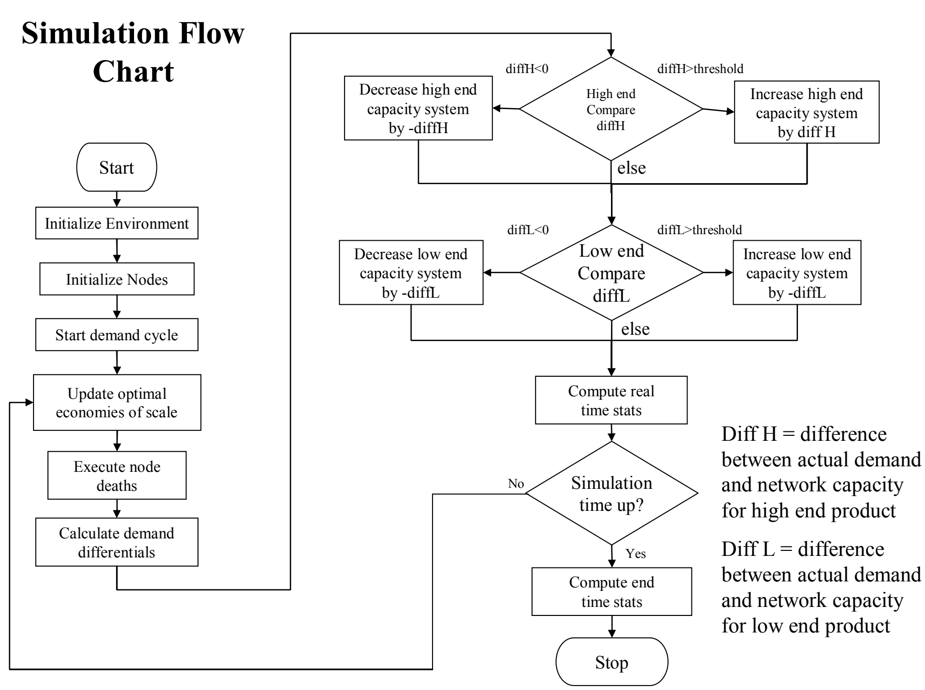
Rate of technological change determines how often manufacturing production capacity must be updated, and is directly related to the issue of obsolescence. Consumers for products characterized by a high rate of technological change expect the end product produced by the supply chain network to keep up with technological trends. Manufacturers that do not keep their capacity up-to-date eventually find themselves with no buyers and subsequently go out of business. Successful manufacturers reinvest in their production capabilities and develop a reputation amongst their buyers.

Growth of economies of scale reflects the phenomenon of increasing production efficiencies with greater plant capacity. Some industries experience rapid growth of economies of scale; semiconductors would be an example of one such industry. Other industries that do not exhibit rapid growth of economies of scale would include many service industries as well as many markets characterized by complexity or customization. In any case, increasing capacity beyond an optimum negatively impacts production efficiency (i.e., diseconomies of scale).

In addition to the problem of diseconomies of scale, recent work suggests that when market dynamics are rapid relative to capacity adjustment (i.e., there is a lag time between changes to market demand and the ability of firms to change their capacity in response), then errors in management's ability to forecast demand negatively influences any production efficiency advantage from having excess capacity (Sterman *et al.*, 2007). This is an issue of *bounded rationality*. The issue of bounded rationality becomes particularly acute when demand begins to decline. Both the issue of bounded rationality and diseconomies of scale are dealt with simply in this model with firms that simply respond to order quantities; nevertheless, the model behaves in accordance with the work by Sterman, et al. (2007).

As a final note, when each company is created it selects to carry out either a high quality or a low quality strategy. The high quality strategy means lower production and a lower optimum economy of scale, but higher prices. A low quality strategy means the converse. When the price differential for high quality versus a low quality product is small, consumers will tend to prefer the high quality product. However, while prices for both classes of product decrease linearly over time, the price for low quality products decreases more rapidly. Eventually as the price differential between the two classes of products decreases, more customers will prefer the savings over the high quality product.

FIGURE 3.4
Model Flowchart



3.1.2. System Dynamics Modeling Step 2) Formulate equations to represent the cause-effect relationships

In this section are included descriptions of variables and their equations.

Strategy: Each company selects either a high quality or a low quality strategy to pursue. Companies following a high quality strategy do business exclusively with buyers and suppliers who also pursue a high quality strategy; companies following a low quality strategy similarly deal exclusively with companies following a low quality strategy.

Life points: Life points (λ) represent the health of the company. All companies start with the same number of life points. Companies gain or lose life points based on their capacity utilization (U). Companies that make efficient use of existing capacity, as reflected by capacity utilization, are considered healthier and more resilient. *Capacity utilization* is calculated as a percent of a company's maximum capacity based on the company's sales, with the assumptions that a company only produces to demand and sells all that it produces. If the capacity utilization falls below the survival threshold (θ), a life point is lost at a rate determined by a parameter called the *basis point division parameter* (β). Capacity utilization and the basis point division parameters work in the following manner. The capacity utilization threshold selected for the model was 70 and the basis point division was arbitrarily set to 20. A capacity utilization of 70% is in accordance with the most recent U.S. Census Bureau plant capacity data (Bureau, 2005). Companies operating above this threshold gain a life point. When a company operates at capacity utilization between 50 and 70, it loses one life point. Companies operating at capacity utilization between 30 and 49 lose 2 life points, between 10 and 29 they lose 3 life points and at less than 10 companies lose 4 life points. Thus a company with a long history of being successful that has fallen upon hard times will take much longer to die out than a newer company or one with a history of being less successful.

Node deaths: When a node dies, all of the capacity it provides both upstream and downstream is removed from the system. The process for removing the capacity is done to ensure that all requirements from downstream demand are balanced against capacity amongst the suppliers. This happens before calculation of node differentials (see the sub-section on *Capacity upgrades*), so any capacity lost due to node death will be supplemented by the system.

The process of node death begins with first by going through the vectors for manufacturers, assemblers, and retailers and marking those with zero or less life points for expiration. Next, capacities for all the nodes marked for expiration are set to zero. Also, all transactions for the expiring node are set to zero, and the current capacity being ordered (either incoming or outgoing) for the expiring node is reduced by the amount affected by the dying node's expiration. For example, if an expiring manufacturer was providing 10 units to an assembler, the assembler's incoming product is reduced by 10, forcing the assembler to find another supplier to provide those 10 units of demand during the next time step. Loss at the retail level is redistributed equally among all retailers. The process of node death proceeds as follows:

1. Mark manufacturers for expiration
2. Mark assemblers for expiration
3. Mark retailers for expiration

4. Remove capacity from the marked records in the assembler vector, then balance the capacities with the affected manufacturers and assemblers
5. Remove capacity from the marked records in the manufacturer vector, then balance down to the affected assemblers, then force a capacity reduction down to the retailers supplied by the affected assemblers
6. Remove capacity from the marked records in the retailer vector, balance the lost capacity up to affected assemblers, then force a capacity reduction up to the manufacturer vector based on the affected assembler nodes
7. Mark the expiring manufacturers as inactive
8. Mark the expiring assemblers as inactive
9. Mark the expiring retailers as inactive

Explanation:

Steps 1, 2 and 3: Marking for expiration:

The algorithm goes through all active nodes of the vector, updates the life points of that company according to its capacity utilization. When life points fall to zero or less, the node is marked as expired.

Step 4: For each company a in the assembler vector that is marked for expiration the following occurs:

A) Loop through the manufacturer to assembler interaction matrix (MtoA) for each interaction associated with company a. For each manufacturing company with an active interaction:

i) for each manufacturer m, reduce the manufacturer's current capacity by MtoA's current units.

ii) reduce MtoA(m,a) current units to zero.

B) Loop through the assembler to retailer interaction matrix (AtoR) for each interaction associated with assembler a. For each active interaction with retailer r:

i) reduce r's current capacity by AtoR's current units.

ii) reduce AtoR(a,r) current units to zero.

Step 5: For each node in the manufacturer vector (M) marked for expiration do the following:

Loop through the MtoA interaction matrix for each interaction associated with manufacturer m. For each active interaction with assembler a:

i) reduce a's current capacity by MtoA's current units.

ii) reduce MtoA(m,a) current units to zero.

iii) Impose a force reduction on retailers served by assembler a, for MtoA(m,a)'s current units.

- This function occurs only here and has a bonus sweep which first removes capacity from retailers that are also expiring, then proceeds to reduce the remaining retailer current capacity based upon the virtual transaction cost vector ordered from highest to lowest.

Step 6: For each retailer (r) in the retailer vector (R) marked for expiration do the following:

Loop through the assembler to retailer interaction matrix (AtoR) for each interaction associated with retailer r. For each active interaction with assembler a:

i) reduce a's current capacity by MtoA's current units.

ii) reduce AtoR(a,r) current units to zero.

iii) Impose a force reduction on assemblers that serve retailer r, for AtoR(a,r)'s current units.

- This is the same function used for normal capacity reduction.
- The bonus sweep described in Step 5 is not required because the expired manufacturer nodes have already been zeroed out.

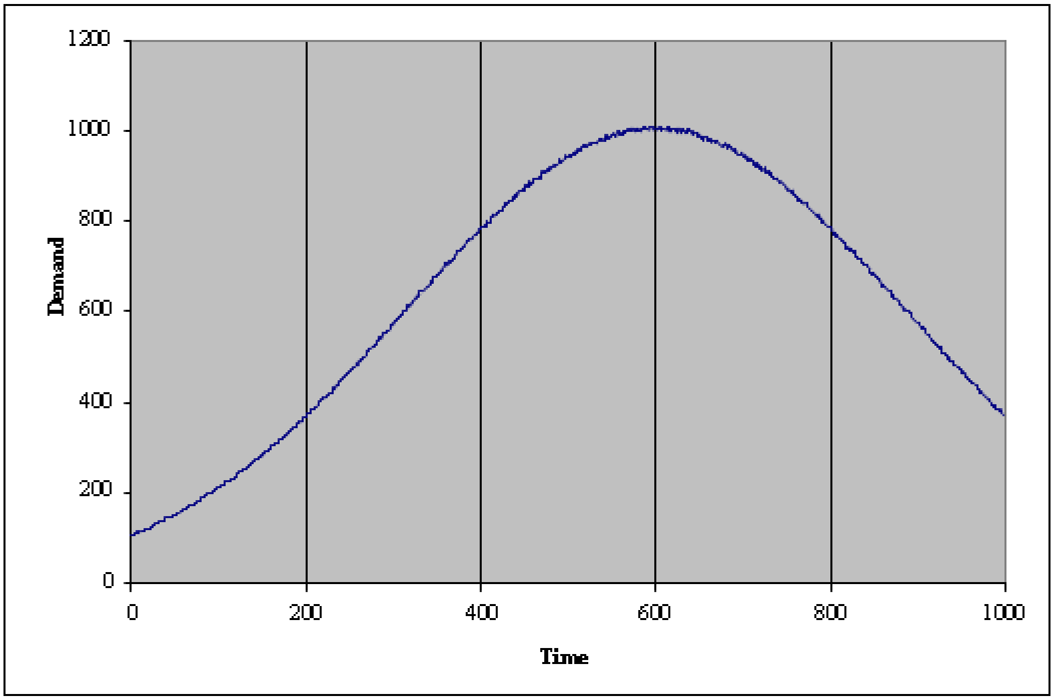
Steps 7, 8 & 9: Mark Inactive:

All companies marked as expired in each vector are marked as inactive for the remainder of the simulation. As a final note, the last time stamp reported for a node includes its death; to report the last time stamp the company went through a cycle as active requires subtracting one.

Demand volume: Demand volume is determined by a function that follows a Gaussian distribution determined by the volume of peak demand (D_{max}) with a peak demand time step (τ) and a scale factor (s). Demand also has a random factor (p) that represents the percent variance from the value determined by the demand distribution function. This is summarized by the following formula where r_t is a random number between 0 and 1 and p is the specified "random" percent of variance (and which is also shown in Figure 3.5):

$$D_t = D_{\max}(e^{-((t-\tau)/s)^2})(1 + r_t p)$$

FIGURE 3.5
Demand Volume Curve



Price: Price starts out the same for both high and low end markets (P_S). Demand is distinguished as being either high end demand (low price sensitivity) or low end demand (high price sensitivity) as determined by the established market price in each market. Prices drop in a linear fashion until the designated end prices for both the high end ($P_{H'}$) and the low end ($P_{L'}$) markets. It is implicitly assumed that price for both high and low end products will decline as the industry matures. An additional implicit assumption is that the price for low end product will always be less, or at most equal to, the price for high end product. As prices drop, demand for low end product increases while demand for high end product decreases. The volume of high end demand is represented by the following formula:

$$D_H = D_t\left(\frac{P_L}{P_H}\right)$$

where P_L is the market price for the low end market and P_H is the market price in the high end market. Conversely, low end demand can be represented by the following equation:

$$D_L = D_t\left(1 - \frac{P_L}{P_H}\right)$$

Economies of scale: As already noted, companies compete based on the price of the finished product that reaches the consumer end market. Price is determined by the production and transaction costs. Economies of scale influence production costs. Production facilities of each company type (i.e., high end manufacturers, low end manufacturers, assemblers, and retailers) have an optimal economy of scale (κ), usually increasing as the industry matures, and it can change linearly over time as determined by the optimum economy of scale size factor (ω). An optimum economy of scale size factor of one reflects a static growth of economies of scale, whereas ω=2 means that the economies of scale double over the course of the simulation. This simplistic implementation of growth of economies of scale was viewed as appropriate considering its role as an independent variable—keeping the growth linear and simple kept the model simpler to control and easier to interpret.

Depending on the deviation of a plant's current capacity from the optimum economies of scale, the plant can experience economies or diseconomies of scale. The closer the current capacity is to optimal capacity, the more efficient the company. The effect of economies of scale primarily influences the decision to increase capacity. Firms will uniformly decide to increase capacity until the optimal capacity is reached; the probability that a firm will increase capacity thereafter is reflected by a Gaussian distribution (see the section on *Capacity Upgrades*).

Technology upgrades: Companies face a moving technological frontier. In order to keep up with the rate of technological change, companies must periodically upgrade their capacity. Competition amongst companies depends on having up-to-date production facilities—keeping up is assumed to be the cost of entry. As such, it is assumed that technology upgrades propagate uniformly throughout the system. The upgrade recovery time parameter (ζ) determines the pace at which plant capacity becomes obsolete and must be upgraded. The process for upgrading technology has been incorporated with the process for capacity upgrades. As a result, early in the simulation the companies will tend to upgrade technology and capacity simultaneously, but as they reach their optimal economies of scale, technology upgrades will tend to occur without increases to capacity.

Capacity upgrades: Upgrades also include increases to plant production capacity. The decision to upgrade depends on three factors: 1) recovery time since last upgrade, 2) relative size of upgrade, and 3) the economies of scale of the resulting upgrade. The decision to upgrade capacity results when the product of the three factors exceeds the company's upgrade decision threshold (υ). A brief description of each of the three factors follows:

1. Recovery time since last upgrade (ρ): This function is based upon the number of time steps since the last capacity upgrade. When the time since the last capacity upgrade reaches the upgrade recovery time parameter ($t_U \geq \zeta$), then $\rho=1$; otherwise, $\rho = \dfrac{t_U}{\zeta}$.
2. Relative size of upgrade (δ): Companies will tend to avoid investing in trivial amounts of capacity upgrade; instead, they will wait until it is worth their while. Companies will also avoid making upgrades too rapidly lest they get ahead of the market. For example, an upgrade of only one unit is unlikely to occur, while an upgrade of 50% is likely to be

much more useful. This function annotates current capacity with C_t, the size of a requested upgrade with C_U, and follows a Gaussian distribution that was designed so that a requested capacity upgrade of 50% returns $\delta = 1$ (see equation below). Very small companies (with a capacity of 1 or 2) are handled differently with a "start up factor" allowing for slightly more drastic relative growth[2].

$$\delta = e^{-\left(\frac{C_t - 2C_U}{C_t + C_U}\right)^2}$$

3. *Economy of scale of the resulting upgrade* (γ): This function leads the company to increase uniformly its capacity until it reaches the optimum economy of scale. The result of the function depends on the company capacity at the optimum economy of scale (κ) and the company's new capacity if the upgrade is implemented ($C_t + C_U$). The economy of scale of the resulting upgrade (γ) is determined by a Gaussian distribution based on κ as follows:

$$\gamma = 1, C_t + C_U < \kappa$$
$$\gamma = e^{-\left(\frac{(C_t + C_U) - \kappa}{\kappa}\right)^2}, C_t + C_U < \kappa$$

A decision threshold (υ) determined when an individual company would go ahead with an upgrade decision. The decision threshold is constant for the entire simulation system, with individual companies going ahead with their decision to upgrade when the product of the three factors is greater than the decision threshold ($\rho\delta\gamma > \upsilon$). A product function was used for calculating the decision threshold due to the advancing economies of scale, which would also affect the magnitude of the relative size of the upgrade; a product function kept all parameters to

[2] Small companies are a special case where δ is based on the current capacity (C_t) and the size of the requested upgrade (C_U). In the case that $C_t<3$ and $C_U \leq 3C_t$, then $\delta=1$; if $C_t<3$ and $C_U \leq 4C_t$, then δ equals a constant.

the same scale. The upgrade parameter (υ) was set based upon trial and error depending on the correspondence with the optimum economy of scale. Upgrading capacity goes through recursion logic as represented in the following steps:

1. Beginning at the consumer end of the supply chain, first the virtual transaction cost vector is created that maps transaction costs from each active company to all other active companies of the same strategy in the upstream vector.
2. The virtual transaction cost vector is ordered from lowest to highest.
3. The ordered transaction cost vector is searched by the downstream node for unused capacity and used if available. (*)
4. If no unused capacity is available, the downstream firm requests upgrades using the ordered virtual transaction cost vector to order additional capacity from a supplier. (*)
5. If no supplier agrees to provide enough needed capacity, a new company is created for the unmet capacity. (*) (**)

(*) When capacity increases, the same process is called recursively at the next level in the supply chain.

(**) If the increase in demand is less than half the optimal economy of scale capacity for a retailer, then instead of upgrading, the demand is left unmet.

In the face of declining demand, system capacity can be downgraded using the following process of recursive logic:

1. Beginning at the consumer end of the supply chain, first the virtual transaction cost vector is created that maps transaction costs from each active company to all other active companies of the same strategy in the upstream vector.

2. The virtual transaction cost vector is ordered from highest to lowest.
3. For retailers, due to their purely transactional relationship with the end consumer market, system capacity reductions are distributed equally through the vector, with round offs favoring the lowest virtual transaction cost companies. For the other levels of the supply chain, system capacity downgrades propagate through most expensive virtual transaction costs first. (*)

(*) When capacity decreases, the same process is called recursively at the next level in the supply chain

Virtual transaction costs: Virtual transaction costs are used to determine a relative current cost associated with a transaction. It consists of the sum of four transaction cost factors between buyer i and supplier j: total units, current units, economy of scale, and life of company. These virtual transaction "costs" are considered by each buyer as it selects a supplier with whom to do business. This reflects the movement of demand information up the supply chain. Buyers always select suppliers in the order of lowest to highest virtual transaction cost in keeping with the desire to seek out the most efficient relationship available, with a bias toward suppliers that are familiar. Each virtual transaction cost factor is briefly described hereafter:

1. *Total units cost* (χ_{ij}): Total units cost results from the total number of units ever exchanged between two companies (h_{ij}) such that $\chi_{ij} = \frac{100}{100 + h_{ij}}$. This cost begins at one and goes down over time as two companies continue to do business.
2. *Current units cost* (ν_{ij}): The units exchanged in the current cycle between two companies (n_{ij}) result in a cost that starts at one and diminishes as the volume of the current transaction increases: $\nu_{ij} = \frac{2}{2 + n_{ij}}$

3. Economy of scale cost (ι_j): This virtual transaction cost depends on the buyer's capacity in relation to its optimum economy of scale. This cost ranges from 0 (optimum) to 0.1 (least optimum) based on current capacity (C_t) and the company capacity at the optimum economy of scale (κ) as follows:

$$\iota_j = \frac{1 - e^{-\left(\frac{C_t - \kappa}{\kappa}\right)^2}}{10}$$

4. *Life of company cost* (φ_j): This cost starts at 0.5 and diminishes as the company matures and is determined by how many time steps the buyer has been active (L):

$$\varphi_j = \frac{5}{10 + L}$$

4. Model Verification

Analogous to manipulation checks for lab experiments, model verification assesses the model's ability to simulate TCA's theoretical logic, TCA's internal validity as portrayed by the simulation, and the interpretability of the simulation results . This should be done at both the micro-level of the individual processes as well as at the level of all the processes working simultaneously.

TCA processes will be checked by running the simulation with different market conditions: homogeneous low cost (high price sensitivity), homogeneous high cost (low price sensitivity), and heterogeneous markets. This allows evaluation of diminishing transaction costs over time as the result of frequent transactions taking place between the same two firms (Williamson, 1975, 1986). When faced by a market dominated by highly price sensitive consumers, exchanges tend to be large and while transaction costs are high on a per exchange basis, they are generally relatively low on a per unit basis. Therefore, the simulation should indicate that when facing a homogeneous low market, the supply chain network evolves more transactional exchanges with less relational exchanges. In contrast, a homogeneous market of high end consumers (low price sensitivity) should lead to the evolution of more relational exchanges since smaller production volumes make transaction costs on a per exchange basis more prominent. A heterogeneous market will lead to the co-existence of supply chains of both types.

The next step of model verification will assess the process of node birth and death. Node birth and death should logically follow the growth of economies of scale, the rate of technological advance, and market structure. Births should follow when unfulfilled demand occurs due to either demand growth or death of existing firms. New firms should appear with sufficient capacity and attractiveness that at least some survive. According to TCA, deaths should logically follow low capacity utilization (poor sales performance) and end environments of increased uncertainty such as more rapid technological advance or more rapid growth of economies of scale should result in more company deaths than a more stable environment (Williamson, 1986).

Capacity decisions, including both increases and upgrades to capacity, will be verified next. Companies should tend to grow toward the optimum economy of scale. Additionally, for manufacturer firms, more rapid moving rate of technology (ζ) should prompt more frequent capacity upgrades, and vice versa. Also, increases to capacity should be non-trivial, and should be relatively much larger for smaller firms.

Lastly, the model needs to be evaluated as a whole for a variety of parameter values. The model needs checked that the interactions of each of the processes do not cause deviations from theoretically implicit propositions, and the model will be checked for robustness to a range of parameter values as well (Davis et al., 2007). This will be done by running the model with different starting assumptions, different technology rates, different economies of scale, different capacity utilization thresholds, and different degrees of randomness of demand. Corrections will be made and the model framework evaluated for adequacy.

5. Experimental Design

5.1. Dependent Variables and Statistical Analysis

Viewed through the lens of organizational studies, evolution is the result of variation, selection, and retention (Van De Ven & Poole, 1995). Variation is the creation of novel forms of organizations and will be assessed by looking at histograms of the populations of each type of company to see how many of each different type evolve over time in response to the different environmental and demand conditions. Selection results from the environment selecting amongst competitors for scarce resources and in the context of supply chain network exchanges will be assessed based on the degree to which the exchanges conducted by each company are transactional or relational. Retention is the perpetuation and maintenance of certain organizational forms and will be assessed via the longevity of each type of company in the supply chain network.

Assessing the processes of evolution as it occurs can be done with time-series analysis (Pathak, 2005; Surana et al., 2005). Time series analysis reveals attractors. *Attractors* are points in time and space where the system returns to over and over (Surana et al., 2005). A time series analysis would indicate attractors in terms of exchange selection in terms of the collaboration index. Since the collaboration index is a variable that depends on the frequency and exclusivity of exchanges, more frequent and exclusive the exchanges between two nodes drive the exchange governance is driven toward relational governance, a time series analysis reveals what level (if any) of relational vs. transactional governance comes to dominate at each level of the supply chain network. Similar analyses were applied to analyze the evolution of the number of firms at each level of the supply chain network over time and levels of price. Time series analysis reveals the cyclicity and trends of these variables, providing important information about their stability and importance over time.

The collaboration index is a scaled variable (from 0 to 1) that describes the exchange behavior for a given company in terms of how exclusive the relationships are that the company maintains with its buyers or suppliers[3]. If E(x,y) represents the total number of units sold by company x to company y, E is approximately the product of the number of exchanges that have occurred and the number of units sold per exchange (x times y). If I_i represents the collaboration index, then the collaboration index is calculated as:

$$I_i = \frac{\sum_{j=1}^{n} E(x_i, y_j)^2}{\left(\sum_{j=1}^{n} E(x_i, y_j) \right)^2}$$

where n is the number of companies j with whom company i does business.

The collaboration index provides a single measure of both the magnitude and duration of the relationship between company x and buyers or suppliers y. This means that a manufacturer will only have one collaboration index for all of its relationships with its downstream buyers, but assemblers have separate collaboration indices for their suppliers and their buyers.

[3] Special thanks to John Loney for developing the collaboration index for this dissertation effort.

This formulation for a collaboration index has the interesting property that for n equal companies that company x does business with, the collaboration index will be $\frac{1}{n}$. This can be demonstrated by assuming that for n equal companies that all have the units exchanged per combination of (i,j),

$$I_i = \frac{\sum_{j=1}^{n} b^2}{\left(\sum_{j=1}^{n} b\right)^2} = \frac{nb^2}{(nb)^2} = \frac{nb^2}{n^2 b^2} = \frac{1}{n}$$

This means that the reciprocal of the collaboration index has the interesting property of equaling the approximate number of companies that are company x's primary suppliers or buyers. In other words, a simple calculation that estimates a "virtual number of companies" that company i does business with can be calculated by simply taking $\frac{1}{I_i}$

5.2. Independent Variables

The independent variables for this dissertation study are growth of economies of scale (rapid versus slow), end market characterization (homogeneous low, homogeneous high, and heterogeneous), and rate of technological advance (rapid and slow). These variables were identified as the most important in the history of the semiconductor industry in Chapter II. The implementation of each of these factors has already been presented in this chapter.

The rate of growth of economies of scale is set by the optimum economy of scale size factor (ω) and represents one aspect of the maturation of an industry. Much of the growth of economies of scale occurs early in the history of an industry, and some industries benefit more from economies of scale than others. Semiconductors are an example of an industry that is both in the early stages of its industrial maturation and also is very sensitive to economies of scale.

End markets are characterized by populations of consumers that are either homogeneous or heterogeneous with regard to price sensitivity. Homogeneous consumers are modeled at two levels (high and low) of price sensitivity. Heterogeneous market simulations begin with markets of consumers that have low price sensitivity, but the price sensitivities of new consumers in the market are drawn from a uniform random distribution.

The advance of technology directly impacts the issue of obsolescence. Manufacturers worry most about the impact of technology since they provide form utility to the product; assemblers and retailers are relatively less sensitive to the advance of technology. As a result, assemblers and retailers depend to a great degree on the availability of manufacturers' abilities to invest properly in capacity and technology in order to eventually serve the end consumer market. As capacity ages, periodic investments are required to maintain the firm's attractiveness to other firms. The rate of technological advance is modeled as rapid and slow.

5.3. Experimentation

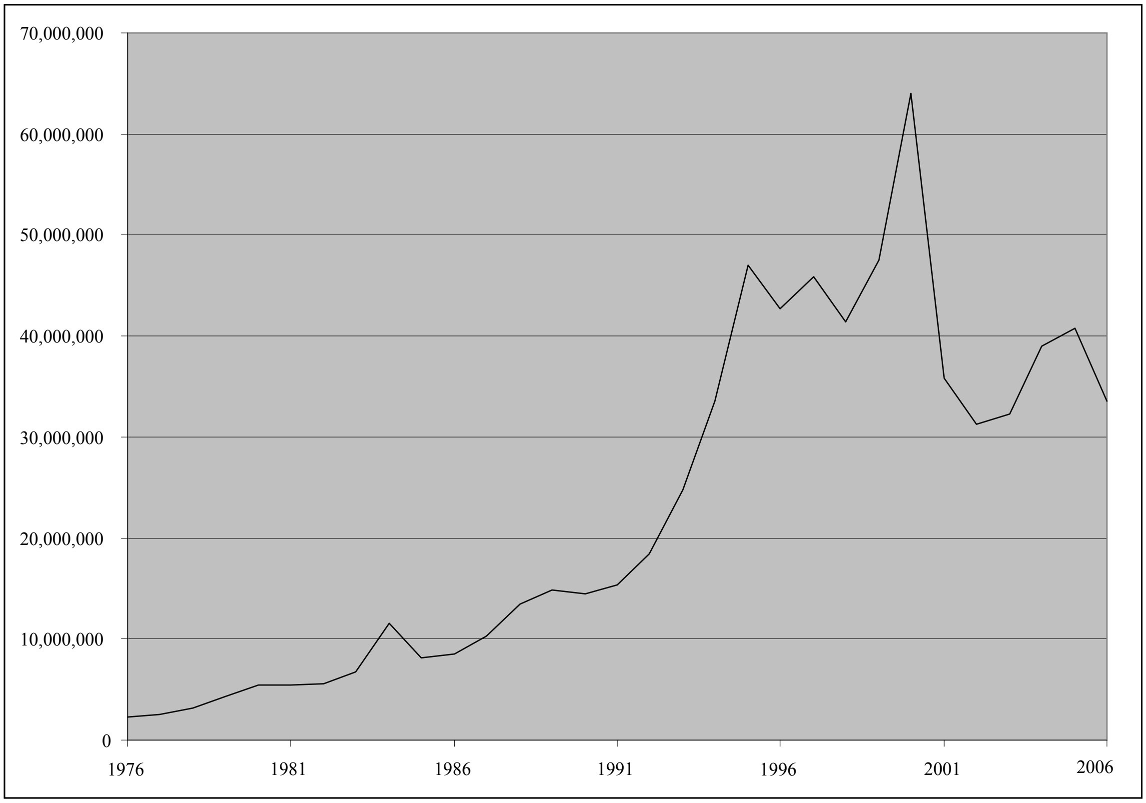
Since the goal of this dissertation is to answer the research question by exploring the interactive effects of the independent variables with respect to the dependent variables, a full factorial experimental design was implemented. With two levels of capacity cost, three levels of consumer end markets (heterogeneous or homogeneous with high and low price sensitivity), and two levels of capacity aging, there are 12 possible experiments. In order to achieve an adequate sample size for each experiment, an *n* of 30 simulations runs was selected. This makes for a total of 360 samples.

6. Empirical Validation

After completing the experimental plan described at the beginning of this chapter, the model will be validated against the semiconductor industry. The three dependent variables will be evaluated and compared to empirical semiconductor data.

The first step to empirically validate the model entails a visual confirmation that the number of semiconductor manufacturing firms follows the semiconductor historical trends. As can be seen in Figure 3.6, the semiconductor industry currently appears to be in the “mature” stage. Although the downward trend of the past few years may be temporary, it has been accompanied by an industry-wide trend of consolidation (Lewis *et al.*, 2006). The number of semiconductor firms remained relatively stable and few in number from 1957 to 1985, rising from 50 to 115 (Liu, 2001). With the rapid proliferation of the personal computer starting in the late 1980s, the number of semiconductor firms exploded to 920 firms in 1992 and 1,097 firms in 1997 (Economic Census, 1992, 1997). The latest data indicates a slight decline in the number of firms to 1,032 in 2002 (Economic Census, 2002).

FIGURE 3.6
Growth of Semiconductor Industry



After confirming the numbers of manufacturers, empirical validation requires assessing the process of variation involved in the evolution of the system. A time series analysis of the CI dependent variable should reveal that the supply chain network evolved from a fully relational (vertically integrated) vertical value chain to a network structure characterized by mostly transactional exchanges, with the exception of a few customers with low price sensitivity being served by more dedicated capacity, as indicated by the continuing existence of relational exchanges. This will happen because the network begins with exclusive buyer-supplier relationships (CI=1), then evolves to less exclusive relationships (consequently reducing CI). Take for example a manufacturer who on the first 100 time steps provides 50 units to an assembler, then increases capacity to 100 and in addition to providing 50 units to the first assembler provides the 50 units of capacity to a second assembler for an additional 100 time steps. The CI for 50 units exchanges for 200 time steps with the first assembler and 50 units exchanged for 100 time steps with the second assembler would be $[((50*200)^2 + (50*100)^2) / (50*200+50*100)^2] = 0.56$, indicating that although much of the manufacturer's exchange history has involved two assemblers, the relationship with one of them is deeper. Assessing the CI after only 110 time steps would result in a $CI = [((50*110)^2 + (50*10)^2) / (50*110+50*10)^2] = 0.84$, indicating that the history of the manufacturer's relationships up to that point had been dominated by exchanging with only one assembler.

A time series analysis of price should reveal a trend of steady decline. Empirical semiconductor data demonstrates that price in relation to function has declined rapidly over time, averaging 29% per year (Goodall *et al.*, 2002). This results from semiconductors' highly sensitive response to economies of scale. A valid simulation of the semiconductor industry should provide average price results with a rapid decline that gradually tapers as the limits of economies of scale are approached.

7. Conclusion

This chapter has presented a methodology for creating a simulation and conducting experiments to explore the interplay between governance and supply chain network dynamics. The results of building of the model in the computer and the tuning of the parameters appear in Chapter IV. Chapter IV also details the results of the experiments and the empirical validation using the semiconductor industry.

CHAPTER IV

ANALYSIS

1. Introduction

This chapter presents the verification, experimentation, and validation stages of building theory with simulation. The verification section presents the steps taken to ensure that the simulation system behaves in accordance with the processes and propositions implicit and explicit in the simple theory. The experimentation section describes the results of the experiments and the resultant development of novel theory. The validation section describes the implementation of the novel theory to predict the evolution of the semiconductor industry. The chapter concludes with a brief summary.

2. Verification

Verification entails "determining whether the conceptual simulation model (model assumptions) has been correctly translated into a computer 'program,' i.e., debugging the simulation computer program" (Law & Kelton, 2000). Verification has been described as analogous to manipulation checks in a laboratory setting, or assessing the correlation matrices in a multivariate analysis (Davis et al., 2007), and is an important step for ensuring that the simulation itself functions as intended. This is distinct from validation, which "...is the process of determining whether a simulation model (as opposed to the computer program) is an accurate representation of the system, for the particular objectives of the study" (Law & Kelton, 2000).

Verification occurs in two primary stages (Davis et al., 2007). First, the researcher compares the simulation results with both the implicit and explicit propositions of the simple theory. This entailed verification of each process and each theory involved in creating the simulation. Second, robustness checks (a.k.a., sensitivity analysis) were conducted to increase confidence that the simulation was stable over a range of conditions. Many techniques may be used to verify a simulation; this study relies on three described by Law and Kelton (2000). The first two techniques carried out the first stage of verification of the simple theory while the third technique carried out the robustness checks.

Verification technique 1 entailed the writing and debugging of the program in modules or sub-programs, with the main program written first, and then the sub-programs were added on and tested. The main program consisted of the supply chain network interacting without transaction costs or capacity decisions. Then transaction costs were implemented. Although absolute transaction costs were originally envisioned, it quickly became apparent that they had little meaning; rather, the relative transaction costs determined the outcomes of relationships. This was in keeping with Coase's vision of "an outside network of relative prices and costs" (1937). A virtual transaction cost interaction vector was developed based on the exchange history (number of units exchanged), the current exchange (number of units), actual vs. optimal economies of scale, and the life of the company (number of cycles the company has been active). The virtual transaction cost as described in detail in Chapter III resulted in the expected model behavior based upon TCA theory.

Implementation of the capacity decision processes used a sub-program. There were two aspects of the capacity upgrade decision that were incorporated into one sub-program: 1) the decision to increase the magnitude of capacity, and 2) the decision to upgrade capacity in order to keep up with an advancing technological frontier. The sub-program as originally written did not allow small firms the opportunity to upgrade capacity. The original sub-program created a cycle of small new firms that were dying out very quickly to be replaced by a new batch of small new firms that repeated the cycle of high mortality. As a result, the sub-program was modified so that small firms could upgrade capacity. The final process as described in Chapter III demonstrated the proposed behavior based upon extant production literature with companies increasing and decreasing capacity following demand in the next level of the SCN (supply chain network) as well as following the increasing economies of scale and periodic upgrades to keep up with the technological frontier.

Technique 2 verification involves a formal review by more than one person in what is called a "structured walk-through of the program" (Law & Kelton, 2000). The computer programmer represented the outside perspective of someone with no education or experience with TCA theory or market governance in general and, although an experienced programmer, had never constructed a simulation of this kind before. The author conducted a line by line walk-through of the computer program with the computer programmer. The walk-through critically assessed two aspects of the computer program. First, it assessed the relationship validity in the program. In other words, did the program reflect the causal links presented in the causal loop diagrams in Chapter III. The relationships were all found to be moving in the right direction and properly assigned a positive or negative relationship. Second, the walk-through examined the validity of the equations indicating specific relationships between the variables. The equations were in keeping with equations verified in previous supply chain dynamics models.

Technique 3 verification involved running the simulation under a variety of settings for the input parameters. This was done to check robustness or sensitivity of the model to different parameter settings. A sufficient model should behave in a reasonable fashion under extreme conditions. Since the model consisted of many parameters that were checked by extensive trial and error, robustness checks proceeded in four stages based upon the key simulation processes:

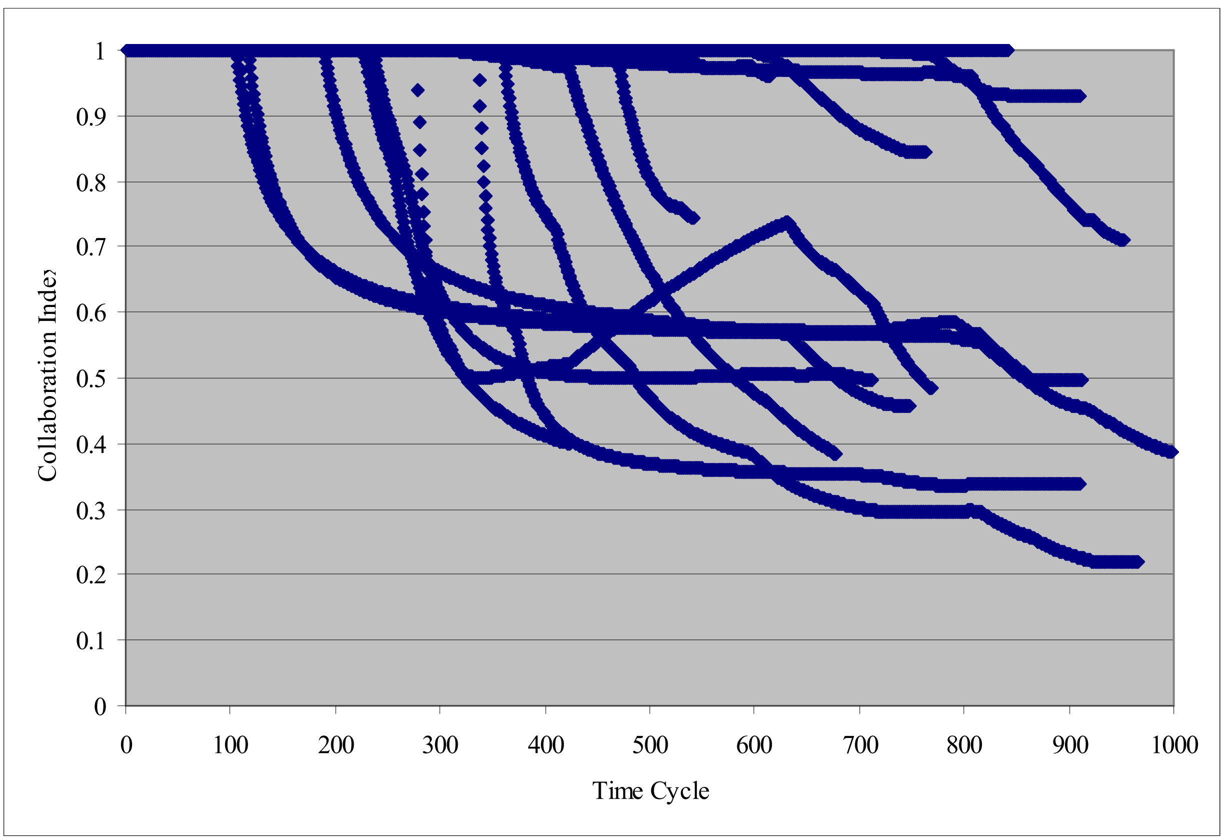
1. TCA processes,
2. Node death and birth processes,
3. Capacity decision processes,
4. Robustness checks for the simulation model as a whole over a range of parameter settings.

2.1. TCA Processes

TCA processes were checked under scenarios of two different markets: homogeneous low price (highly price sensitive end consumers) and homogeneous high price (consumers characterized by low price sensitivity). TCA predicts that open market transactions will come to dominate low cost, commodity-type markets where efficiency dominates efficacy (Williamson, 1975, 1986). Beginning with a market dominated by high end manufacturers, assemblers, and retailers, TCA theory predicts that a firm that specializes in a low cost market should develop more efficient exchanges and relationships that are less collaborative. Conversely, TCA theory predicts that a firm that specializes in a high end market dominated by efficacy over efficiency, the opposite should be true: firms will evolve toward more collaborative relationships and less connectedness (i.e., firms will deal more exclusively, and have fewer suppliers and buyers).

The model accurately reproduced TCA's theoretical predictions. Although the homogeneous, low price market scenario started with 10 firms of each type (manufacturer, assembler, and retailer) that focused on the high price strategy, by the end of 1000 time steps the low price manufacturers outnumbered the high price firms by at least two to one. In comparison, the homogeneous high price market scenario ended with no low price firms in existence. This is an expected outcome since this scenario is constituted of end consumers with low price sensitivity who opt for the higher quality product even when it costs much more. Additionally, the collaboration indices in the homogeneous low market model behave as expected with high end firms exhibiting more collaboration and fewer relationships with other firms (see Figure 4.1 for an example) than firms following a low price strategy (see Figure 4.2 for an example).

FIGURE 4.1
Evolution of Collaboration Indices for High Price Manufacturers: Homogeneous Low Price Market



2.2. Node death and birth processes

Verification of the birth and death process for nodes entailed assessing longevity and the number of births versus deaths of companies under different conditions. Under the scenario of a homogeneous, low price market starting with 10 firms of each type, by the end of a typical run, 94% of high price strategy assemblers had appeared and died, compared to 75% of low price strategy assemblers (see Table 4.1; percentages were similar for manufacturers and retailers). However, interestingly, the high price strategy firms exhibited greater longevity, albeit with a greater variance (see Table 4.2). The greater variance resulted from the far greater number of high price firms compared to low price firms. The greater longevity appeared to be the result of closer relationships and stronger assurances on serving the high end segment of the market; this conjecture was explored further during experimentation.

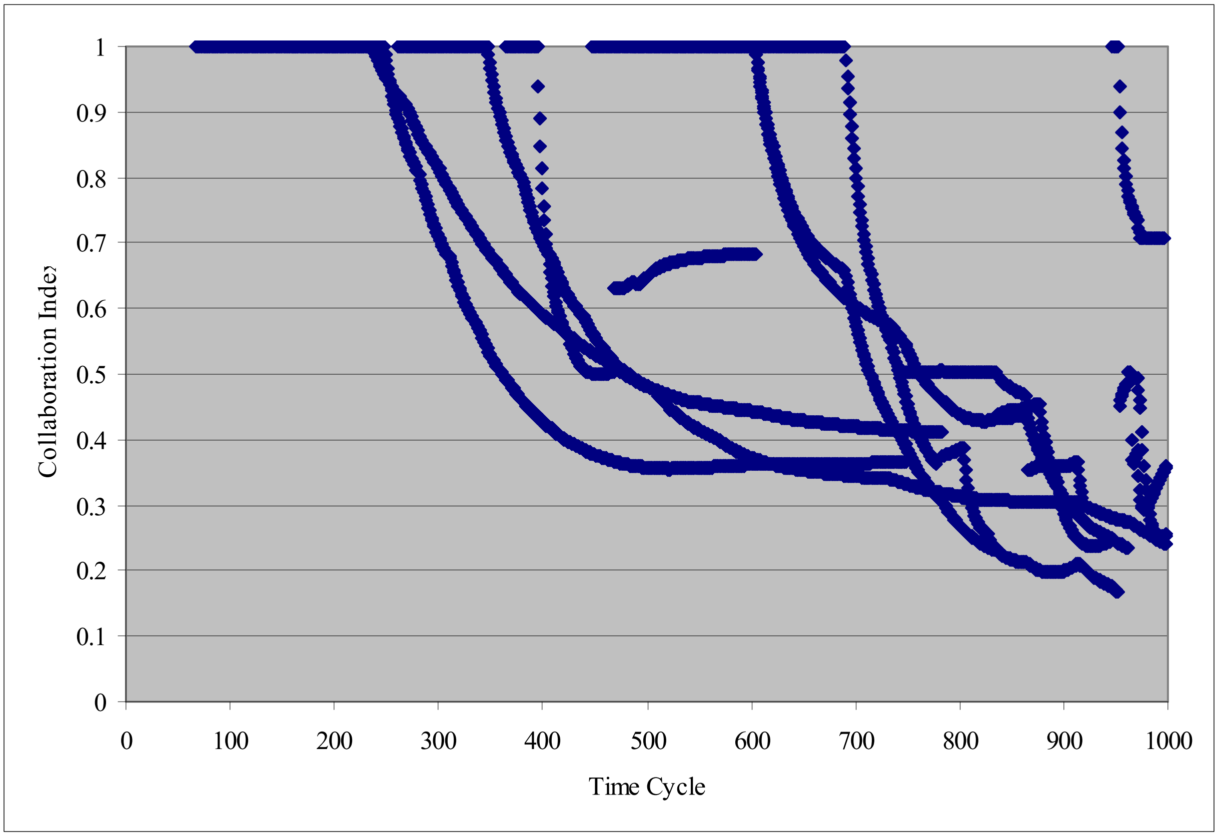
TABLE 4.1
Births and Deaths: Homogeneous Low Price Market

	Active	Inactive	Total
High	1 (6%)	16 (94%)	17
Low	4 (25%)	12 (75%)	16
Total	5 (15%)	28 (85%)	33

TABLE 4.2
Longevity (in Time Steps): Homogeneous Low Price Market

	All	High Price	Low price
Mean	379.69	476.88	276.44
Standard Error	57.08	82.76	72.05
Median	388	598	92.5
Standard Deviation	327.89	341.25	288.22

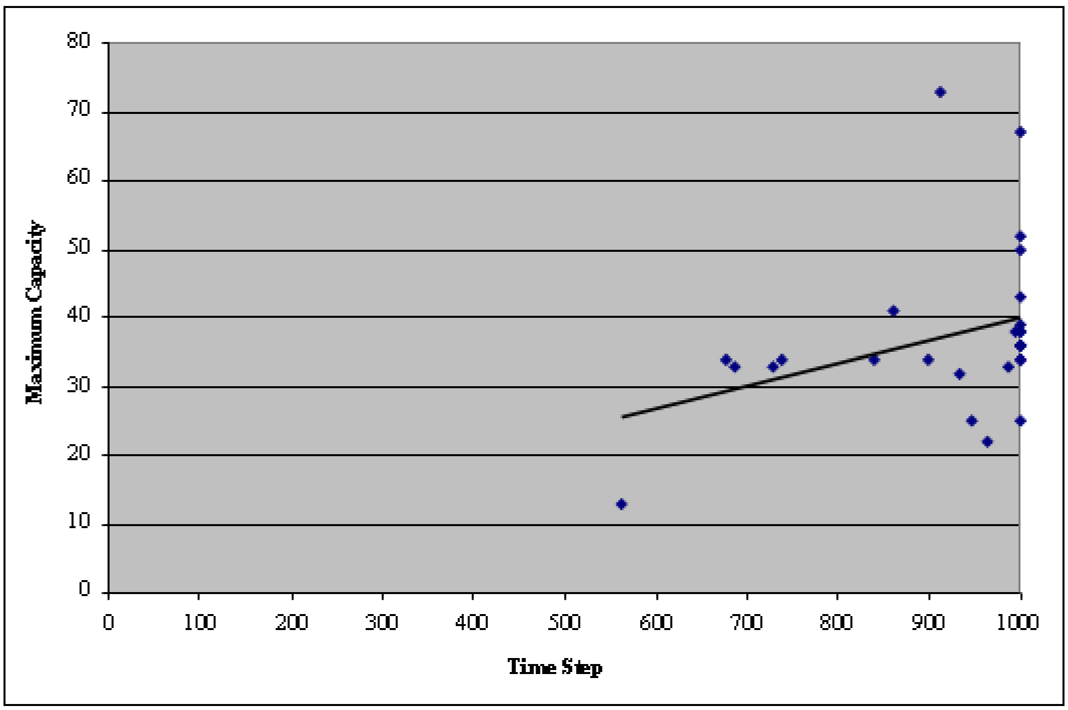
FIGURE 4.2
Evolution of Collaboration Indices for Low Price Manufacturers: Homogeneous Low Price Market



2.3. Capacity Decision Processes

Capacity for manufacturers should generally increase in a linear fashion, according to the optimum economy of scale size factor (ω) as the market grows. When the market reaches optimal size (ω=3), the average ending maximum capacities for the manufacturers should increase approximately linearly until they approximately triple by the end of the simulation. Figure 4.3 is a scattergram from a test case with the time step plotted against the manufacturer's maximum capacity when it died or at the end of the simulation, whichever came first. In this test case, only high end manufacturers were present with a starting capacity of 25 units and ω=3. The dark line represents a regression trend line. The maximum capacity of the first companies to die was around 35 units; by the end of the simulation, the biggest companies have increased to near the 75 units maximum capacity predicted by the model's parameters. It is important to note that a delay exists between the change in optimal capacity and its influence on companies that upgrade or appear afterwards.

FIGURE 4.3
Capacity Increases at Node Death or Simulation Complete



2.4. Robustness Checks

The model was tested across a wide variety of parameter settings until it reached the point of instability. In all cases, the model behaved in accordance with predictions. Variation in demand caused the most unstable model response starting with about a 10% possible random deviance from the demand curve at each time cycle. Such high randomness resulted in excessively high node mortality throughout the simulation, in turn leading to underserved markets, low collaboration index scores, and generally unstable model behavior. The model proved highly robust across a wide range of settings for the other parameters, sufficient to model any realistic supply chain scenarios.

3. Experimentation

As presented in Chapter III, experimentation consisted of simulating each combination of end market conditions, rate of technological advance, and rate of increasing economies of scale. End markets were set as homogeneous (low price sensitivity), homogeneous (high price sensitivity), or heterogeneous, with the rate of technological advance and economies of scale set to either fast or slow. This resulted in a 3x2x2 experimental design with n=30 for a total of 12 experiments and 360 samples.

In this section, analyses of the experimental results are presented in several stages with regard to their evolutionary implications. First, variation time series are presented to provide an idea of which types of firms and strategies propagate in the different supply chain network scenarios. Second, retention analyses are described—the longevity of the firms under different experimental conditions was assessed using general linear models and survival analysis. Third, selection as reflected by the evolution of interfirm relationships was assessed using proportional time series analysis. Fourth, the relationships between each of these three evolutionary mechanisms are discussed and theoretical extensions are proposed. Lastly, the theoretical extensions are validated against an empirical sample by attempting to use the proposed theoretical insights to reproduce (via simulation) the evolution of the semiconductor industry from 1976 to 2006.

3.1. Variation

Variation analysis was carried out using differencing and generalized linear modeling (GLM). Differencing compares the difference in the number of firms between the current and the previous time steps (i.e., a positive difference indicates an increase in the number of firms). Differencing is often used in time series analysis of non-stationary processes as a way of focusing on change (Granger & Newbold, 1977; Nelson, 1973).

A look (see Figure 4.4 for an example) at the time series plots of the average of the number of each type of firm for the 30 samples in each experiment (all 36 plots appear in the appendix) reveals that the differences should be approximately linear—starting at a positive number during the growth phase, diminishing gradually to zero than increasing in a negative direction. Thus generalized linear modeling was selected to analyze the differencing—GLM is a tool that which provides significance and parameter estimates that are commonly understood to assess the changes to the numbers of firms of each type as well as the interactions. This makes it ideal for distinguishing whether one firm strategy has an advantage in terms of prolificacy, particularly given that the demand environment grows and shrinks.

The GLM procedure in SAS version 9.1 was used to model the differencing scores as the dependent variable with time and strategy as the independent variables individually for each experiment except the homogeneous high price scenarios in which no low price firms were spawned. All the GLM models returned significant overall F-scores. Table 4.3 displays the parameter estimates and their significance for manufacturers, assemblers, and retailers across all 12 experiments. Time cycles were divided by 1000 to put it closer to the same relative scale as the average differences.

A significant parameter estimate for time indicates that differences increase over time—either the number of firms increases at first than decreases over time (negative parameter estimate), or it decreases at first then increases (positive parameter estimate). A zero (statistically non-significant) time estimate indicates that there was no trend in the differencing over time—in other words, neither proliferation nor diminishment occurs systematically. In this last situation, a trend of variation was not occurring, compared to the situation of a significant parameter estimate indicating that a trend of variation was occurring.

FIGURE 4.4
Example Time Series Plot of the Average Differences for Manufacturers (n=30)

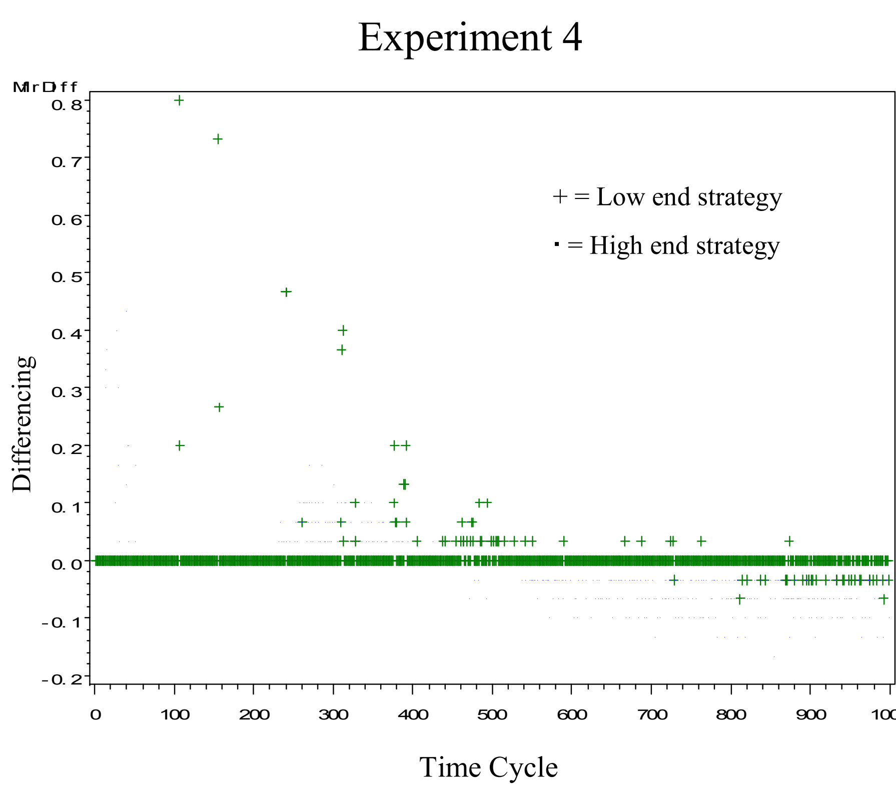


TABLE 4.3
Variation Analysis Results

Experiment	Parameter	Manufacturers Estimate	Manufacturers Pr > |t|	Assemblers Estimate	Assemblers Pr > |t|	Retailers Estimate	Retailers Pr > |t|
1	Time	-0.0112	0.0066	-0.0275	<.0001	-0.0315	<.0001
	Strategy	0.0246	<.0001	-0.0119	<.0001	0.0176	<.0001
	Time*Strategy	-0.0681	<.0001			-0.0602	<.0001
2	Time	-0.0096	0.0185	-0.0272	<.0001	-0.0290	<.0001
	Strategy	0.0232	<.0001	-0.0136	<.0001	0.0146	0.0015
	Time*Strategy	-0.0699	<.0001			-0.0673	<.0001
3	Time	-0.0259	<.0001	-0.0412	<.0001	-0.0379	<.0001
	Strategy	0.0213	<.0001	-0.0121	<.0001	0.0194	<.0001
	Time*Strategy	-0.0618	<.0001			-0.0638	<.0001
4	Time	-0.0215	<.0001	-0.0388	<.0001	-0.0353	<.0001
	Strategy	0.0222	<.0001	-0.0141	<.0001	0.0163	0.0013
	Time*Strategy	-0.0696	<.0001			-0.0710	<.0001
5	Time	-0.0978	<.0001	-0.0453	<.0001	-0.1151	<.0001
6	Time	-0.0986	<.0001	-0.0386	<.0001	-0.1240	<.0001
7	Time	-0.1134	<.0001	-0.0615	<.0001	-0.1259	<.0001
8	Time	-0.1094	<.0001	-0.0508	<.0001	-0.1348	<.0001
9	Time	-0.0400	<.0001	-0.0319	<.0001	-0.0636	<.0001
	Strategy	-0.0115	<.0001	-0.0126	<.0001	-0.0163	<.0001
10	Time	-0.0356	<.0001	-0.0304	<.0001	-0.0627	<.0001
	Strategy	-0.0135	<.0001	-0.0148	<.0001	-0.0222	<.0001
11	Time	-0.0534	<.0001	-0.0471	<.0001	-0.0703	<.0001
	Strategy	-0.0120	<.0001	-0.0130	<.0001	-0.0157	<.0001
12	Time	-0.0496	<.0001	-0.0439	<.0001	-0.0710	<.0001
	Strategy	-0.0136	<.0001	-0.0152	<.0001	-0.0216	<.0001

A significant parameter estimate for strategy indicates that there was a statistically significant difference for the amount of variation occurring between the high and the low price strategy firms. The differences begin either higher or lower, with commensurately lesser or greater differences toward the end of the simulation. This provides insight into population stability over time.

The interaction term between time and strategy measures the extent to which variation depends on how time impacts the effect of strategy. In other words, the interaction term indicates whether strategy changes the slope of the line or magnitude of the advantage or disadvantage for a strategy over the course of simulation time. Firms of a certain strategy may propagate slowly at first but then variation increases rapidly as the simulation progresses. Conversely, a certain strategy may prove successful early on, but loses its luster as the supply chain network or market conditions evolve. Overall, variation appears to depend strongly on end market conditions. Presentation of experimental results are grouped by end market scenarios.

Heterogeneous Demand. Experiments 1 through 4 occurred in a heterogeneous end market. Analysis of the parameter estimation results of the variation analysis for manufacturers and retailers reveals statistically significant parameter estimates for time, strategy and the interaction term. Additionally, for both manufacturers and retailers, the parameter estimates for all four experiments were negative for the effect of time while they were positive for the effect of strategy. A negative slope on the time estimate indicates that the number of firms starts out by growing then decreases until it becomes negative, at which point firms begin dying out. The positive strategy parameter estimates indicates that the differencing for the high price firms cross zero later than for low price firms—initial population growth was faster for high price firms, but so was later population decline.

The interactive effect was significant and negative for manufacturers and retailers for all four experiments. High price firms experience relatively greater negative population growth over the course of the simulation compared to low price firms. Overall, this paints a picture for heterogeneous end markets prompting growth early in the simulation for both low and high price firms. After demand peaks, the number of both high and low price firms declines, but much more so for high price firms. The magnitudes of the parameter estimates indicate the slopes of the differences from time step to time step, and thus were commensurate with the amount of growth then decline. Since manufacturers and retailers each had the same starting populations, the greater parameter estimates suggest that the retailers propagated to a higher population than manufacturers before rapidly dying out.

Assemblers had statistically significant negative parameter estimates for time and strategy, but once the interaction term was added strategy lost its significance. The simpler models exhibited greater R-square values and were retained. These results describe a life cycle for assemblers of initial growth that eventually turns to diminishment in keeping with the pattern of demand growth and shrinkage, but whereas high price assemblers gradually decline in population over the course of the simulation, low price manufacturers were spawned to pick up unserved market share. The lack of significance for the interaction term indicates that assembler population does not have a significant growth-then-decline like manufacturers and retailers—instead, the population remains relatively steady then high price assemblers decline as low price assemblers profligate.

Homogeneous High Demand. All four experiments with a homogeneous high price demonstrated statistically significant negative parameter estimates for time for all three firm types. This indicates that all firms profligate rapidly at first with a steady decline in the rate of population growth followed by an increasing loss in population from time step to time step. The parameter estimates indicate the greatest variation (magnitude) for retailers and the least for assemblers. Assemblers apparently enjoy some benefit from being in the middle of the supply chain—retailers face the brunt of variability in demand, and manufacturers were impacted by variation in the success of their products, but assemblers feel these effects only secondarily. Since the population of manufacturers and retailers buffers the volatility of end market demand, assemblers only have to respond to their buyer and supplier markets.

Homogeneous Low Demand. For all firm types in all four experiments with a homogeneous low price demand setting, significant negative parameter estimates resulted for time and strategy. Introducing the interactive term reduced the overall R-square and resulted in a non-significant strategy coefficient. Based on this evidence, the simpler model was retained.

The parameter estimates for retailers exhibited the greatest magnitude for both time and strategy. This reveals that retailers exhibit the greatest increase at the beginning followed by greater declines in numbers of retailers. The negative value for strategy indicates that as high strategy firms begin to decline in numbers, low strategy firms increase in numbers. This relationship was relatively stronger for retailers than it was for manufacturers and retailers. The lack of a significant interaction term indicates that the increasing rate of population growth for low price firms does not change during the course of the simulation.

3.2. Retention

Retention was assessed using survival analysis. SAS 9.1 was used to conduct all retention analyses. Logistic regression could have been used were the variable of interest simply survival or death. But assessing retention requires insight into the longevity of the companies. Survival analysis was used when the time until an event occurs was important, such as time until failure or death. Survival analysis offers the following benefits over other methods (Harrell, 2001):

1. It addresses the positive-only skewed distribution of time to occurrence of an event.
2. It provides a probability of surviving past a certain time, which is often more useful than an expected time of survival.
3. The hazard function can provide insights into the causes of failure.

4. It addresses censoring, or the situation where a subject has not died or dropped out before the end of the study.

Kaplan-Meier product-limit estimation using conditional probabilities is recommended as a starting off point for survival analysis since it is a non-parametric method less sensitive to assumptions and can help in the selection of more in-depth statistical analyses (Harrell, 2001; Hosmer & Lemeshow, 1999). Although the most popular survival analysis technique--Cox regression—is a semi-parametric technique that does not make any assumptions regarding the underlying distribution of the data, it does not specifically measure time-dependent covariance. Indeed, time dependence violates the assumption of proportional hazards required by Cox regression. Since the supply chain network under study obviously evolves over time, parametric survival analysis was selected since it does specifically measure the time-dependence (Harrell, 2001).

Separate analyses were conducted for each of the three firm types: manufacturers, assemblers, and retailers. Since the true form of the survival distribution was unknown, data were first assessed by comparing Kaplan-Meier non-parametric estimation to parametric survival analysis using different distributions, and the best distribution was selected for specialized regression (parametric survival analysis) (Hosmer & Lemeshow, 1999).

Table 4.4 presents the log likelihood for model assessment of manufacturer longevity using dummy coding for the independent variables with strategy (high price vs. low price) and maximum capacity included as covariates. The different distributions included Weibull, log-logistic, exponential, generalized gamma, and normal. Plots of the cumulative distribution functions against the Kaplan-Meier cumulative hazard functions are shown in Figure 4.4; a straight line with a slope of one represents the ideal fit. The log likelihood and plots suggest that the generalized gamma distribution provides the most appropriate distribution for more in-depth analysis. Results for assemblers and retailers mirrored the results for manufacturers. These results seem logical in face of the shape of the demand curve used in the simulation—it was a Gaussian distribution, with an increase in demand followed by the early stages of a decrease. A Weibull distribution models a monotonically increasing (or decreasing) hazard rate; the exponential distribution corresponds to the assumption of a constant hazard rate (Nardi & Schemper, 2003). The log-logistic distribution assumes an increase followed by a decrease in hazard rate; the generalized gamma distribution and normal distributions are more flexible versions of distributions from the exponential family. The most flexible of these was the generalized gamma distribution.

Separate assessments were made including the independent variables for environment, economies of scale, and rate of technological advance with either strategy or both strategy and maximum capacity as covariates. As the results indicate in Table 4.4, the inclusion of both strategy and maximum capacity resulted in lower log likelihood when modeled using the generalized gamma distribution based upon the likelihood ratio test (-2(-9150.254568-(-9786.742276))= 636.487596 with 1 degree of freedom); it also resulted in the lowest Akaike Information Criterion (AIC). Remaining longevity analysis includes both strategy and maximum capacity as covariates in the model.

Based upon its log-likelihood score and graphical analysis, the generalized gamma distribution was selected for use in subsequent parametric survival analysis using SAS's LIFEREG function. Indeed, the quality of model fit is commonly assessed by plotting the

Kaplan-Meier estimates of the cumulative hazard function against the Cox-Snell residuals (Hosmer & Lemeshow, 1999). The graphs in Figures 4.5, 4.6, 4.7, and 4.8 show the plots of parametric regression residuals using various distributions versus the Kaplain-Meier estimates. The plots indicate that the parametric regression model using the generalized gamma distribution is adequate for the exploratory nature of this study.

TABLE 4.4
Model Fit Results for Distribution Selection

	Log Likelihood		*AIC*	
Distribution	*Strategy and Max Capacity*	*Strategy*	*Strategy and Max Capacity*	*Strategy*
Weibull	-9787.34	-9787.34	19578.67	21217.02
Normal	-55151.14	-55898.17	110306.28	111800.33
Log-normal	-10887.18	-11572.86	21778.37	23149.71
Log-logistic	-10399.48	-11307.14	20862.97	22618.27
Exponential	-11729.62	-11729.62	23461.23	24166.91
Generalized gamma	-9150.25	-9786.74	18306.51	19579.48

Table 4.5 shows the parameter estimates for parametric regression models for manufacturers, assemblers, and retailers. This table does not include interactive effects; instead, analysis of each of the individual experimental conditions is discussed following the overall experimental results. Raising *e* to the power of the parameter estimate provides the estimated ratio of expected survival times for the two groups. As can be seen, all the independent variables demonstrated a statistically significant influence on firm longevity except for environment. The end market environment is significant for the longevity of manufacturers and retailers, but not for the assemblers. This is an important finding with regard to the interaction of the firm's position in the network relative to the demand environment; the theoretical implications of this finding are further discussed in Chapter V. Maximum capacity was statistically non-significant

for retailers; this is an expected finding as retailers as modeled have little potential for capacity growth, making maximum capacity of little value as a predictor.

Another interesting insight from the parameter estimates were how many parameters were near zero. The heterogeneous environment and maximum capacity were near zero for all three firm types. The effects of these variables when aggregated across all experimental conditions was not large; results of the interaction of the control variables with firm longevity by strategy type are discussed in the results of the individual.

Demand Environment. The homogeneous, high price (i.e., consumers with low price sensitivity) environment had little overall effect on the longevity of assemblers, but exhibited a positive relationship with longevity for manufacturers and retailers. Manufacturers and retailers "lived" on average 25% and 31% longer, respectively, in a homogeneous high price environment. Since the high end firms required to serve these markets do not grow as rapidly as low end firms, the growing demand in these end markets keeps extant companies in business while new companies must appear in order for the supply chain network as a whole to serve the end demand volume.

On the other hand, no statistically significant effect on longevity was found for assemblers in homogeneous, high price markets. This was an interesting finding that perhaps results from the assemblers' position in the middle of the supply chain. Retailers gain a loyal customer base, and manufacturers enjoy the benefits of an oligopoly while demand growth outstrips manufacturer capacity, but assemblers have no special protection.

FIGURE 4.5
Plot of Generalized Gamma Function vs. Kaplan-Meier Cumulative Hazard Function

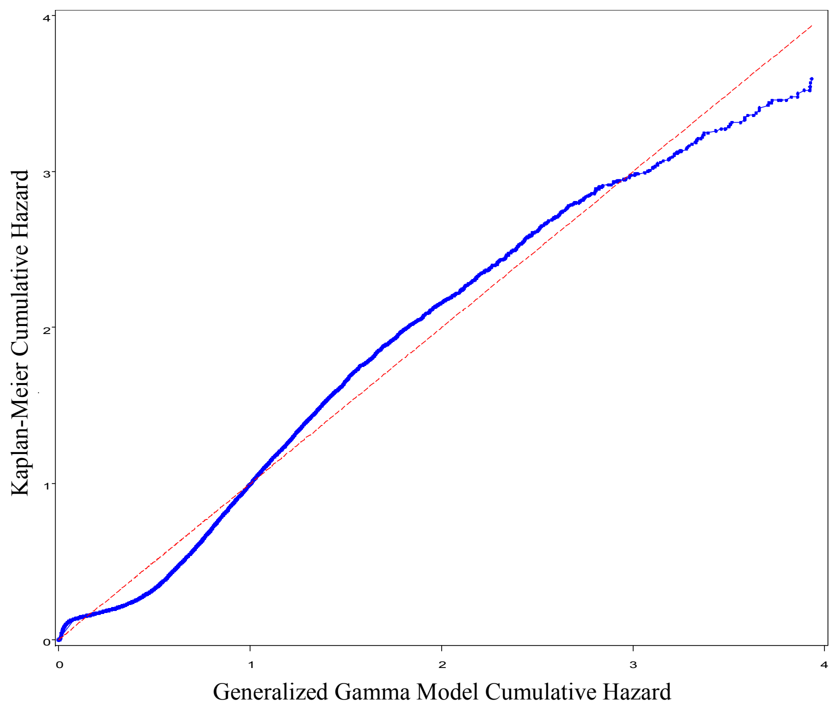


FIGURE 4.6
Plot of Log-Logistic Function vs. Kaplan-Meier Cumulative Hazard Function

Analysis of the individual experimental results (see Table 4.7) revealed that low price manufacturers enjoyed greater longevity in all 12 experimental settings. But the effect was greatest in the homogeneous low price market with a slow rate of technological advance and slow rate of change for economies of scale (β=0.839, or 131% increase in longevity over high price manufacturers). On the other hand, the effect was least strong for experiments 10 and 11 (albeit with a β=0.6604 and 0.6796, still a 94% and 97% difference, respectively). These results suggest that manufacturers facing a homogeneous low price market tend to persist longer in the extreme cases that both technology and economies of scale advance either quickly or slowly.

FIGURE 4.7
Plot of Weibull Function vs. Kaplan-Meier Cumulative Hazard Function

For assemblers, longevity was greater by 40-53% for three out of four experiments with homogeneous low price markets. The exception was the case that both technology and economies of scale advanced slowly, which resulted in a non-significant, near zero parameter estimate for strategy. Only two experiments with a heterogeneous end market had statistically significant parameter estimates for strategy, both in the case of fast growing economies of scale (this finding is discussed in the section on economies of scale). For retailers, the end market environment seemed to have little influence on longevity.

FIGURE 4.8
Plot of Exponential Function vs. Kaplan-Meier Cumulative Hazard Function

TABLE 4.5
Longevity Analysis Parameter Estimates

Parameter	DF	Estimate	Standard Error	e^{β}	Chi Square	Pr > ChiSq
Manufacturers						
Intercept	1	5.7502	0.0232	314.2535	61412.1	<.0001
Emhet	1	0.0401	0.008	1.0409	24.96	<.0001
Emhom	1	0.2249	0.012	1.2522	353.96	<.0001
RTA	1	-0.1177	0.0088	0.8890	177.31	<.0001
EOS	1	0.0866	0.0074	1.0905	135.58	<.0001
strat	1	0.6933	0.0146	2.0003	2261.44	<.0001
MaxCapacity	1	0.0079	0.0002	1.0079	1359.68	<.0001
Scale	1	0.2634	0.0064	1.3013		
Shape	1	2.4924	0.0697	12.0903		
Assemblers						
Intercept	1	6.3363	0.024	564.7030	69902.3	<.0001
Emhet	1	-0.0025	0.0087	0.9975	0.08	0.7752
Emhom	1	0.0044	0.0124	1.0044	0.13	0.7225
RTA	1	-0.124	0.0087	0.8834	201.32	<.0001
EOS	1	0.0723	0.0081	1.0750	79.11	<.0001
strat	1	0.1147	0.0142	1.1215	65.26	<.0001
MaxCapacity	1	0.0045	0.0002	1.0045	461.53	<.0001
Scale	1	0.3075	0.0075	1.3600		
Shape	1	3.5761	0.0952	35.7339		
Retailers						
Intercept	1	6.9069	0.0382	999.1451	32721.7	<.0001
Emhet	1	0.0182	0.0082	1.0184	4.94	0.0263
Emhom	1	0.2726	0.0122	1.3134	497.45	<.0001
RTA	1	-0.0236	0.0075	0.9767	10.04	0.0015
EOS	1	0.1717	0.009	1.1873	361.63	<.0001
strat	1	-0.227	0.0143	0.7969	252	<.0001
MaxCapacity	1	0.0009	0.0009	1.0009	0.89	0.346
Scale	1	0.2488	0.0089	1.2825		
Shape	1	3.6792	0.1373	39.6147		

Rate of Technological Advance. Manufacturers and assemblers exhibited 11% and 12% reductions in longevity, respectively, in the face of rapid technological advancement. Retailers also exhibit a statistically significant but very small (<3%) decrease to longevity in markets characterized by rapid technological advancement. This was to be expected since manufacturers take the onus of keeping up with technological advances, and assemblers depend on a small number of manufacturers. An assembler who chooses poorly ends up having suppliers who go out of business. Another factor for assembler longevity was the strength of relationships with manufacturers and retailers (this is elaborated further in the analysis of the evolution of the collaboration index).

With regard to individual experimental results (Table 4.6), the evidence for the influence of rate of technological advance for manufacturers indicates no outstanding inter-experimental differences with relation to manufacturing strategy—the high price strategy for manufacturers always greatly increased the chances of living longer.

For assemblers a fast rate of technological advance appeared to favor (i.e., positively related to greater longevity) the high price strategy with homogeneous, low price end markets (39% and 53% greater longevity respectively for the fast and slow increase to economies of scale). This apparently paradoxical result results from the growth in the low end market that prompts a lot of inter-firm competition among low-price strategy firms; high end firms have fewer new companies to compete with, and so tend to persist. This situation was less stable for assemblers when technology and economies of scale grow slowly—in such a scenario, the difference between high and low end product was less pronounced, taking away the competitive edge for high end assemblers. Assemblers also appear to benefit from having a more homogeneous pool of suppliers and buyers—such a situation provides them with more substitutes in the event that existing suppliers and buyers switch assemblers or go out of business.

The effect of rate of technological advance on retailers appears indeterminate; rather, economies of scale appeared to have a much stronger influence on retailer longevity.

TABLE 4.6
Longevity Parameter Estimates by Experiment

Market	RTA	EOS	Experiment	Manufacturer *Strategy*	Manufacturer *Max Capacity*	Assembler *Strategy*	Assembler *Max Capacity*	Retailer *Strategy*	Retailer *Max Capacity*
Heterogeneous	*Fast*	*Fast*	1	0.7024	0.0035	0.1291	0.0029	0.1715	0.0159
				<.0001	<.0001	0.0384	<.0001	0.0021	<.0001
		Slow	2	0.7517	0.0048	0.0026	0.0255	-0.3849	-0.0718
				<.0001	<.0001	0.9705	<.0001	<.0001	<.0001
	Slow	*Fast*	3	0.7238	0.0108	0.1579	0.0028	0.254	0.0272
				<.0001	<.0001	0.0073	<.0001	<.0001	<.0001
		Slow	4	0.7599	0.014	0.1307	0.0246	-0.3452	-0.0522
				<.0001	<.0001	0.0862	<.0001	<.0001	<.0001
Homogeneous High	*Fast*	*Fast*	5	.	0.0226	.	0.0073	.	-0.0106
				.	<.0001	.	<.0001	.	<.0001
		Slow	6	.	0.0206	.	0.0264	.	-0.0958
				.	<.0001	.	<.0001	.	<.0001
	Slow	*Fast*	7	.	0.0235	.	0.0039	.	0.0116
				.	<.0001	.	<.0001	.	0.0006
		Slow	8	.	0.0182	.	0.0067	.	-0.0923
				.	<.0001	.	0.0002	.	<.0001
Homogeneous Low	*Fast*	*Fast*	9	0.7938	0.0046	0.328	0.0046	0.032	0.0205
				<.0001	<.0001	<.0001	<.0001	0.336	<.0001
		Slow	10	0.6796	0.004	0.4256	0.0217	-0.4116	-0.0328
				<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	Slow	*Fast*	11	0.6604	0.013	0.2464	0.0042	0.1081	0.0279
				<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
		Slow	12	0.839	0.0172	0.0622	0.0044	-0.3391	-0.021
				<.0001	<.0001	0.0901	<.0001	<.0001	0.0013

Economies of Scale. All three firm types demonstrated statistically significant increases to longevity with rapidly growing economies of scale. In the presence of rapidly increasing economies of scale, manufacturers, assemblers, and retailers demonstrated 9%, 7.5%, and 18.7% greater longevity. In the scenario of rapidly increasing economies of scale, larger companies enjoy the benefits of lower production costs and the additional stability of serving larger market shares, at least in markets characterized by demand growth. Retailers that survive longer likely benefit from additional demand stability from having larger market share; those retailers who do not invest in capacity increases in such a scenario likely died earlier.

Analysis of the individual experimental results, economies of scale appeared to have a similar positive effect on longevity for manufacturers across all experimental conditions. For assemblers, the high price strategy related positively to increased longevity for the heterogeneous end market when the rate of increase of economies of scale was high (longevity for these assemblers was 13-14% greater); this effect was even greater for the homogeneous low price end market with a fast rate of technological advance (where high price assemblers lived 53% longer). Parametric regression results were statistically non-significant for assemblers in both a homogeneous low price end and heterogeneous markets with a slow rate of technological advance.

Results for the effect of economies of scale on retailers was quite strong and almost polar in nature. For a fast-paced increase of economies of scale in both heterogeneous and homogeneous low price markets, the high price strategy led to increased (from 11-29%) longevity of retailers, except in the statistically non-significant case of the homogeneous low price end market with a fast rate of technological advance. On the other hand, a slowly increasing economies of scale factor resulted in the opposite effect—high price retailers lived 29-34% less than low-price retailers in heterogeneous or homogeneous low price end markets. Relative to low price retailers, high price retailers did not have a lock on enough end market demand to survive fluctuations and competition. The impact of economies of scale at the retail level reflects real life where large retailers quickly drive small retailers out of business.

3.3. Selection

Analysis of selection focused on stability in the nature of exchanges between firms. Changes in the nature of the exchanges over time indicate that firms continue to do business only if they change their exchange relationships. Selection was operationalized as instability in the exchange relationships between successive time periods; exchange relationships were measured using the “collaboration index” presented in Chapter III.

The evolutionary process of selection was implemented with binary encoding. The thousand time cycle duration of the simulation was divided into 5 time steps of 200 demand cycles each (see Figure 4.9). Simple univariate analysis (via PROC GLM in SAS) was used to create 95% confidence intervals of the collaboration index for each time step. Successive time steps were assessed for significant changes to the collaboration index, with a 1 encoding indicating that a statistically significant change had occurred from one time step to the next; a 0 indicated no significant time change had occurred, and therefore evolution of the exchange relationships had remained stable. The series of 1’s and 0’s were then analyzed using a multinomial logit model defined by Agresti (1990) and frequently used for this type of analysis (Fokianos & Kedem, 2003).

FIGURE 4.9
Demand Curve Showing Time Steps

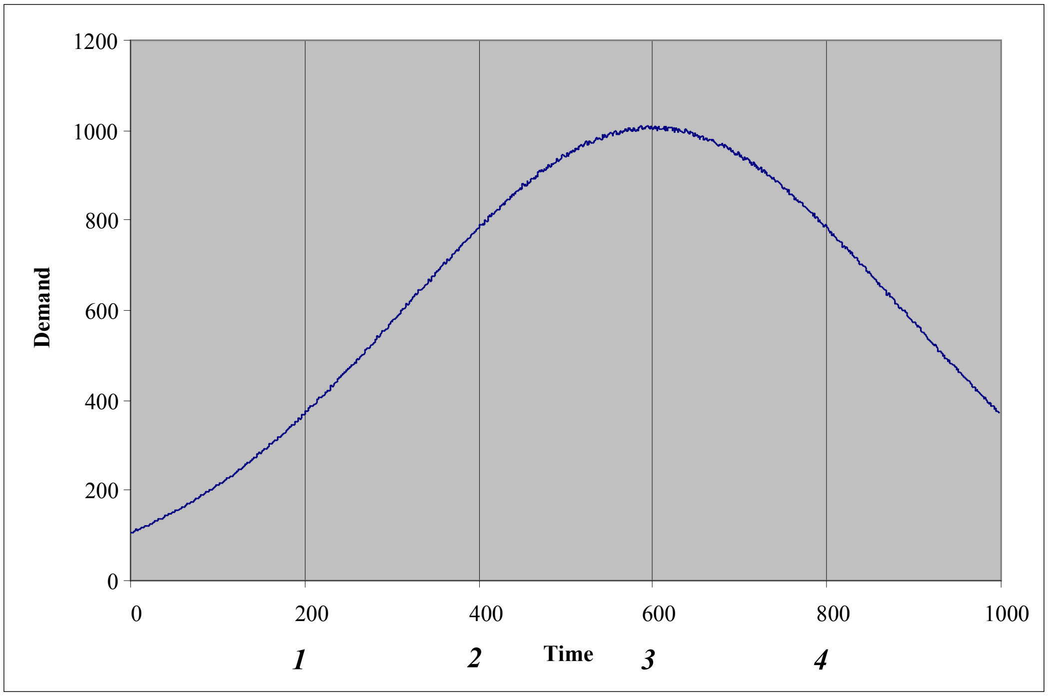


TABLE 4.7
Interaction Effects for Evolutionary Selection

Analysis of Variance

		Manufacturers		Assemblers--Up		Assemblers--Down		Retailers	
Source	*DF*	*Chi-Square*	*Pr > ChiSq*	*Chi-Square*	*Pr > ChiSq*	*Chi-Square*	*Pr > ChiSq*	*Chi-Square*	*Pr > ChiSq*
TimeStep	4	37.46	<.0001	37.14	<.0001	184.14	<.0001	8.49	0.0751
TimeStep*strat	4	87.18	<.0001	185.81	<.0001	49.36	<.0001	25.23	<.0001
TimeStep*EOS	4	10.77	0.0293	5.99	0.2001	18.48	0.001	1.12	0.8912
TimeStep*RTA	4	7.59	0.1076	8.31	0.0808	4.15	0.386	11.28	0.0236
TimeStep*EMhet	4	13.12	0.0107	46.62	<.0001	1.38	0.8471	4.65	0.3248
TimeStep*EMhom	4	13.2	0.0103	49.28	<.0001	40.13	<.0001	16.24	0.0027
TimeStep*strat*EOS	4	9.12	0.0582	16.48	0.0024	0.05	0.9997	3.98	0.4091
TimeStep*strat*RTA	4	45.71	<.0001	23.15	0.0001	2.56	0.6341	27.96	<.0001
TimeStep*strat*EMhet	4	21.58	0.0002	41.72	<.0001	2.26	0.688	20.56	0.0004
TimeStep*EOS*RTA	4	0.81	0.9366	1.44	0.8376	1.19	0.8797	2.62	0.6233
TimeStep*RTA*EMhet	4	9.02	0.0605	17.78	0.0014	1.04	0.9036	4.37	0.3579
TimeStep*RTA*EMhom	4	0.48	0.9759	0.06	0.9996	0.75	0.9452	0.19	0.996
TimeStep*strat*EOS*RTA	4	1.22	0.8745	0.7	0.9509	0.27	0.9919	0.77	0.9429
TimeStep*strat*RTA*EMhet	4	7.49	0.1122	21.38	0.0003	10.69	0.0302	3.89	0.4204
Time*strat*EOS*RTA*EMhet	4	2.7	0.6099	3.13	0.5368	0.57	0.9666	0.5	0.9735
Time*strat*EOS*RTA*EMhom	4	0.42	0.981	8.57	0.0729	0.37	0.9846	0.17	0.9967

All 12 experiments were coded for exchange relationship instability from each firm's point of view. Assemblers were unique in that they had relationships both upstream with manufacturers and downstream with retailers. A complete statistical analysis for all 30 samples per experiment and four exchange perspectives per sample looked for any statistical significant interactions between the three independent variables (economies of scale, rate of technological advance, and end market conditions) and the dependent variable of instability. Firm strategy was also included as a key covariate. Results from the CATMOD function in SAS 9.1 are displayed in Table 4.7.

As was noted in the retention (longevity) analysis, strategy has a significant effect on the evolution of the nature of exchange relationships from all relationship perspectives. Also, the extreme environments as operationalized by homogeneous high and low markets with regard to consumer price sensitivity were also statistically significant across all relationship perspectives. Time and strategy interacted significantly both with rate of technological advance and heterogeneous environments for three out of four perspectives—only the assembler-to-retailer relationships did not appear to be affected by those three-way interactions. It appears that a heterogeneous environment had an important effect on the evolution of exchanges between manufacturers and assemblers, but economies of scale only mattered from a supplier's perspective—it was significant for both manufacturers and for the assembler-to-retailer exchanges. Strategy and economies of scale interacted over time to influence assembler-to-manufacturer exchanges, but were not quite significant from the manufacturers' perspective (p=0.0582). Rate of technological advance was significant from the buyer's perspective—in the case of the assembler-to-manufacturer perspective, it rate of technology was significant both with and without strategy as a covariate in a heterogeneous market environment, and it was also significant for retailers even without strategy as a covariate.

The preceding results were used as the basis for more detailed selection analysis by exchange perspective. Parameter estimates for the proportional time series analysis for manufacturer, assembler-to-manufacturer, assembler-to-retailer, and retailer perspectives follow. Since observations indicated strategy was a significant discriminator of collaboration index evolution, results are shown separately for low price (strat=0) and high price (strat=1) strategies.

Manufacturer. Overall, once results were parsed by strategy and time, only the end market environment and economies of scale had statistically significant effects on the collaboration indices for manufacturers (see Table 4.8). For low price manufacturers, strategy interacted significantly with time throughout the simulation. Collaboration indices for low price manufacturers start out high but drop over the course of the simulation. This indicates that as demand increases, low price manufacturers increase the number of firms they do business with. The increase was greatest when demand growth was greatest, and the increase diminishes somewhat toward the end of the simulation when demand begins to decline. This was not true for high price manufacturers—although the parameter estimate indicates a decline in the collaboration index (and a concomitant increase in the number of firms they do business with) the results were not statistically significant.

A setting characterized by rapidly growing economies of scale appeared to have the same effect on manufacturing firms' exchanges, regardless of strategy. It appears that as demand declines toward the tail end of the product life cycle that rapidly growing economies of scale force an increase in the number of firms manufacturers exchange with. The effect was relatively slightly stronger for high price manufacturers.

TABLE 4.8
Manufacturer Selection Parameter Estimates by Strategy

		Low Price Strategy		*High Price Strategy*	
Parameter		*Estimate*	*Pr > ChiSq*	*Estimate*	*Pr > ChiSq*
TimeStep	1	4.96	<.0001	-0.35	0.4236
	2	-1.19	0.0015	-0.35	0.4236
	3	-2.49	<.0001	-0.35	0.4236
	4	-1.71	<.0001	0.16	0.7035
TimeStep*Economies of Scale	1	0.13	0.7312	0.22	0.5233
	2	0.39	0.2796	0.10	0.7691
	3	0.36	0.3588	0.10	0.7691
	4	-0.61	0.0658	-0.76	0.0087
TimeStep*Het. End Market	1	0.35	0.374	-0.24	0.5599
	2	-0.93	0.0135	-0.42	0.3242
	3	0.37	0.3566	-0.42	0.3242
	4	0.40	0.2137	0.30	0.3408
TimeStep*Hom. End Market	1	.	.	-0.51	0.2272
	2	.	.	-0.69	0.1128
	3	.	.	-0.69	0.1128
	4	.	.	0.54	0.1439

With regard to end market characteristics, since no low price manufacturers appeared in the homogeneous high price scenario, the estimates based on only the time step form the baseline case of a homogeneous low price end market with a slow rate of technological advance and slow growth of economies of scale. Low price manufacturers appear to rapidly increase the number of buyers with whom they do business. In the case of a heterogeneous end market, low price manufacturers increase the number of buyers (assemblers) at the time when demand growth transitions from growth, peaks, and begins to decline. Although the end market characteristics appear to be important to the evolution of exchange relationships for low price manufacturers, for high price manufacturers, the end market did not demonstrate any statistically significant effect.

In connection with the effect of economies of scale, the only significant relationship was found for high price manufacturers during the declining stages of demand. In that scenario, manufacturers reduce the exclusivity of their clientele considerably—in other words, they must diversify who they deal with. This could be due to either the death of tried-and-true customers (assemblers who have gone out of business), or the possibility that by the end of the simulation very few customers were not satisfied by the low product. In the latter case, most high end manufacturers would go out of business, with those left having enough capacity that they can produce at a low enough cost to serve remaining customers who were less price sensitive.

Assemblers (upstream). The baseline scenario of homogeneous low price end market with slow rate of technological advance and slow growth of economies of scale had a significant effect over time on the degree of collaboration assemblers had with their suppliers (manufacturers). During rapid demand growth, both high and low price assemblers increased the number of manufacturers with whom they exchanged (see Table 4.9). When demand peaked, high price assemblers continued to increase their supplier base, but low price assemblers did not. Once demand started to decline, low price assemblers significantly increased the number of suppliers while high price assemblers did not.

TABLE 4.9
Assembler Upstream Selection Parameter Estimates by Strategy

		Low Price Strategy		*High Price Strategy*	
Parameter		*Estimate*	*Pr > ChiSq*	*Estimate*	*Pr > ChiSq*
TimeStep	1	1.73	<.0001	-1.13	0.0093
	2	-1.50	<.0001	-1.13	0.0093
	3	0.06	0.7513	-1.13	0.0093
	4	-0.40	0.0453	-0.24	0.4893
TimeStep*EMhet	1	2.03	<.0001	0.33	0.4136
	2	0.61	0.0032	-0.04	0.9283
	3	-1.29	<.0001	-0.04	0.9283
	4	-0.97	<.0001	-0.30	0.2947
TimeStep*EMhom	1	.	.	-0.09	0.8273
	2	.	.	-0.45	0.2896
	3	.	.	-0.45	0.2896
	4	.	.	-0.12	0.7428
TimeStep*RTA*EMhet	1	-0.82	0.0006	0.25	0.5312
	2	1.27	<.0001	-0.11	0.7897
	3	-0.19	0.3033	-0.11	0.7897
	4	-0.33	0.1123	0.17	0.6171

With regard to the effect of the end market demand environment, a heterogeneous market related to an initial increase in the collaboration index during the periods of rapid demand growth followed by decreases during the time steps of demand decline. This likely results from the initially limited number of low price manufacturers; once the preponderance of the market purchases the low price product, assemblers have more manufacturers to choose from. Also, declining demand leads to more deaths among manufacturers, necessitating that assemblers broaden their supplier base to find enough manufacturing capacity to meet their customers' demands. A homogeneous high price market had no statistically significant effect on high price assemblers' relationships with their manufacturers.

Rate of technological advance in a heterogeneous market pushed low price assemblers to decrease collaboration from time step 1 to time step 2 (early demand growth), then increase collaboration (decreasing the number of suppliers) from time step 2 to time step 3 (during the period of rapid demand growth). This latter finding probably results from the limited availability of low price manufacturers able to keep up with the rapid pace of technological turnover until the market matures.

Assemblers (downstream). Assemblers' exchanges downstream with their buyers (retailers) exhibited significant changes over time, but with little statistical evidence that the independent variables in this study had any effect (see Table 4.10). Only economies of scale provided any statistical evidence of an effect on the collaboration index, with a relatively large decrease (i.e., the assemblers were doing business with more retailers) when demand begins to decline.

TABLE 4.10
Assembler Downstream Selection Parameter Estimates by Strategy

		Low Price Strategy		*High Price Strategy*	
Parameter		*Estimate*	*Pr > ChiSq*	*Estimate*	*Pr > ChiSq*
TimeStep	1	-1.16	0.0073	-1.01	0.0195
	2	-1.16	0.0073	-1.01	0.0195
	3	-1.16	0.0073	-1.01	0.0195
	4	0.87	0.0035	-0.05	0.8868
TimeStep*EOS	1	0.33	0.436	0.27	0.4147
	2	0.33	0.436	0.33	0.3392
	3	0.33	0.436	0.20	0.564
	4	-0.95	0.0012	-0.78	0.0031
TimeStep*EMhom	1	.	.	-0.31	0.4371
	2	.	.	-0.61	0.1469
	3	.	.	-0.41	0.322
	4	.	.	0.46	0.1334

Retailers. Low price retailers in the base scenario (homogeneous low price market, slow rates of technological advance and economies of scale) at first increased collaboration, and then decreased it rapidly as demand grew rapidly (see Table 4.11). In early decline no statistically significant change to collaboration indices occurred, but during the late decline phase low price retailers decreased collaboration (i.e., increased the number of suppliers). High price retailers decreased collaboration throughout the demand growth and up until the early demand decline phases.

In a heterogeneous market, only low price retailers showed any statistically significant change to their level of collaboration, with increases in collaboration while demand grew. However, when the market was both heterogeneous and experiencing a high rate of technological advance, instead of increasing collaboration, retailers decrease collaboration (i.e., use more suppliers) during the early phase of slow demand growth, then increase collaboration (i.e., use less suppliers) during the phase of rapid growth. These findings paint the picture of limited upstream low price capacity—demand outstripped what assemblers were able to provide until demand began to flatten. This would force the retailers to maintain existing business relationships as few alternatives exist that were not already obligated.

TABLE 4.11
Retailer Selection Parameter Estimates by Strategy

		Low Price Strategy		*High Price Strategy*	
Parameter		*Estimate*	*Pr > ChiSq*	*Estimate*	*Pr > ChiSq*
TimeStep	1	1.73	<.0001	-1.13	0.0093
	2	-1.50	<.0001	-1.13	0.0093
	3	0.06	0.7513	-1.13	0.0093
	4	-0.40	0.0453	-0.24	0.4893
TimeStep*RTA	1	1.48	<.0001	0.04	0.9181
	2	-1.21	<.0001	0.04	0.9181
	3	-0.03	0.8663	0.04	0.9181
	4	0.03	0.8948	-0.12	0.7204
TimeStep*EMhet	1	2.03	<.0001	0.33	0.4136
	2	0.61	0.0032	-0.04	0.9283
	3	-1.29	<.0001	-0.04	0.9283
	4	-0.97	<.0001	-0.30	0.2947
TimeStep*EMhom	1	.	.	-0.09	0.8273
	2	.	.	-0.45	0.2896
	3	.	.	-0.45	0.2896
	4	.	.	-0.12	0.7428
TimeStep*RTA*EMhet	1	-0.82	0.0006	0.25	0.5312
	2	1.27	<.0001	-0.11	0.7897
	3	-0.19	0.3033	-0.11	0.7897
	4	-0.33	0.1123	0.17	0.6171

4. Development of Theoretical Extensions

TCA offers an empirically well studied starting point for a dynamic, network-focused model of supply chain networks. Empirically, TCA has strong support for firm and dyadic level predictions of the effects of frequency of transactions and asset specificity on the form of exchange governance. However, TCA's predictive ability is limited to the extreme cases of transactional (open market) versus vertical integration; empirical studies of hybrid forms of governance have returned ambiguous results. Also ambiguous have been TCA's empirical findings regarding the effects of uncertainty.

In addition to ambiguous empirical findings regarding TCA's predictions, some scholars have identified short-comings of TCA as a theory of exchange. Hunt and Morgan (1995) point out TCA's inability to distinguish firm-level factors—TCA makes one prediction for all firms when in reality different firms facing the same exogenous variables will often arrive at different but equally successful exchange solutions. TCA is ambivalent regarding the effect of the demand environment, with some claiming that transactional governance will be better due to the ability to switch and others claiming that relational governance will prove superior due to increased adaptability.

Other shortcomings of TCA theory that prompted this dissertation include its firm-focus and its static nature. For the purposes of this dissertation, any theoretical extension must address the network setting and dynamism of real-life supply chain networks in addition to addressing Hunt and Morgan's (1995) concerns regarding TCA's inability to distinguish firm-level factors and the effect of the demand environment on exchange governance. Current marketing scholarship also displays a paucity with regard to the importance of production factors, despite Coase's (1937) original vision of balancing the marginal contribution of owning production versus managing via exchanges. By presenting a framework uniting these factors it is hoped that a contribution may be made toward elucidating the ambiguous aspects of TCA's empirical track record.

4.1. Extensions to TCA

This dissertation study makes several important contributions to extend TCA theory to the dynamic, network domain. It also suggests an important change to TCA theory itself which may disambiguate future empirical studies based on TCA. The salient extensions made in this dissertation were the inclusion of end market and production factors in the modeling of interfirm governance decisions in a supply chain network. Coase's 1937 paper that spawned the TCA literature goes into depth regarding the tradeoffs of production and exchange costs, but these tradeoffs have been understudied in recent marketing exchange literature.

One of the more salient production factors is capacity. In general, greater capacity results in lower per unit cost of production. The enhanced efficiency that results from greater capacity serves as a buffer as well as a competitive advantage. Greater capacity enables a firm to serve more customers, and when technology changes rapidly, cheaper per unit cost of production provides a competitive edge for keeping customers when demand was down.

Heterogeneity also proved important, particularly in its interactions with the rate of technological advance. Very little heterogeneity equates to homogeneity, which suggests that the dominant consumer will determine the rate of technological advance. Too much heterogeneity leads to small fractured markets that maximize the instability in a supply chain network while simultaneously providing multiple end consumer market niches for companies to exploit. Heterogeneity proves beneficial when technology and economies of scale grow rapidly because once technology advances far enough, most consumers were satisfied with the products of a few, large manufacturers who supply the rest of the network.

The rate of market growth also appears to be an important factor since demand growth that outstrips capacity growth will lead to a shortage of capacity. In such a scenario, companies tend to have more exclusive relationships as a means of guaranteeing a source of supply, regardless of other factors. This is an important factor at the industry level for determining governance decisions.

Analysis of the TCA theory's constructs, uncertainty appears to embody too many conceptually and empirically different concepts. Although this criticism needs explored further, it appears that whether uncertainty was an antecedent or independent of asset specificity depends on the type of uncertainty (c.f., Rangan et al., 1993). Bounded rationality appears to be related to production factors and was presented as an antecedent to asset specificity in the proposed theoretical framework presented by this dissertation. Behavioral uncertainty was more immediate to the exchange process and in this dissertation's proposed framework it remains independent of asset specificity. This proposed extension to TCA theory appears in Figure 4.10.

FIGURE 4.10
Proposed Extension to TCA Theory

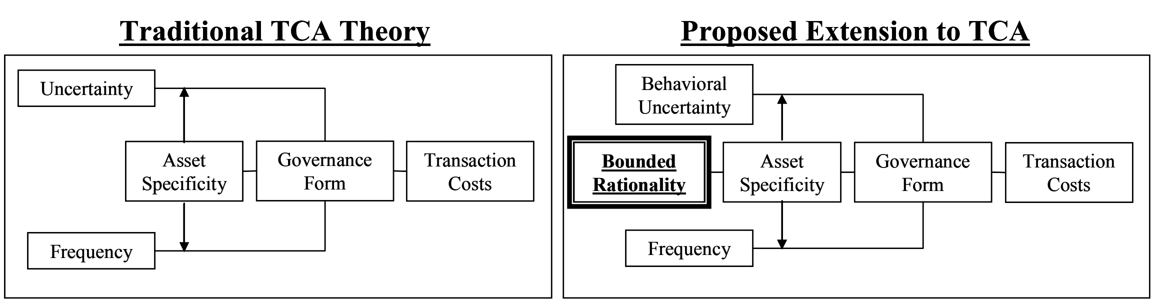
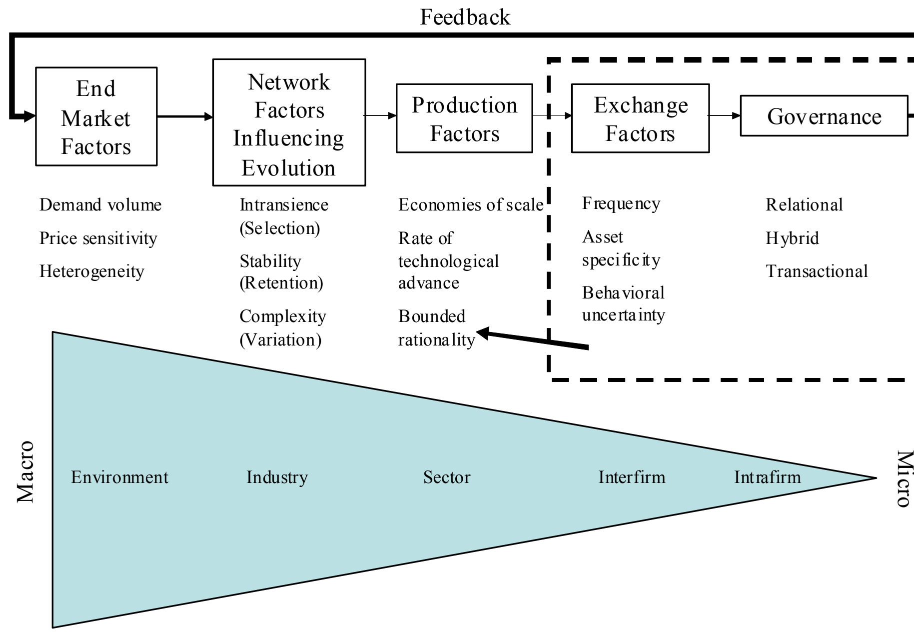


Figure 4.11 presents a proposed conceptual map of the relationships between the demand environment, network factors, production factors, exchange factors and firm performance.

Although a less parsimonious model than TCA, extending exchange governance theory to the network domain requires taking into account the salient factors affecting supply chain network evolution. In this conceptualization TCA retains an essentially firm-centered focus on the exchange governance decision-making process, but it was placed in the context of framework that ranges from the macro-environmental to the individual firm performance outcome. A feedback loop represented the influence of the individual firm success and survival on both satisfying and shaping end consumer demand. In turn, the end consumer demand provided the environment to which various aggregations of firms will adapt themselves. The presented framework pictures each successive type of factors as environmental niches. An analogy is a marine ecosystem with pan-global algae forming the end market, a geographic region forming the network factor, the strata or role comprising the production factors, the in vivo interactions between animals forming the exchange factors, and the survival of the fittest at the end based on those best adapted, healthiest, and otherwise fortunate enough to survive long enough to reproduce.

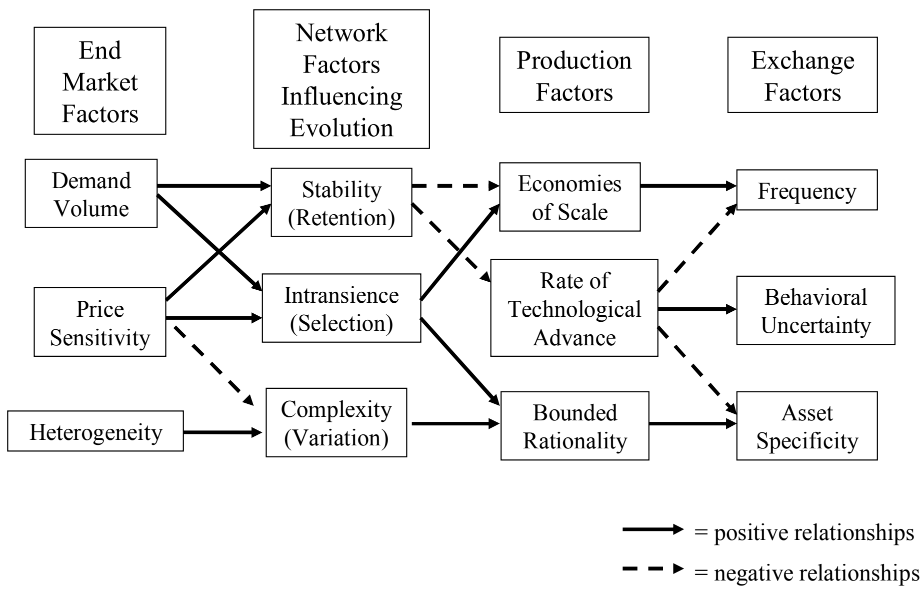
FIGURE 4.11
Drivers of SCN Interfirm Governance



Like the algae in the previous analogy, the end consumer demand environment provides the energy and determines the possible network configurations for an industry. Whether based on *willingness to pay* or *utility*, consumers were only willing to pay so much in order to acquire products for their needs or wants, and the groups of consumers form the basis for environmental niches for industries. The available industry network resources determined the production factors which vary from sector to sector of an industry. Within the sectors of an industry, firms decide their interfirm exchanges. In the end, the individual firm either enters the appropriate governance form that enables it to survive and prosper or it does not and eventually dies. The types of firms that survive in turn help shape consumer perceptions of what their options were, thus creating new or changing old environmental niches of end consumer demand. In this way a feedback loop leading to the appearance of regular patterns over time appears in keeping with the behavior of a complex adaptive system.

What follows are descriptions of each of the factors of this conceptual framework. It is important to note that there was also a feedback loop between each successive level of factors, but the conceptual model presents the order of layering of the factors from macro to micro in the belief that macro factors outweigh micro factors in terms of predictive power. Figure 4.12 provides a graphic portrayal the predicted relationships for the propositions.

FIGURE 4.12
Predicted Relationships



4.2. End Market Factors

Demand Volume. The concept that develops from assessing the insights described in the previous paragraphs was one of balancing aggregate capacity with aggregate demand. Demand pushes firm size up toward optimal production capacity. This simulation makes the simplifying assumption that over the long run surviving firms were all equally capable of identifying and attaining the optimal production capacity. In keeping with the conceptualization of a complex adaptive system, a feedback loop based upon the firm's performance feeds back into the system—the firm that performs well enough to stay in business goes through the process of fitting itself into the network in terms of its production capacity, product offering, and interrelationships with other firms.

Foremost among the evidence discerned in the experimental results was the balance between network capacity and end consumer demand. Growth in consumer demand prompts both capacity growth among existing firms and—when existing firms cannot keep up—appearance of new firms. Over the long run, the sum of the capacities for all the firms in the network will equal the total capacity required to satisfy consumer demand. In an environment of rapidly growing demand, capacity to keep up with demand becomes important, and so the network will be characterized by rapid growth in the number of firms. When capacity declines, only the most efficient firms will be selected as the overall number of firms declines. These insights lead to the following two propositions:

Proposition 1a: The growth of demand volume will positively relate to the intransience of a supply chain network.

Proposition 1b: The growth of demand volume will inversely relate to the stability of a supply chain network.

Price Sensitivity. Price sensitivity of the end consumer market determines the amount of "energy" provided by the individual consumer to feed the supply chain network ecosystem. Low price sensitivity indicates that the end market provides little motivation for the supply chain network (SCN) to develop greater efficiency whereas high price sensitivity indicates that change will continuously push the SCN toward greater improvement in efficiency, or greater efficacy at the same level of efficiency. Price sensitivity impacts the importance of change in how networks reconfigure themselves to better adapt to the end consumer environment, and thus also affects the complexity of a network. Highly price sensitive consumers will not provide the margins necessary to support a large number of companies—this paints a picture of less value added and more efficient, large firms that focus on mass production. Low price sensitivity means more firms can be supported and value added will likely be higher. Additionally, price sensitivity was an important determinant of complexity as highly price sensitive consumers will drive down the number of firms required to bring a product to market while low price sensitivity will increase the incentive to add value using more steps or value adding firms.

Proposition 2a: Price sensitivity will positively relate to the intransience in a supply chain network.

Proposition 2b: Price sensitivity will inversely relate to the stability by the supply chain network.

Proposition 2c: Price sensitivity will inversely relate to the complexity of the supply chain network.

Heterogeneity. The degree of heterogeneity provides richness to end consumer demand. More heterogeneity in terms of price sensitivity provides more environmental niches—in other words, multiple configurations of firms can co-exist since both high and low price sensitive consumers will need demand fulfilled. The result was that heterogeneity allows more complex network topologies to exist than would exist in a purely homogeneous demand environment.

Proposition 3: Degree of heterogeneity will positively relate to the complexity of the supply chain network.

Network Factors

Intransience. Intransience is described as the inability to predict exchange partners over time. This study found that changes to network capacity due to changes in the demand environment seemed to have a strong effect on the intransience of the network. A simple way to assess intransience is by looking at the evolution of the collaboration index, which tends to go down as the population of firms increases. The number of firms generally relates to the aggregate capacity of a network. Early in the evolution of the network, a multitude of firms appear each struggling for survival. However, with more firms, pricing pressure increases greatly as the consequence of increased competitive pressures, particularly when economies of scale are increasing fairly rapidly. As the trend of increasing economies of scale continues, eventually only the most efficient firms will be selected, particularly once the market enters a severe decline. The surviving firms will be larger in order to continue to meet the demand of the end market. This evolution toward efficiency increases the likelihood of survival of firms with large economies of scale.

The upshot of intransience is difficulty predicting who will be the future exchange partners for a given firm. At the individual firm level, managers do not have a way of guaranteeing that their exchange partners will continue to be the best trading partner into the future because of the problem of advancing frontiers for technological efficacy and production efficiency. This translates into a problem of bounded rationality for the managers.

The experiments revealed that an important factor in the degree of collaboration between firms is the existence of other firms. The existence of other firms was enough to reduce collaboration because when it was preferable to switch buyers or suppliers, the more viable opportunities that existed, the more likely such switching would occur. As such, it increased intransience. Increased intransience makes survival of small firms less likely; instead, firms are pushed to increase their customer base, primarily through increased capacity. Such a scenario implies that increased intransience will lead to increases in economies of scale.

Proposition 4a: The intransience of a network will positively relate to bounded rationality.

Proposition 4b: The intransience of a network will positively relate to the rate of growth in economies of scale.

Stability. Stability is defined as the continued presence of the same firms in a network. This can be measured by longevity of the individual firms. Uncertainty serves as the destabilizing force. The two destabilizing effects highlighted by this research effort were rate of technological advance and rate of change to economies of scale. Although one could argue the opposite relationship—that the rate of technological advance and economies of scale influence instability—the opposite is argued here due to the existence of competitive forces. Were firms merely responding to market forces, from the neo-classical economical or resource-based perspectives the result would be a monopoly as the firm with the best product and best resources came to dominate the end market. However, the de-stabilizing effect of competition and the continuous change in the numbers of firms and their choices of exchange partners means that firms are motivated to improve technology and economies of scale to avoid the fate of their unsuccessful peers. All other variables held constant, it appears that the effect of these factors varies inversely with longevity. These insights lead to the following insights:

Proposition 5a: Stability of a network will relate negatively to the rate of technological advance.

Proposition 5b: Stability of a network will relate negatively to growth of economies of scale.

Complexity. Complexity refers to the existence of numerous possible combinations of firms to produce a final product in a supply chain network. Less complexity means one structure predominates, with a single vertically integrated supply chain serving a market as the extreme example. More types of firms and variations in governance mechanisms between firms equate to increased complexity.

Complex adaptive systems theory indicates that complex networks are more expensive and fragile to maintain than simpler networks, but they provide greater robustness to environmental fluctuations. The results of this simulation indicate that more complex networks in heterogeneous environments tend to be more resilient in the face of a rapid rate of technological advance. However, a more complex network environment also equates to increased complexity in decision making. A homogeneous end market alleviates the problem of bounded rationality as even a homogeneous end market characterized by rapid technological advance and rapidly growing economies of scale will be relatively easy to predict compared to the predicting a heterogeneous, complex end consumer market. Increased complexity in turn makes rational decision making more difficult, and therefore is an important contributing factor to bounded rationality. Based upon the foregoing insights, the following proposition is presented:

Proposition 6: Complexity will positively relate to bounded rationality.

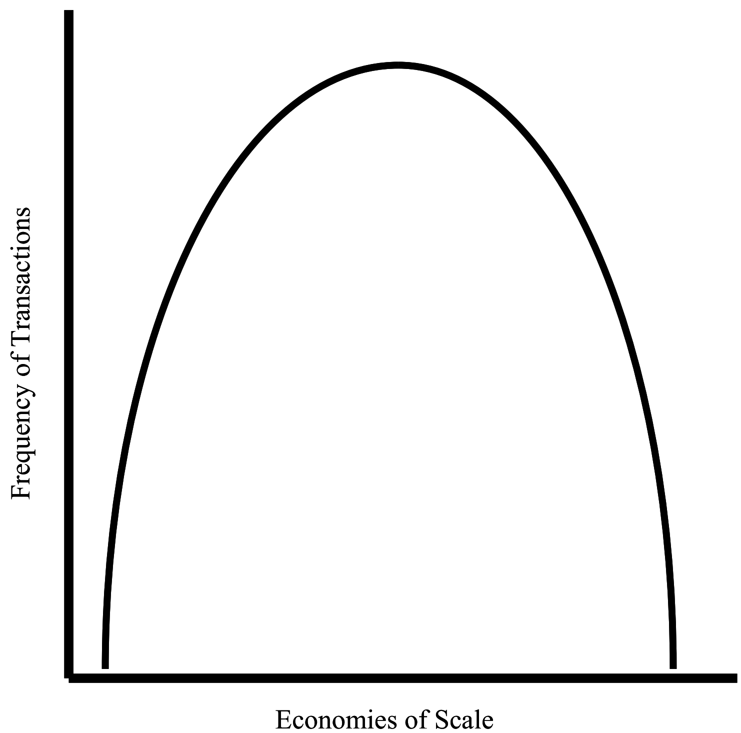
4.3. Production Factors

Economies of Scale. From the suppliers' perspective, manufacturers and assemblers in the simulation demonstrated a significant relationship between decreasing collaboration and high economies of scale. As suppliers were pushed to increase their capacity rapidly, they must find more buyers to purchase their product, keeping up their utilization rate and thus keeping production costs low. Where capacity remains constrained due to slow-growing economies of scale, or because of a limited market volume (as in the case of demand for high end product with a heterogeneous end market), more collaboration occurs because most supplier capacity was locked in by buyers. This mirrors real life market forces, but provides an interesting network perspective on the importance of balancing supply chain network capacity with end market demands. In such a case, a U-shaped or backwards J-shape curve describes the evolution of collaboration since in the beginning a few small firms trade with each other, firms proliferate and relationships become more transactional, and as time goes on the supply chain becomes more concentrated at most or all levels, resulting in repeated transactions among a few big players (see Figure 4.13). In longer lived industries, there may be cyclicity to this evolution.

Collaboration can provide another buffer to uncertainty under the right circumstances. When capacity was less than demand, collaboration between two companies ensures ("locks in") a source of supply for the downstream members of a supply chain. "Locking in" not only keeps the buyer in business, it also raises a barrier to entry for new competitors. From the supplier's perspective, there will always be an interested buyer in a rapidly growing industry; but from the buyer's perspective, somehow guaranteeing a reliable portion of the limited available supply becomes a critical competitive advantage. However, once demand begins to decline enough to result in excess capacity, buying firms can pick the lowest cost suppliers with excess capacity.

Proposition 7: Economies of scale will have a U-shaped relationship with the frequency of transactions.

FIGURE 4.13
Relationship between Economies of Scale and Frequency of Transactions



Rate of Technological Advance. From the buyers' perspective, the evidence indicates that the rate of technological advance was the most important factor relating to asset specificity. In markets of rapidly aging supplier capacity, buyers have a powerful incentive to switch suppliers more frequently in order to keep up with whoever has the least obsolete technology or as the result of increased mortality among suppliers due to the increased hurdle to attracting business. A further factor with a rapid rate of technological advance, at least as modeled in this simulation, was that upgrading technology was a decision made at the same time as upgrading the capacity of a firm. This suggests that firms keeping up with technology gain the additional advantage of improvements in per unit price due to capacity expansion (relative to the optimal capacity, of course). Furthermore, simply having more capacity leads firms to advantages in terms of resilience to fluctuations in demand as a result of their increased efficiency relative to smaller firms. These insights lead to the following propositions:

Proposition 8a: The rate of technological advance will inversely relate to the frequency of transactions.

Proposition 8b: There will be an inverse relationship between the rate of technological advance and asset specificity.

Proposition 8c: The rate of technological advance will relate positively to the degree of behavioral uncertainty.

Bounded Rationality. The previously described findings find support in Coase's (1937) work wherein he discusses at length the trade off of size and efficiency both in terms of production efficiency and management's ability to run larger firms. Indeed, he argues that the reason that firms do not grow until one firm provides all production to the market (a monopoly) was the problem of efficiency of management of the resources–mistakes are magnified as the firm grew in size. The implication of this line of reasoning was that the costs of mistakes must be compared to the costs of organizing production capacity. When it was expensive or difficult to acquire capacity, the cost of a mistake becomes much higher. All things being equal, at the aggregate firms have a way of discovering what needs to be completed to keep up with the requirements of innovation, but at the individual firm level, increased uncertainty in the form of technological advances and capacity investments increases the likelihood of making the wrong choice. This fact comprises the limit of bounded rationality.

Counteracting the limitations imposed by bounded rationality is size of the firm. Large firm size may buffer the impact of mistakes, increasing the probability of surviving a mistake. This buffering effect results not only from a larger firm's ability greater ability to weather turbulence, but also from the increased knowledge and resources they have to innovate and develop new products in response to changing demand conditions (Chandy & Tellis, 2000). In addition to the production efficiency advantage, having a large firm size in a rapidly growing industry provides additional advantages of attracting a more diverse supplier base. A more diverse supplier base buffers against mortality which may result from bounded rationality; it also provides an edge in capturing the business of the growing number of new firms appearing downstream. These advantages prove especially beneficial when demand declines since large firms will have the greatest advantage in price and will thus be able to capture more of the remaining customers more easily than smaller firms.

Bounded rationality therefore presents a complex variable. Although mistakes occur more often in larger firms, larger firms have more ability to recover from a mistake as the result of greater resistance to troubled times, more diverse supplier base, and more resources to respond to market demands. In effect, one can argue that larger firms suffer less bounded rationality than smaller firms. Smaller firms have a reduced set of options for responding to or surviving changing market conditions; therefore they have more bounded rationality. In either case, bounded rationality is the catalyst that increases asset specificity; asset specificity is simply a method employed by managerial decision-makers as a mechanism for reducing the cognitive load imposed by an uncertain production environment.

Proposition 9: There will be a positive relationship between bounded rationality and asset specificity.

5. Validation

5.1. Background

Validation was the last step of this research endeavor. The importance of validation is described as dependent on the source of the simple theory that underlies the simulation (Davis et al., 2007). When the simple theory or basic processes that underlie the simulation enjoy external validity due to a strong foundation in empirical evidence, external validation becomes less important. Purely theoretical constructs or the results of empirically unstudied analytical methods require stronger validation in order to bolster the external validity of the simulation. The extent to which the final simulation theory-building exercise requires validation depends on whether and how many of the underlying simple theories or basic processes enjoy strong empirical support. In the case of this research dissertation, the underlying simple theory (TCA) and basic processes (from the production literature) enjoy considerable empirical support. This increases confidence in the results of the validation procedure.

Validation can consist of detailed statistical analysis using pre-existing datasets or it may use a case study approach (Davis et al., 2007). When using a pre-existing dataset the simulation attempts to predict the results of the dataset whereas the case study approach demonstrates consistency with the specific details of one or a few samples. Selection of validation method usually depends on the availability of data. This validation takes the latter approach to external validation of the simulation by using extant semiconductor data. Although much data is available on the semiconductor industry, no single dataset exists that accurately describes the evolution of the industry. Furthermore, several important features of exchange governance such as extent of collaboration have no accepted quantifiable measure. This renders a case study approach as the most logical choice for validation.

A précis of the evolution of the semiconductor industry appeared in Chapter II. It forms the basis for this validation. The simulation run modeled the semiconductor industry as having a heterogeneous end market and rapid rates of technological change and increases to economies of scale. The results indicate that the simulation accurately portrays the evolution of the semiconductor supply chain network. Validation was completed in two steps. First, the ability of the simulation to re-create the patterns of evolution in the semiconductor industry is assessed. Second, the propositions developed as the result of experimentation are compared to the empirical data. A discussion of the validation results follows.

Chapter II presented five stages for the evolution of the advanced semiconductor industry. Drawing upon the literature review presented in Chapter II, these five stages are summarized as follows:

1959 to 1978:	Small market (low demand), low price sensitivity, vertically integrated firms
1979 to 1985:	Division of the microprocessor industry into two groups: 1) large mass producers of standard designs, 2) small producers of proprietary (high end) designs. At this point, the number of firms had started to proliferate but the market was just starting to take off.
1985 to 2001:	Explosive growth in demand spurs a sudden shift to large scale manufacturing. The trend starts in computer memory but soon spreads to other types of semiconductors. Much of this growth is made up of the increasingly price sensitive end consumer market. At first, large Japanese firms come to dominate the market, and much production in the industry becomes concentrated in a few manufacturers. Soon small American firms re-assert their positions as providers of custom or high end designs.
2001 to 2006:	Large decline in semiconductor demand, leading to an industry-wide shakeup. Many firms go out of business or are acquired by other firms. A common trend is “value chain modularity” wherein firms

	attempt to shift back to more relational networks, but the lack of capital and the astronomical costs of foundry capacity suggest that contract manufacturing prevails. Contract manufacturing also has the benefit of reducing reliance on one company, a decision that leaves companies very vulnerable in this fast-paced industry.
Current end state	Even traditionally innovative firms like Intel are increasingly going the route of large contract manufacturing. Langlois' (2002) "modular" networks of firms increasingly dominated the industry. These networks are characterized by a more hybrid approach between relational and purely transactional exchanges with firms doing repeated exchanges with a core of buyers and suppliers who remain the same.

5.2. Validation

Proceeding chronologically and starting with the number of manufacturers, we see that the simulation began with a few high end manufacturers and no low end manufacturers (see Figure 4.14). This early stage continued for about a fifth of the simulation with an increase of only one high end and one low end manufacturer. Demand at this point was not very great, and relationships between the manufacturers and the assemblers were exclusive (see Figures 4.15 and 4.16). At this stage, the simulation closely matched the early history of the semiconductor industry.

FIGURE 4.14
Average Number of Manufacturers Over Time (*n*=30)

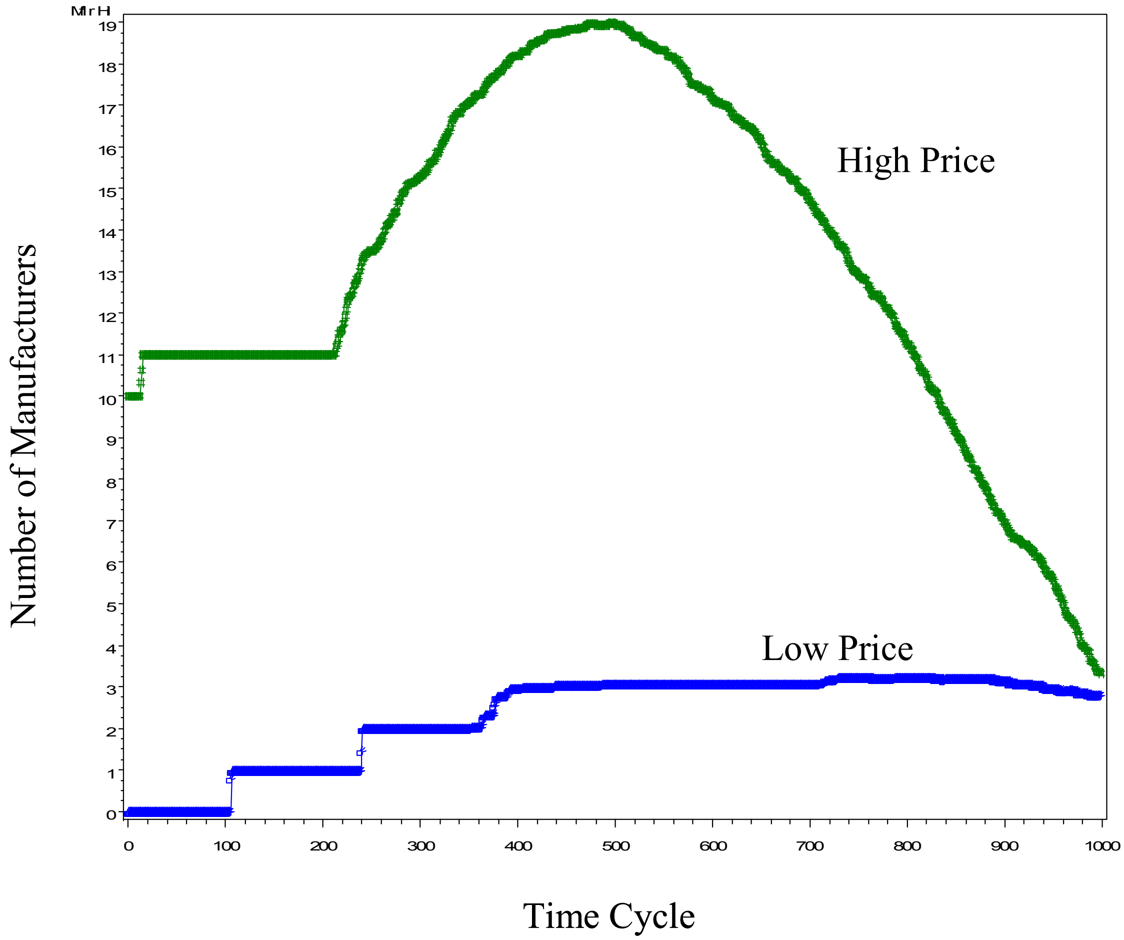


TABLE 4.15
Average Manufacturer Collaboration Index Over Time (n=30)

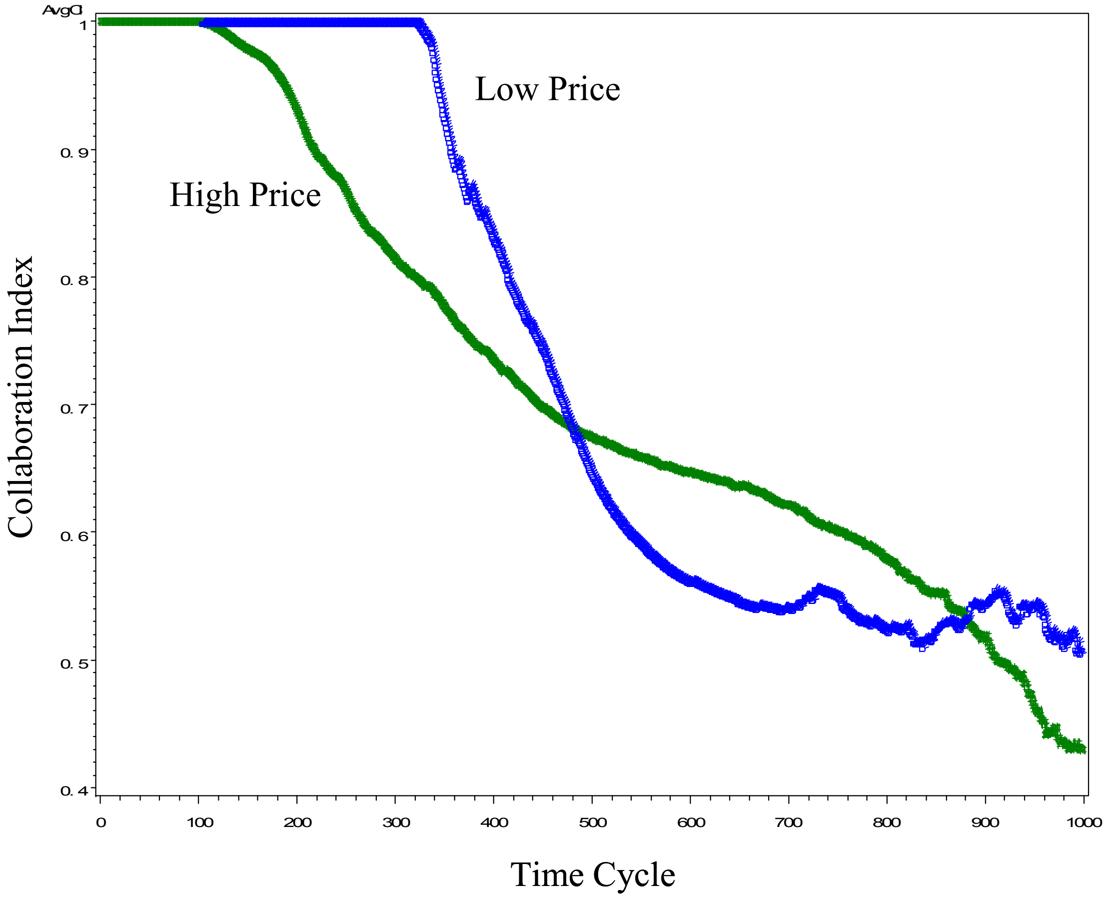
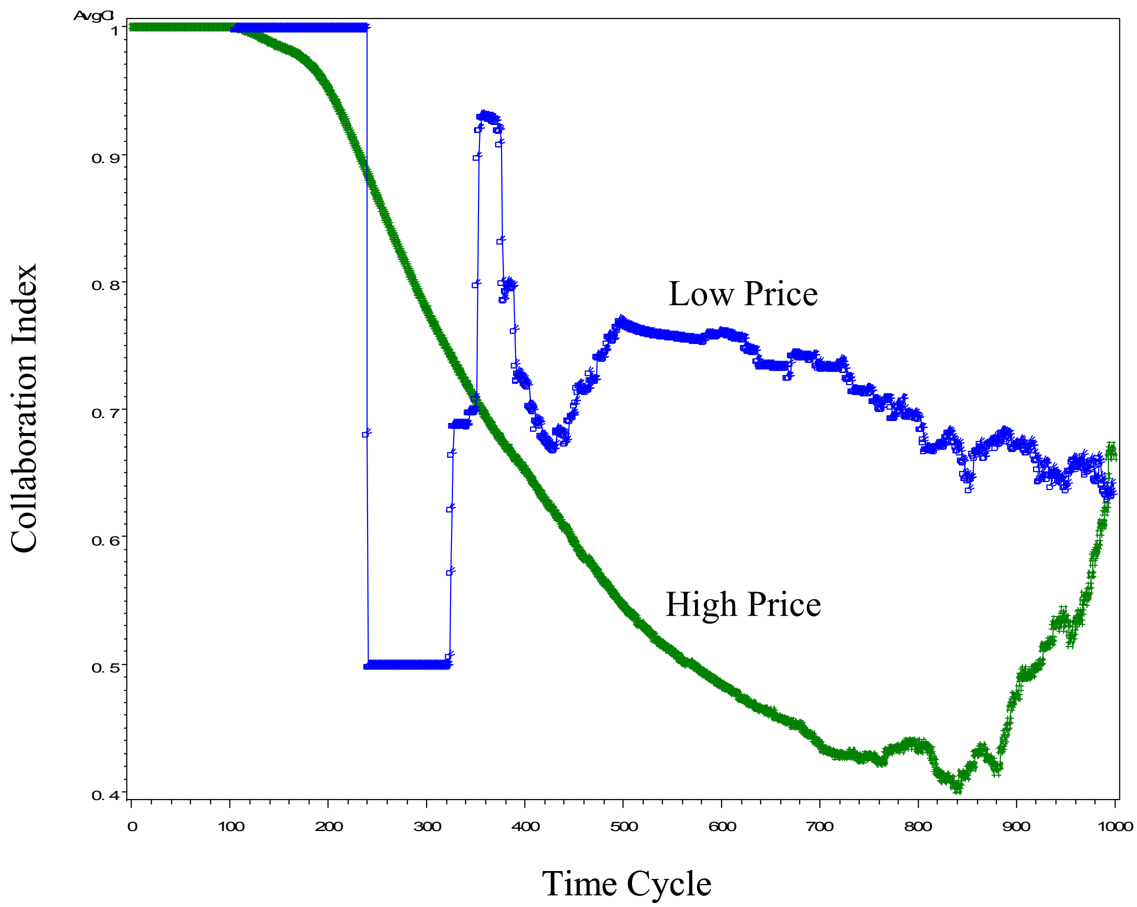


TABLE 4.16
Average Assembler (Upstream) Collaboration Index Over Time (n=30)

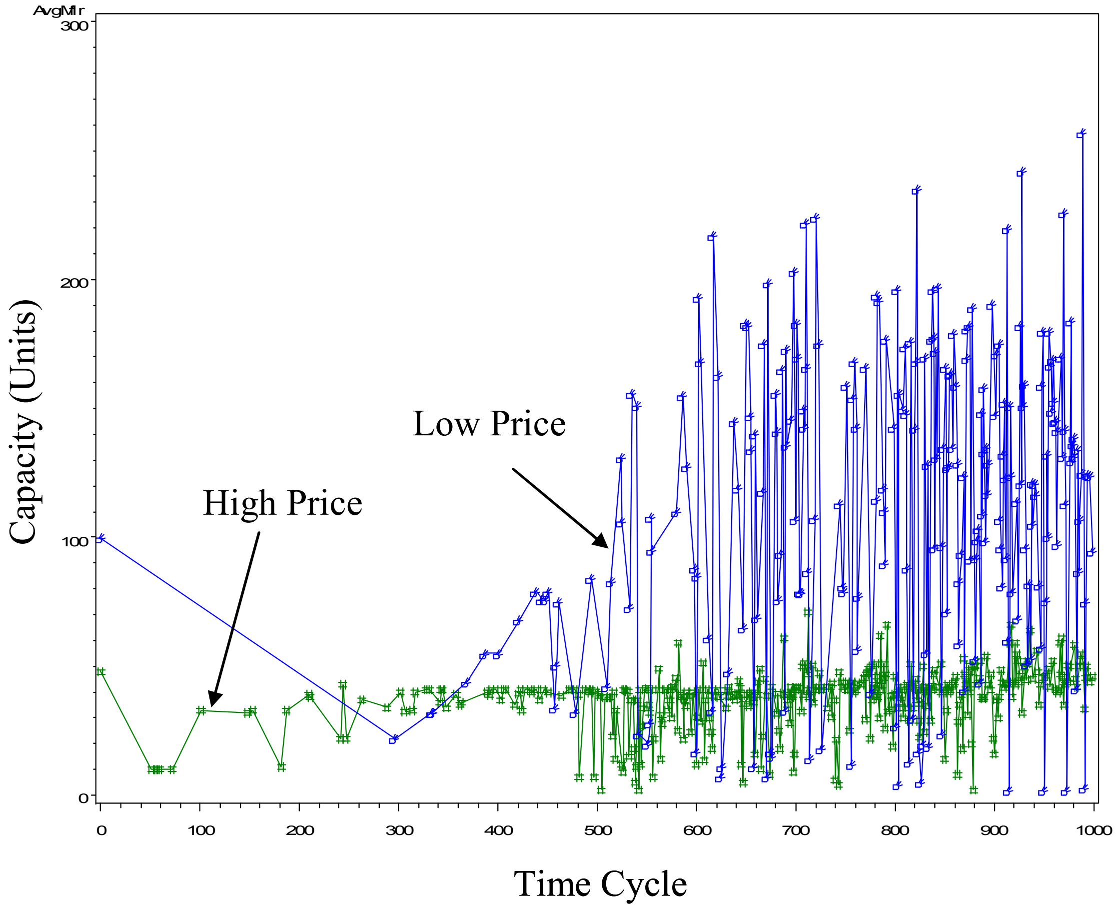


Interestingly, for manufacturers, assemblers, and retailers, the firms then split into two groups prior to the explosive growth in demand. This mirrored the empirical history of the semiconductor industry where early small growth in demand spawned the appearance of low price firms. We see in Figure 4.17 that the average maximum capacity for the new low price firm started out somewhat higher or the same as for the high price, low volume producers—a situation that did not last long.

Once demand volume started to explode, the number of manufacturing firms climbed steeply for the high end manufacturers, but very slowly for low end manufacturers. However, what the low end manufacturers lacked in firm numbers they make up for in cumulative volume of production. Two-thirds of the way through the simulation the total volume of low end production equaled that of high end production, but all of this demand was met by only three low end manufacturers instead of the 15 firms required to meet high end demand. This reflects the trends described in the literature review for 1985-2001 when mass production concentrated in a few firms but small American firms fought and eventually won the struggle to re-assert themselves.

The effect of the dramatic growth in demand on collaboration between firms presents an interesting result (Figure 4.17). When low end manufacturers and assemblers first appeared, they actually formed more exclusive relationships than the high end firms. This situation did not last long—only about 350 time steps—and for the rest of the simulation both high and low end manufacturers increased the numbers of buyers. Assemblers exhibited a sharper split in how they manage their exchange relationships; the low end assemblers actually had higher collaboration indices than the high end assemblers. This resulted from the fact that a few low end assemblers had to deal with the same small number of manufacturers (an average of three), and preferred to purchase all product from one source. This reflects the modular firms that Langlois (2002) described. Interestingly, it appears that with enough high end assemblers in existence that exclusivity of exchanges became a thing of the past. However, the high end firms did not exercise a purely transactional exchange approach; the collaboration index stayed between 0.4 and 0.7, indicating that they did business with 1.4 to 2.5 firms on average every time step. Both high and low end firms tended toward repeated exchanges among a small group of buyers or suppliers, thus gaining some benefit in reducing transaction costs.

FIGURE 4.17
Average Manufacturer Capacity Over Time (n=30)



During the demand decline stage, the number of high end manufacturers declined rapidly until reaching the number of low end producers. Assemblers and retailers showed commensurate population declines. This reflected the "dot com" crash. In the simulation, many firms went out of business and collaboration declined rapidly for high end firms as they tried to find new sources of supply or buy. Such turning points have been observed in other industries such as automotive manufacturing (i.e., Utterback & Abernathy, 1975). Collaboration declined somewhat for low end firms, but stayed relatively high as the already concentrated low end sector became even more concentrated following the market crash.

Overall, it appears that the simulation was highly successful in recreating the evolution of the semiconductor industry using only three factors (rate of technological advance, economies of scale, end market characteristics), TCA theory, and basic processes from production. Although successful, these results are merely the first step toward a more comprehensive understanding of interfirm exchange governance in a dynamic supply chain network.

5.3. Support for Propositions

As the last step in the validation process, the theoretical extensions are compared to the empirical sample. What follows is an assessment of how each of the propositions developed as a result of the experimentation in this study compares to the empirical data. Table 4.12 and Figure 4.18 summarize the results of this validation exercise. These results are merely preliminary and merely provide an initial estimate of the value of continuing more in-depth empirical investigation based upon the proposed theoretical extensions. For this work to advance to more intense research requires a demonstration of at least enough external validity to pass this exploratory assessment.

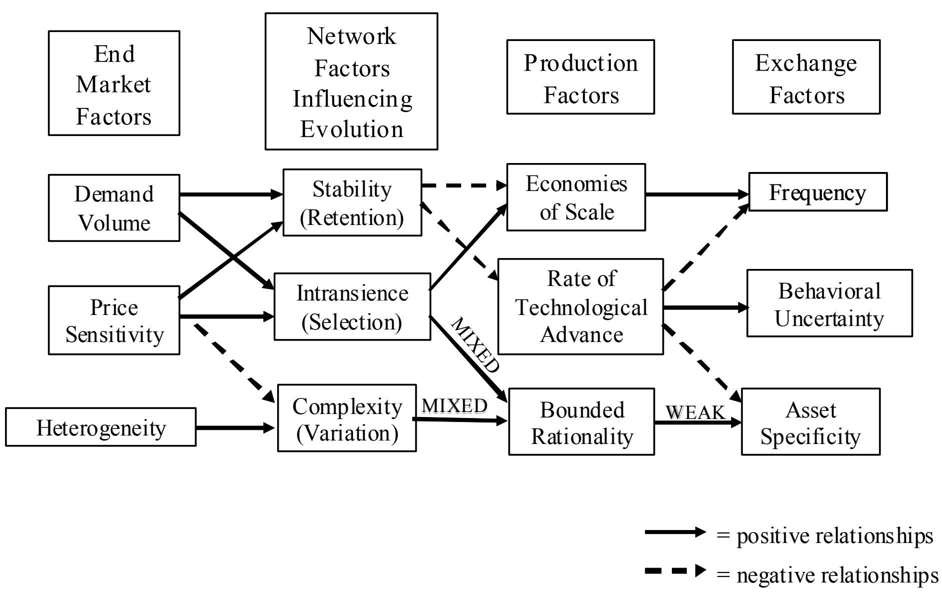
TABLE 4.12
Empirical Support for Propositions

Propositions	Empirical Support
END MARKET FACTORS	
Proposition 1a: The growth of demand volume will positively relate to the intransience of a supply chain network.	Strong
Proposition 1b: The growth of demand volume will inversely relate to the stability of a supply chain network.	Strong
Proposition 2a: Price sensitivity will positively relate to the intransience in a supply chain network.	Strong

Proposition 2b: Price sensitivity will inversely relate to the stability by the supply chain network.	Strong
Proposition 2c: Price sensitivity will inversely relate to the complexity of the supply chain network.	Strong
Proposition 3: Degree of heterogeneity will positively relate to the complexity of the supply chain network.	Strong
NETWORK FACTORS	
Proposition 4a: The intransience of a network will positively relate to bounded rationality.	Mixed
Proposition 4b: The intransience of a network will positively relate to the rate of growth in economies of scale.	Strong
Proposition 5a: Stability of a network will relate negatively to the rate of technological advance.	Strong
Proposition 5b: Stability of a network will relate negatively to growth of economies of scale.	Strong
Proposition 6: Complexity will positively relate to bounded rationality.	Mixed
PRODUCTION FACTORS	
Proposition 7: Economies of scale will have a U-shaped relationship with the frequency of transactions.	Strong
Proposition 8a: The rate of technological advance will inversely relate to the frequency of transactions between two given firms.	Strong
Proposition 8b: There will be an inverse relationship between the rate of technological advance and asset specificity.	Strong
Proposition 8c: The rate of technological advance will relate positively to the degree of behavioral uncertainty.	Strong
Proposition 9: There will be a positive relationship between bounded rationality and asset specificity.	Weak

End Market Factors. The propositions regarding the effects of growth of demand volume appear to be strongly supported in the context of the semiconductor industry. The semiconductor industry exhibited a rapid growth in demand followed by the beginnings of a decline. As the network grew in response to demand growth, vertically integrated firms began to do business with multiple exchange partners. Furthermore, exchange partners could switch without warning, changing more frequently in response to increasingly demanding consumers. This supports Proposition 1a which states that the growth of demand volume will positively relate to the intransience of a supply chain network. As demand grew (or shrunk), network stability changed apace, with competitiveness described as endemic in the semiconductor industry, supporting Proposition 1b which stated that the growth of demand volume will inversely relate to the stability of a supply chain network.

FIGURE 4.18
Empirical Support for Propositions



Network factors. Propositions 4a and 4b dealt with intransience. The semiconductor industry was characterized by high levels of intransience during most of its evolution. So much intransience took a toll on managerial ability to predict which technology would dominate and which company would attain or maintain market supremacy. In this regard, the semiconductor industry can be said to pose greater limits to bounded rationality, thus supporting Proposition 4a which states that the intransience of a network will positively relate to bounded rationality. However, certain firms seem to be very successful at assessing their local environments, prompting the question of whether other factors play a role. Perhaps bounded rationality as a problem can be alleviated by dominance of certain consumer market niches. Overall, although the evidence generally tends to support Proposition 4a, there is enough counter-evidence to adjudge the evidence for this proposition as mixed.

The evidence provides strong support for Proposition 4b which states that the intransience of a network will positively relate to the rate of growth in economies of scale. The intransience that pervades the semiconductor industry seems to have created an environment where high capacity ensures the survival of at least the manufacturers. Larger firms enjoy the advantage of greater production efficiency when facing a price sensitive end consumer market; large firms also have greater ability to weather the ravages of poor decision-making, and thus have a greater likelihood of surviving a mismatch between product and demand until the next product is introduced. The push toward ever greater economies of scale is one of the defining characteristics of the industry.

Propositions 5a and 5b describe the effect of network stability on the rate of advance for technology and economies of scale at the production level. Network stability—or rather, lack of stability—in the semiconductor industry has pushed firms toward ever greater technological improvements at ever lower prices. To accomplish these opposing goals that assured their survival, semiconductor firms have had to rapidly advance technology and then reduce the cost of production by massively leveraging economies of scale. Thus the evidence from the semiconductor industry is deemed to provide strong support for Propositions 5a and 5b.

Proposition 6 related complexity to bounded rationality. It seems almost trivial to cite a connection between increased network complexity and increased bounds to rationality; however, future research needs to explore the exact nature of this relationship in order for scholars to arrive at an accurate model of how network complexity and bounded rationality relate to each other. Some firms in the semiconductor industry have done quite well navigating the increasingly complex interrelationships and structure that characterize the industry. As such, this proposition is deemed to receive mixed empirical support from the semiconductor industry.

Production factors. Proposition 7 described the relationship between economies of scale and frequency of transactions. The semiconductor industry has demonstrated the predicted U-shaped curve described in Chapter IV. The early semiconductor industry was mostly vertically integrated or characterized by exchange relationships that were long-term, in part due to the small number of firms in the nascent industry. As the number of firms multiplied, the frequency of transactions between any two firms diminished owing to the large number of competitors for the same business. However, “modularity” began to appear and has limited true open market transactions to a scenario more like an oligopoly wherein a small number of firms specializing in a certain market niche have frequent exchanges amongst themselves. Later, the “dot com” crash resulted in a significant increase to industry concentration, driving firms to increasingly do business with the surviving firms that were generally larger and more efficient. Thus the semiconductor industry provides strong empirical support for Proposition 7.

Propositions 8a, 8b, and 8c relate the rate of technological advance to frequency, asset specificity, and behavioral uncertainty. The semiconductor industry has been characterized by a fast rate of technological advance. This has resulted in strong incentives for the appearance of contract manufacturing and “fabless” firms in order for firms to retain the ability to switch suppliers and buyers. Additionally, the informal “20% rule” (Langlois, 2002; Langlois & Steinmueller, 2000) wherein large firms traditionally do not lock in more than 20% of their capacity—either has a buyer or a supplier—pushes down the frequency of transactions with a particular exchange partner and leads to increased use of standards instead of asset specificity as a means of reducing transaction costs. On the other hand, the need for a “20% rule” and standards are indicative that the rate of technological advance has elevated the importance of behavioral uncertainty to the point that institutionalized practices are required to manage it. Overall, Propositions 8a, 8b, and 8c enjoy strong empirical support from the semiconductor industry.

Proposition 9 describes a positive relationship between bounded rationality and asset specificity. The semiconductor industry seems to have overcome the problem of bounded rationality with standards rather than resorting to asset specificity. The industry is characterized by standardized interfaces between firms, with most exceptions occurring in vertically integrated functions. Therefore Proposition 9 receives weak empirical support from the semiconductor industry; whether this is unique to the semiconductor industry depends upon the outcome of other research endeavors.

6. Conclusion

The analysis revealed important insights into the dynamics of supply chain networks. Specifically, the evolutionary mechanisms of variation, selection and retention were used to assess how supply chain networks change over time in relation to the experimental conditions (rate of technological change, economies of scale, end market characteristics), TCA processes, and basic production processes. New insights were gained and formed into nine propositions for further research.

The validation process confirmed that the simulation framework developed in this dissertation effort successfully reproduced the evolution of the semiconductor industry. Furthermore, the majority of the propositions developed as theoretical extensions to TCA enjoy strong empirical support from the semiconductor industry, although one received weak support and there was mixed support for two others.

CHAPTER V

DISCUSSION AND IMPLICATIONS

1. Research Summary

The purpose of this research was to examine the factors that may help answer the research question: How does a dynamic network environment influence selection of transactional and relational exchange governance in a semiconductor supply chain network?

This research endeavored to answer this question with two purposes. First, a simulation model was developed to provide theoretical insights used for extending TCA's insights to the dynamic, network context. Second, using the experimental results, it created a theoretical framework and model that reproduced the evolution of the semiconductor industry. The semiconductor industry served as a "fruit fly" example for the study of rapid evolution in a highly dynamic industry (Fine, 1998); according to Fine, "fruit fly" industries serve as useful examples that can provide insights for both similar industries and slower industries.

The result has been the extension of TCA to include firm, production, and network factors to the theoretical framework that successfully reproduced the evolution of the semiconductor industry. Since the framework extends transaction cost theory to a complex adaptive systems perspective of network dynamics, the Complex Adaptive Framework for Exchange (CAFE) seems an appropriate name for this contribution. CAFE provides a foundation for a future research program while remaining amenable to modification based upon future research findings.

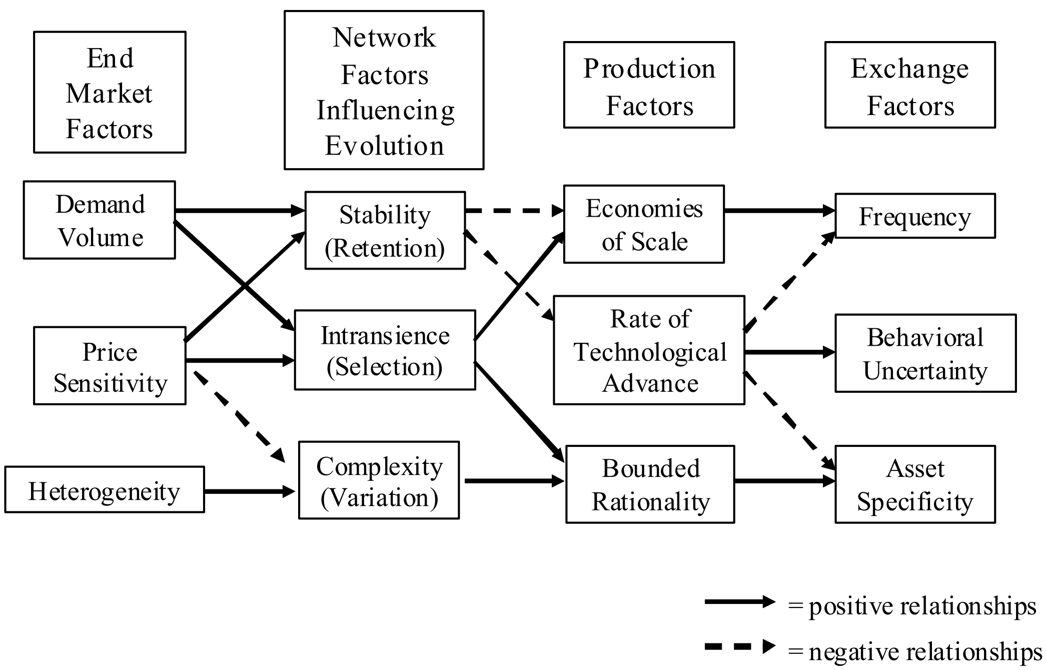
The experimental results revealed a few surprises. The evolution of exchange governance depends not only on exogenous factors, but also such network factors as the number of firms available to trade with. Large firms producing commodity type items will still develop more exclusive relationships due to the increased concentration of industries characterized by a small number of large firms interacting. Additionally, it appears that past scholarly suggestion that in TCA uncertainty and asset specificity may be a sequential rather than independent constructs (Rangan et al., 1993) received partial support from this research effort; results imply that it is important to distinguish the type of uncertainty before making such a determination. Relatedly, the TCA construct *bounded rationality* requires further elaboration; it is a complex and multifaceted construct whose content and relation to other constructs are not clearly defined. Another interesting insight was the importance of capacity as a buffer against firm mortality.

All of these findings implicate the central role of the managerial decision-maker in the evolution of supply chain networks. Manager decisions regarding which suppliers and buyers to use and how to govern the exchanges form the core issue of supply chain network evolution. The findings regarding bounded rationality and the strategic location in the CAFE model of bounded rationality, intransience, and complexity indicate that while not all dynamic network exchange factors are under managerial influence, decision-makers comprise the filter through which key information is filtered and acted upon. Phenomena such as the “bullwhip effect” (Lee et al., 1997b) have only begun to scratch the surface of the insights to be gained through a dynamic, network-based view of interfirm exchange relationships.

2. Contribution

The primary contribution of this research effort has been the development of the CAFE extension to TCA (replicated in Figure 5.1). This contribution provides a means of conceptually relating dynamic network factors to production and firm-level factors. The CAFE model is a step toward answering the call to bridge the gap between past dyadic and firm-focused deterministic theories of exchange with the scholarly future vision of exchanges embedded in interconnected communities that adapt to the rapidly changing environments that characterize modern markets (Achrol, 1997; Achrol & Kotler, 1999; Lusch & Vargo, 2006; Sanchez & Mahoney, 1996; Vargo & Lusch, 2004). As a further contribution, whereas past models tend to focus only on industries such as semiconductors and automobiles that are characterized by interconnected communities characterized by demand uncertainty, complex products, and human asset specificity (e.g., Jones *et al.*, 1997), the CAFE model demonstrated its greater flexibility by additionally replicating commodity and heterogeneous markets.

FIGURE 5.1
Complex Adaptive Framework for Exchange (CAFE)



The primary insight gained from the CAFE model is the placing of managerial decision-making in the larger context of production, network, and end market forces. Managerial decision-makers both shape and are shaped by the network which they inhabit, as predicted by the complex adaptive systems perspective of supply chain networks (Choi et al., 2001; Surana et al., 2005). The case of Wal-Mart provides an important illustration of the balancing act of control versus emergence in managerial influence in a supply chain network. Wal-Mart has the power to exert tremendous influence on its suppliers; however, Wal-Mart's ability to shape its supply chain network is limited on the supplier-side by the availability of suppliers and their pre-existing network relationships. This fact is illustrated by Wal-Mart's difficulties in several foreign markets where the supplier-base has refused to respond the way American suppliers have responded for both cultural and regulatory reasons (Fernie & Arnold, 2002). Wal-Mart's limitations to determine the supply chain network is also limited on the buyer-side—consumers are both influenced by and determine the threshold of acceptability for the products and prices that Wal-Mart makes available. Wal-Mart's inability to mandate consumer needs is precisely why they spend a lot of effort to forecast consumer needs (Foote, 2001). Conversely, Wal-Mart's success at using point of sale information to enhance supply chain network efficiency for the end consumer has become a benchmark for retail America.

The second primary contribution of this dissertation effort is the underscoring of uncertainty, and bounded rationality in particular, as critical understudied constructs. Uncertainty in the past has been classified as "external" when applied to market or environmental turbulence (e.g., Jaworski & Kohli, 1993) or "internal" when applied to managerial decision-making within the firm or uncertainty in aspects of the exchange relationship such as product quality (e.g., Heide & John, 1990). However, in the long run, all firms deal with uncertainty. More focus needs to be made on the decision-making process for dealing with uncertainty; managerial *bounded rationality* appears as a key mediating variable for converting those factors outside of the firm's sphere of influence into competitive advantage. Business scholars, and marketing scholars in particular, must aggressively assert their roles as the investigators of the interfaces between organizations. In a network economy, marketing and supply chain theory will form a new core for creating and managing exchanges for firms facing increasingly empowered consumers (Achrol & Kotler, 1999; Fuller *et al.*, 1993; Innis & La Londe, 1994; Langley & Holcomb, 1992).

3. Implications

The next two sections describe some of the theoretical and managerial implications of the CAFE model. The managerial tension between shaping the supply chain environment and allowing it to "emerge" or shape itself forms one important underlying current of logic. Managerial decision-making is the fulcrum that shapes supply chain network evolution. Another underlying logical current is the use of TCA as a point of disembarkation for theoretical extensions.

3.1. Theoretical Implications

Based upon the description provided by Coase's (1937) seminal paper that described firms as existing in a network that is both adaptive and interdependent, this dissertation study demonstrated that using complex adaptive system as the underlying paradigm successfully recreated the evolution of a semiconductor's supply chain network. Complex adaptive systems possess the most salient qualities that both Coase (1937) and Williamson (1991) ascribed to market exchanges: movement from one equilibrium point to another, continuously dynamic, firm dependence on an outside network of other firms and prices, and made up of autonomous but not entirely independent actors.

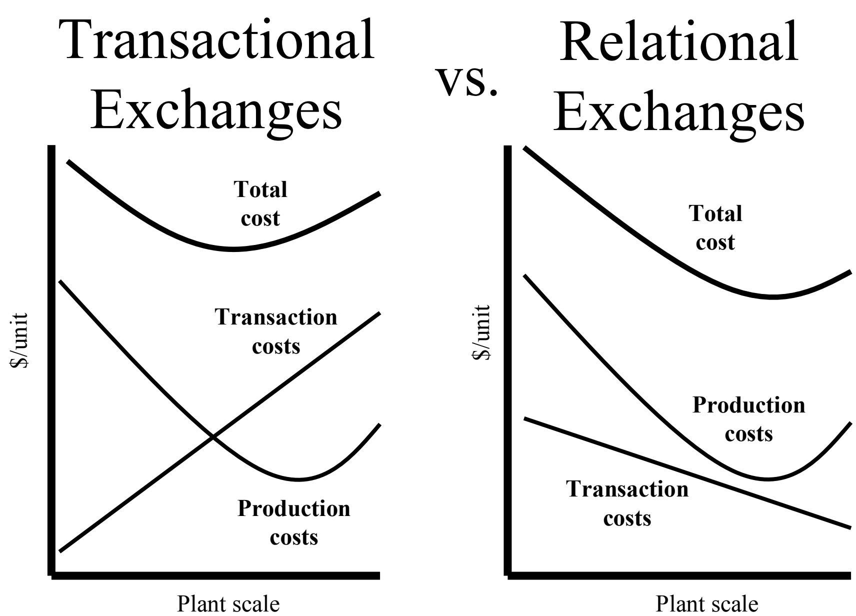
If, indeed, market exchanges constitute the interactive process of a complex adaptive system, this insight leads to several important theoretical implications. Firstly, the search for a "deterministic" model of interfirm governance via marketing's traditional confirmatory methods is at odds with a dynamic system that moves from equilibrium point to equilibrium point. This may partially explain the failure of marketing to arrive at a general theory of exchange (Shelby D. Hunt, 1992). Exchange is a process—rather than predicting or explaining whether an exchange is transactional or relational based upon *a priori* deliberation as many studies have, a more positivist and exploratory approach based upon observation and analysis may be needed to more thoroughly document and understand exchange as an evolutionary and interactive course of development for the relationships between firms. At a minimum, the positivist and exploratory approach proves insightful for the theory building process; but like the resource-advantage theory that also addresses exchange as a processual phenomenon (Shelby D. Hunt, 2000), use of complexity to explain the evolution of supply chain network exchange trades predictive precision for explanatory power. However, as Hunt (2000) states, such theory can be positive but with "normative implications". Managers can still gather strategic insights perhaps improve the outcomes of their decisions by even a small amount, especially in scenarios of high volatility (Choi et al., 2001; Surana et al., 2005).

As the underlying "simple theory," TCA functioned very well across all experimental settings. However, past criticism that TCA does not address how the same exogenous variables give rise to a variety of firms and exchange adaptations is well-founded (Shelby D. Hunt &

Morgan, 1995). Coase (1937) originally described a trade off between production and exchange to meet the firm's needs—specifically, firms will use the open market when "...the cost of an extra transaction in each firm is the same" (Coase, 1937). This implies the situation where the transaction costs for integrating or collaborating within or between firms is the same for all firms in a market that there is no competitive advantage to closely monitoring such transactions. At that point, management will reduce their cognitive loading and use open market transactions—freeing up resources for other areas that do provide a return on time and effort invested. The question then becomes how to determine when firms have reached that point.

One important insight concerns the nature of the cost trade offs inherent between transaction costs and production costs. TCA makes the implicit assumption that as a firm's capacity grows, it deals with more open market transactions, and transaction costs increase per unit as the result of having more trading partners whose needs must be tracked, more information to be gathered and compared before making exchange decisions and generally the increased costs of greater managerial scope (see Figure 5.2).

FIGURE 5.2
Total Cost Curves for Transactional and Relational Exchanges



On the other hand, relational exchange theory assumes that only one or a few trading partners are maintained, and the per unit transaction cost should decrease as the result of greater efficiencies (see Figure 5.2). In a supply chain network such as that of the semiconductor industry where “modularity” exists, the transaction cost curve is somewhere in the middle of the transactional and relational scenarios. Knowing the exact slope and shape of the transaction cost curve line is of great importance to understanding the exchange behavior, as well as for managers knowing which governance form will lead to the lowest total cost. This is an area that urgently needs additional research to explore, although the intractability of measuring transaction costs has been a major hurdle to research conducted thus far.

Determining the point that an extra transaction costs the same for each firm requires linking the firm characteristics to the broader network of prices. Current TCA theory as commonly embodied by Williamson's (1975, 1986) seminal vision includes firm or dyadic-specific variables of frequency, uncertainty, and asset specificity—but no means of comparing costs between firms in a larger network. Instead, the traditional vision of TCA is a firm-centered, go, no-go theory for determining what governance form a firm will select. This explains its difficulty in predicting hybrid forms of governance—the three primary constructs of uncertainty, frequency and asset specificity do not provide adequate detail regarding the exchange's circumstances to permit more fine detail in the governance decision. The outcomes of these variables are in terms of high and low, and nowhere is there a feedback loop to take into account the interactions with other firms. Additionally, the current embodiment of TCA does not explicitly address the adaptive ability of firms as continuously changing actors facing a dynamic environment.

This research also highlighted the value of simultaneously assessing production and marketing considerations. The traditional marketing approach of looking only at exchange factors does not appear sufficient for understanding how supply chain networks arrive at their dominant governance forms—production effects and the existence of a network of competitors and collaborators also influence selection of governance form. Furthermore, governance evolves in response to changes in the network and demand environments. Looking at exchange in isolation is like studying one tree rather than the whole forest. Research goals and circumstances dictate which perspective is most valid.

Two important influencers of production and supply chain network evolution were included in this dissertation study—rate of technological change and the pace of growth for economies of scale—along with the end market conditions. It appears that in the context of this study's experimentation that firms seek a balance of freedom to switch suppliers with cost savings associated with repeated transactions. An unexpected but intuitively obvious finding was that when industries became highly concentrated, the result was a small number of manufacturers and assemblers repeating transactions amongst themselves. Rather than resulting from any active strategy or design by the firms' decision-makers, the governance form resulted from supply chain network and market conditions that left no choice but for less than pure open market transactions. This provides insight into some possible mechanisms for the modular theory of the firm that so accurately describes high tech industries (Langlois, 2002).

These results reveal the danger of following neo-classical economics' assumptions of a large number of homogeneous and anonymous firms available on the open market. The degree to which this is true depends on economies of scale, size of end market, and other factors, but large markets may be served by small groups of firms in a closely knit industry, at least in certain segments of the supply chain network. Competition does not appear to be pure—it is strongly influenced by firm interdependencies both in terms of exchange (transaction costs and knowledge sharing) and production capabilities. In light of the importance of innovation and new product development to competitiveness in modern markets (Han *et al.*, 1998; Sood & Tellis, 2005), it is surprising that more work has not been completed to integrate production with exchange considerations.

Looking at the insights garnered with regard to TCA's theoretical content, this research revealed that uncertainty appears to embody too many conceptually and empirically different concepts. This study found that bounded rationality seemed related to production factors and functioned as an antecedent of asset specificity. Behavioral uncertainty occurred as a part of the exchange process and remained independent of asset specificity. Although this finding requires further exploration, it seems clear that uncertainty requires clearer precision and definition, some aspects of which likely should constitute constructs of their own.

With regard to the framework presented following the experimental results, it provides an early and very exploratory attempt at tying together the micro and macro factors surrounding the evolution of interfirm governance in a supply chain network. As an attempt at extending the dominant governance theory, it returned intriguing results regarding the value of the concept of complexity to assess a continuously evolving system. Williamson called adaptation the "central problem of economic organization" (1991), and additionally linked firm adaptation to an environment made up of other firms. Given the success of complexity theory at explaining adaptation in the biological and information sciences, and the success of this research at studying adaptation in the context of interfirm governance, the implication is that adaptation itself and not the form of governance provides key new insights into market phenomena. This fact will only be truer as markets continue to evolve faster, particularly in high-tech, high fashion and other markets characterized by innovation.

3.2. Managerial Implications

Several managerial implications can be derived as the fruits of this labor. Firstly, managers need re-assured that supply chains are not created—they evolve often as the result of forces out of the control of an individual manager or firm. But even if no exact predictions can be made, these evolutionary forces can be recognized and possible outcomes assessed in a rational manner. A model of possible or probable outcomes allows managers to recognize which strategies stand the best chance of surviving under the given circumstances, and highlights which factors are most important to succeed. Although this perspective does not provide a "checklist" to success for the intrepid decision-maker, it does provide a deeper understanding of how the firm fits into the larger network of firms. The value of a deeper understanding lies in knowing when to expend resources in order to influence events or simply allow events to emerge (Choi et al., 2001).

One of the factors highlighted as most important when deciding upon the exclusivity of relationships turned out to be capacity. When demand grows rapidly, growth of production capacity throughout the supply chain network takes time to catch up. In order for firms to successfully fulfill the end market demand, they reduce their uncertainty of supply by creating closer relationships in order to assure access to product. Closer relationships lock out rivals' access to scarce product while also reducing transaction costs. This finding took on more urgency during the decline in demand as only the firms with the largest capacity (and greatest economies of scale) survived. All things being equal, wise managers invest in capacity in order to reduce production costs.

Wise managers also should be aware of where their industry lies on the product life cycle curve. The evolution of the degree of collaboration followed the product life cycle curve. Managers can use the curve to predict when to switch from a strategy of remaining intimacy with suppliers or buyers to an open market strategy that relies on having built up large amounts of capacity. Without sufficient capacity firms will not survive the inevitable decline of demand. While other strategies may permit a firm to guarantee business during the decline, capacity seems to present the surest buffer to volatility, both from the standpoint of minimizing the impact of a lost customer or supplier, and from the viewpoint of having a diverse portfolio.

4. Limitations and Future Research

This dissertation study demonstrates several limitations while also opening doors onto new opportunities for future research. As a theory-extending effort, limitations and future research opportunities comprise a particularly important outcome of the dissertation effort. The following sections describe the limitations and future research opportunities.

4.1. Limitations

Several issues were discovered during the building of this research effort that limit the potential findings. One is the treatment of innovation as an ability that is equal across all firms. A more realistic situation would have included heterogeneous advantages for keeping up with technology (Macher, 2006). Similarly, another simplifying assumption of this research has been that over the long run all firms are equally capable of identifying and attaining the optimal production capacity. Production technology and product innovation are inextricably linked, and future research efforts should attempt to more realistically model these important facets of production and exchange.

Another limitation embodies the interactive effects of the supply chain on creating demand. This research effort held demand relatively fixed with a characteristic product-life cycle curve. However, the supply chain network's success at satisfying demand may create more demand, and failure to produce an attractive product may drive a market to extinction before it has a chance to take off. The interplay of end market environment with supply chain network ability to adapt and innovate is an area that requires more research. Specifically, diffusion models such as the Bass model are well-established, robust, and easily fit into the scope of the CAFE model for future research (Bass *et al.*, 1994; Mahajan *et al.*, 1990).

This dissertation study simplified the product life cycle curve. The traditional product life cycle curve can be expanded upon. Most industries do not decline into extinction, but rather a new innovation will jumpstart the industry again (Chandy & Tellis, 1998). Will this cycle of continuous innovation create a repeating cycle of evolution for interfirm governance as seen in this study? Or do future exchanges retain the memory (or at least the influence) of even distantly past interchanges?

This study had very specific starting conditions. Complex adaptive systems are very sensitive to starting conditions. A simplifying assumption of this study was to make all experiments start with a small number of firms characterized by exclusive relationships. Other starting conditions may be more realistic for certain industries, or beginning conditions of certain markets may be unknown or involve so much history that their recreation makes simulation unwieldy. In any case, future studies should assess sensitivity of the model to starting conditions.

Lastly, another simplifying assumption of this study is the stylized, open market relationship between end consumers and retailers. With the advent of "mass customization" and proponents of greater customer closeness (such as customer relationship management), increasingly supply chain networks are realizing the importance of retail relationships with the end consumer (e.g., Fornell, 1992; e.g., Langley & Holcomb, 1992).

4.2. Future Research

Two avenues to future research are presented hereafter. The first avenue is based upon further elaboration of the propositions presented by the CAFE model. The second avenue places the experimental results of this dissertation study in the broader context of future business scholarly research.

CAFE Propositions. Table 5.1 presents the CAFE model's propositions along with their corresponding areas of future research. Citations are provided to provide starting points for follow on research. The breadth of literature seems astounding at first, but with only three categories of factors (end market, network, and production factors), relatively few processes explain a wide variety of supply chain network exchange activity. The suggested future research for each proposition is briefly elucidated in the following paragraphs.

TABLE 5.1

Future Research Based Upon CAFE Propositions

Propositions	Future Research	Article
END MARKET FACTORS		
Proposition 1a *The growth of demand volume will positively relate to the intransience of a supply chain network.*	End market dynamism in the technology sector has been shown to reduce the closeness of interfirm relationships at the dyadic level. Future field research needs to assess which aspects of end market dynamism are most prominent and their effect size.	(Heide & John, 1990; Stump & Heide, 1996)
Proposition 1b *The growth of demand volume will inversely relate to the stability of a supply chain network.*	Stable pools of supply with uncertain demand have the effect of decoupling or decreasing vertical integration in order to prevent low asset utilization; increasing growth of demand should have the opposite effect. More research needs to be completed to investigate the off-setting effect of demand growth on uncertainty in highly turbulent industries such as fashion, film, and high tech. This can be done via assessment of industry data available from archival sources, as well as by considering managerial decision-making processes.	(Jones et al., 1997)
Proposition 2a	End market dynamism in the technology	(Heide & John,

Propositions	Future Research	Article
Price sensitivity will positively relate to the intransience in a supply chain network.	sector has been shown to reduce the closeness of interfirm relationships at the dyadic level. Future field research needs to assess which aspects of end market dynamism are most prominent and their effect size.	1990; Stump & Heide, 1996)
Proposition 2b *Price sensitivity will inversely relate to the stability by the supply chain network.*	Consumer willingness to pay has been implicated via simulation study as an important factor in disrupting supply chain networks. This work requires further research and connection with exchange factors both via simulation as well as case study research of this relatively new area of research.	(R. Adner & Levinthal, 2001)
Proposition 2c *Price sensitivity will inversely relate to the complexity of the supply chain network.*	Analytical work supports the existence of a relationship between complexity of the supply chain network in the form of firm innovative choices and increasing performance at a stable price. This research requires empirical validation via survey work to determine if this results from consumer satiation or exhausted technologies.	(R. Adner & Levinthal, 2001)
Proposition 3 *Degree of heterogeneity will positively relate to the complexity of the supply chain network.*	Some researchers have proposed increased variety or customization of products as a way to compete in the future. However, where in the supply chain the variety or customization should be created presents a research challenge, as well as the connection between consumer learning and the required degree of variety or customization.	(Aitken *et al.*, 2005; Kahn, 1998)
NETWORK FACTORS		
Proposition 4a *The intransience of a network will positively relate to bounded rationality.*	Stable network forms (such as keiretsu) reduce the intransience of a network while also reducing the bounded rationality. Research of such network forms ought to provide insights.	(Dyer, 1996)
Proposition 4b	Other simulation work has found that	(M. D. Johnson

Propositions	Future Research	Article
The intransience of a network will positively relate to the rate of growth in economies of scale.	managerial bounded rationality interacts with market dynamics in determining competitive outcomes of different strategies, specifically with regard to investments in capacity. Extending this research would address this proposition. Also, changes to economies of scale have been illustrated to prompt changes in exchange relationships. The relationship between the rate of change to economies of scale and exchange attractiveness across the spectrum of exchange relationships requires empirical validation which could be carried out by archival research using existing industry data.	& Selnes, 2004; Sterman et al., 2007)
Proposition 5a *Stability of a network will relate negatively to the rate of technological advance.*	Empirical evidence supports that consumer preferences for different product traits to a great extent determine market structure. Although examined at the firm level, the impact on the broader network perspective would be the next level application of techniques such as multidimensional scaling.	(Desarbo et al., 2006)
Proposition 5b *Stability of a network will relate negatively to growth of economies of scale.*	Changes to economies of scale have been illustrated to prompt changes in exchange relationships. The relationship between the rate of change to economies of scale and the attractiveness across the spectrum of exchange relationships requires empirical validation which could be carried out by archival research using existing industry data.	(M. D. Johnson & Selnes, 2004)
Proposition 6 *Complexity will positively relate to bounded rationality.*	Complexity in the macro environment has been proposed to increase strategic complexity, particularly with regard to managerial ability to respond (flexibility). This under-researched area requires field work to explore the content and boundaries of the bounded rationality construct, as well as real-life strategies employed by managers to successfully deal with complexity.	(J. L. Johnson et al., 2003)

Propositions	Future Research	Article
PRODUCTION FACTORS		
Proposition 7 *Economies of scale will have a U-shaped relationship with the frequency of transactions.*	Historical research ought to shed light on this proposition. The well-known product life cycle predicts that industries start out with several small companies, increase in the number of companies, then eventually a few large companies come to dominate the industry. As the number of companies decreases, fewer companies are forced to exchange amongst themselves with increased frequency. This is one factor in the appearance of network forms of economy and modular firms.	(Inkpen & Tsang, 2005; Jones et al., 1997; Langlois, 2002)
Proposition 8a *The rate of technological advance will inversely relate to the frequency of transactions between two given firms.*	Although some work suggests that a high rate of technological advance will positively relate to the frequency of transactions in a supply chain network, the same work also suggests that increased interfirm cooperation is necessary in the face of increased complexity and uncertainty in the environment. Empirical work mapping networks is needed to assess whether the level of interfirm cooperation outweighs the effect of increased frequency of transactions.	(Achrol & Kotler, 1999; Inkpen & Tsang, 2005; Jones et al., 1997)
Proposition 8b *There will be an inverse relationship between the rate of technological advance and asset specificity.*	The modular theory of the firm and empirical evidence from the semiconductor industry argue that rate of technological advance will inspire methods that reduce asset specificity (such as standardization). Additional work needs to be completed to see if this relationship holds true in other industries.	(Langlois, 2002; Sanchez & Mahoney, 1996; Sturgeon, 2002)
Proposition 8c *The rate of technological advance will relate positively to the degree of*	This study found an increased rate of technological change reduced the exclusivity of exchanges. Decreased exclusivity of relationships, as well as past work that suggests that reduced firm cooperation increases behavioral	(J. C. Anderson et al., 1994; Antia & Frazier, 2001; Heide, 1994; Roy *et al.*,

Propositions	Future Research	Article
behavioral uncertainty.	uncertainty, leaves an opportunity for more external validation of the relationship between rate of technology and degree of behavioral uncertainty. Extending extant survey and analytical research would answer this proposition.	2004)
Proposition 9 *There will be a positive relationship between bounded rationality and asset specificity.*	Work on information technology in the supply chain management context found that administrative advantages outweighed any technological advantage. More work needs to be completed regarding bounded rationality versus asset specificity and management's ability to manage complex inter-organizational relationships as a source of competitive advantage.	(D. Kim *et al.*, 2006)

The End Market factors consist of three propositions that describe the relationship of the volume, price sensitivity and heterogeneity of demand with the intransience, stability, and complexity of the supply chain network. Although market growth has been implicitly included as a market-level factor in some past research (Narver & Slater, 1990), most research on the effects of end market factors tend to look only at "uncertainty" or "turbulence" (Jaworski & Kohli, 1993; Wathne & Heide, 2004). The lack of precision regarding the different types of "turbulence" perhaps explains the mixed findings in the research regarding its effects (Kirca *et al.*, 2005).

The CAFE model has attempted to define end market factors on three dimensions: 1) growth of demand volume, 2) price sensitivity, and 3) degree of heterogeneity. A key difference between the CAFE model and most extant marketing and supply chain models is the holistic view of supply chain networks comprising a system permits definition of end market factors—this converts end market considerations into an endogenous variable. The prevalent methods of dealing with variation in demand due to turbulence or uncertainty measure only the symptoms and make the end market an exogenous variable.

Growth, whether positive or negative, relates to opportunities for firms in the supply chain network. Rapid growth provides more profit possibilities and insofar as it provides more opportunity, it will inspire less asset specificity and increase the health of individual firms. Past research supports this logic in the technology sector, indicating that at the dyadic level, end market dynamism reduces the closeness of interfirm relationships (Heide & John, 1990; Stump & Heide, 1996). This directly affects intransience as firms will more often change partners. With regard to stability of supply chain networks, many network forms appear to have come into being in order to pool supply capacity in the face of uncertain demand fluctuations (Jones et al., 1997). Future research needs to address the strength of the relationship between demand growth (positive or negative) and the extent to which the additional opportunities offered by growing demand (or the reduced opportunities of shrinking demand) impact the intransience and stability of supply chain networks. U.S. Census Bureau data may provide a starting point for exploring Propositions 1a and 1b; other sources of industry data such as Research Insights (previously called COMPUSTAT) could also be used.

However, the extent to which growth of demand influences stability and intransience may also depend on other variables. Proposition 2 describes the different facets of how price sensitivity relates to supply chain network characteristics. Price sensitivity depends on the consumer willingness to pay for certain levels of functionality (R. Adner & Levinthal, 2001). The supply chain network's ability to produce the requisite level of functionality at or below the consumer's price threshold results from the sums of all the prices incurred at each step of the production process plus the transaction costs (i.e., costs of monitoring, transportation, etc.)

required to bring the product to market. Low price sensitivity equates to low incentive for the supply chain network to reconfigure itself in order to find a more efficient means of bringing product to market. As price sensitivity of the end consumer market increases, the incentive to find more efficient means of producing and transacting also increases. This leads to more changes in how firms exchange (intransience) and which firms are able to survive the changes (stability). End market uncertainty based on technological turbulence and variation in demand volume have been studied (e.g., Heide & John, 1990; Stump & Heide, 1996), but more work needs to be completed to understand the effects at the supply chain network level from the exchange (interfirm governance) perspective. Calls for further research on the effects of price sensitivity on supply chain network complexity has thus far focused on areas such as product innovation choices (R. Adner & Levinthal, 2001) and firm-focused knowledge based views (Macher, 2006). To the author's knowledge, no extant work assesses price sensitivity simultaneously in the context of exchange governance, innovation, and a network perspective. Future research should assess the managerial decision-making processes for dealing with consumer price sensitivity with field research using survey work to assess the importance of price sensitivity to decisions related to supplier and buyer selection and governance in different industry settings.

Proposition 3 describes the relationship between the heterogeneity of end consumer demand and the complexity of the supply chain network. Although the case of uniform end consumer demand seems intuitively straightforward, the case of markets that require great variety of products or customization presents a special research challenge with regard to where in the supply chain network the customization will occur (Aitken et al., 2005). Further complicating the relationship between end consumer market heterogeneity and complexity of the supply chain network is the consumer ability to learn, thereby increasing end consumer expectations of product variety (Kahn, 1998). One possible future research effort could extend the well established Bass model to the case of product prolificacy (Mahajan et al., 1990). Other opportunities for future research lie in qualitative field work among supply chain professionals in order to further explore how decision-makers deal with product variety and interfirm governance.

The Network Factors relate changes in the network configuration (intransience, stability, complexity) to production factors (rate of growth in economies of scale, rate of technological advance, and bounded rationality). Proposition 4a and 4b posit a positive relationship by intransience on bounded rationality and rate of growth of economies of scale. The existence of stable network forms such as *keiretsu* in Japan provide an example of networks dealing with the issue of bounded rationality (Dyer, 1996). Additionally, changes to economies of scale have been implicated as prompting changes to exchange relationships (M. D. Johnson & Selnes, 2004). Recent simulation work also found that managerial bounded rationality interacts with market dynamics in determining the competitive outcomes of different strategies, specifically with regard to capacity investments (Sterman et al., 2007). U.S. Census data tracks plant capacity (Bureau, 2005) and provides a point of disembarkation for future research on the relationship between intransience and rate of growth of economies of scale.

The before-mentioned U.S. Census data can also be used as a point of departure for studying Proposition 5b since growth of economies of scale have also been implicated in the stability of supply chain networks (M. D. Johnson & Selnes, 2004). Other existing industry data could also be used to provide the starting point for exploring the connection between increases (or decreases) to economies of scale and the stability of firm populations in supply chain networks. The other factor proposed to affect network stability is the rate of technological advance. The rate of technological advance in the context of an end consumer market ultimately depends on consumer preferences for different product traits. Other research has investigated the link between consumer preferences and the abilities of different firms to satisfy those preferences (Desarbo et al., 2006). By extending the firm-centered perspective of this past research to a network perspective, Proposition 5a could be explored. As an additional outcome, the CAFE model could be expanded to include other factors important to consumers than rate of technological advance, perhaps thereby broadening its applicability to different product markets.

Proposition 6 states that complexity will positively relate to bounded rationality. Bounded rationality essentially replaces the hyperrationality assumption of neo-classical economics by acknowledging that human agents do not always maximize their opportunities. This can happen due to different utility functions, costs or errors in gathering and processing information, or competing goals—all reasons that humans often use heuristics to make decisions (Williamson, 1986). A game of checkers serves to illustrate bounded rationality: humans can understand all the rules of the game, but be completely incapable of predicting the outcome. As complexity in the environment increases, managerial flexibility or ability to respond becomes more challenged (J. L. Johnson et al., 2003). Managerial techniques for dealing with bounded rationality comprise an under-studied area for future research. The validation phase of this dissertation found that some semiconductor manufacturing firms seem very successful at managing bounded rationality in a very turbulent industry. Future research in this area should begin with field interviews to determine the heuristics managers use. It is possible that different managers or organization forms have different thresholds for bounded rationality, although the exact nature of this phenomenon remains unclear.

The three propositions for production factors relate the production factors (economies of scale, rate of technological change, and bounded rationality) to TCA's exchange factors (frequency, asset specificity, and behavioral uncertainty). Proposition 7 proposes that economies of scale will have a U-shaped relationship with the frequency of transactions due to the increase then decrease in number of firms in a supply chain network according to the product life cycle curve. The ability of firms to form communities to perpetuate modular and network forms of exchange communities appears in several important extant studies, along with calls for further study of factors that prompt their appearance and sustainment (Inkpen & Tsang, 2005; Jones et al., 1997; Langlois, 2002). Specifically, past studies have called for future research to identify at what size does a supply chain or community of firms become a network and how is power exercised among members (Jones et al., 1997). Both of these issues relate to economies of scale and frequency of transactions. Future research could find initial support for this proposition with historical research.

Propositions 8a, 8b, and 8c relate the rate of technological advance to frequency, asset specificity, and behavioral uncertainty. Past work suggests that a high rate of technological advance will lead to more frequency of transactions since more firm cooperation is necessary in the face of complex products and markets (Achrol & Kotler, 1999; Jones et al., 1997; Macher, 2006). However, there is little understanding of whether the level of interfirm cooperation at a community level outweighs the effect of frequency of transactions at the dyadic level. More empirical work mapping networks and comparing the efficacy of their product solutions needs to be completed.

Whereas frequency may go up as the rate of technological advance increases, Proposition 8b posits that asset specificity will go down. Evidence from the semiconductor and other high tech industries argues that rapid technological advance is dealt with at a network level with the use of standardization and modularity as much for the production process as for the products (Langlois, 2002; Sturgeon, 2002). More work needs to be completed to see if this prediction depends on the rate of technological advance or other product-market factors not considered in this research.

Proposition 8c rests on this study's findings that a fast rate of technological advance reduced the exclusivity of exchanges. Past work has established that increased cooperation between firms reduces behavioral uncertainty (J. C. Anderson et al., 1994; Heide, 1994; Roy et al., 2004). Less exclusive exchanges and a more complex production environment are both factors that would increase behavioral uncertainty. Extending extant research to include specifically the rate of technological advance would answer this proposition.

Proposition 9 deals with the relationship between bounded rationality and asset specificity. Interestingly, one common form of asset specificity in supply chains, information technology, was found to be less important than administrative advantages (D. Kim et al., 2006). This agrees with the previously cited work on *keiretsu* (Dyer, 1996) that are based on administrative rather than technological forms of asset specificity. Qualitative field work needs to be completed regarding bounded rationality versus asset specificity with regard to management's ability to manage complex inter-organizational relationships as a source of competitive advantage.

The Broader Context. With regard to future research in the broader context of supply chain and marketing theory, the tendency in most research is to simplify the problem in order to clearly understand a piece or simple causal effect. If one accepts that exchange governance occurs in increasingly complex and evolving networks with only temporary equilibrium points as proposed by eminent scholars such as Coase (1937), Achrol (1997), and Vargo and Lusch (2004), simplification compromises validity. Theory related to interfirm governance has matured greatly in the past few decades; future research should explore the interconnections between the bodies of literature that enjoy strong empirical support. Keeping this in mind, five principle areas for future research present themselves: 1) exchange governance, 2) supply chain management, 3) strategy, 4) network paradigm, and 5) public policy.

Past research into exchange governance has focused on the spectrum of relationships that characterize exchanges (Day, 2000). However, the dominant exchange theory (TCA) has failed to explain all forms of exchange relationships found in real markets. Particularly, the view that information asymmetry may explain at least in part the various hybrid and other relative cost-benefits of exchange characteristics lends itself as an area of extension that complements well the results of this research study (Dutta *et al.*, 1999; Kaufman *et al.*, 2000). The decision sciences literature has done much work in exploring the importance of information asymmetry and information sharing on exchange coordination (for a good review, see Sahin & Robinson, 2002).

One area particularly ripe for future research would be to combine the view that transaction costs lie at the heart of supply chain theory (Hobbs, 1996) with the effects of information distortion in supply chains (Lee et al., 1997b). The presented framework presents one possible path to explore the many interconnections between information, exchange costs and supply chain management. The advantage of the present framework is its integrative, positive nature which could serve as a springboard into a more confirmatory body of theory more useful for making predictions. A previously mentioned important area of future research related to transaction costs and supply chain theory would be the determination of the shapes and slopes of transaction cost curves relative to production cost curves in determining the total cost of interfirm exchanges.

The strategy literature presents many opportunities for investigating the effects of strategic decisions on network and governance factors. A complex adaptive network characterized by movement from equilibrium to equilibrium broaches the question of how a firm can hope to survive perpetual change. The primary strategy perspectives are the competence-based view (Prahalad & Hamel, 1990), the resource-based view (Barney, 1991), and Porter's five forces (Porter, 1985), as well as the controversial resource-advantage theory (Shelby D. Hunt, 2000). This study's proposed framework offers the opportunity to explore the differential explanatory power of each of these perspectives. However, some strategy researchers have already proposed a new strategy that leverages the "edge of chaos" that characterizes complex adaptive systems (K. M. Eisenhardt & Brown, 1998). Indeed, a whole body of dynamic capabilities strategy literature has arisen that remains essentially firm-centered or dyadic in nature with no clear ties to the well-established literatures of transaction cost analysis or empirically well-studied production processes (Kathleen M. Eisenhardt & Martin, 2000; M. D. Johnson & Selnes, 2004; Teece *et al.*, 1997). It would be a relatively simple extension to model more complex firm strategic decision-making capability then observe the effects.

Related to the strategy literature, the public policy dimension has important implications in a dynamic, globalized economy. The interplay of institutional environments with firm ability to act either as strategy or different forms of exchange has important national and international implications with regard to marketing's influence on a global scale (Grewal & Dharwadkar, 2002). Most notably, the institutional environment affects the ability for firms from one nation to interact (conduct exchanges) with firms from another nation. Work that incorporates production and transaction cost constructs has already been completed with regard to this issue and would make a suitable starting point for additional public policy research (Bello & Lohtia, 1995).

5. Conclusion

This research dissertation started out with the simple question, “Which form of governance performs better in a dynamic environment?” However, it soon became apparent that governance evolves and changes in response to a dynamic environment. The better question would have been, “How does a dynamic environment drive the evolution of governance to better performance?” These findings support that firms adapt themselves by mixing and matching the value offerings available in their supply chain network in a heterogeneous manner in a way that enables them to “adapt to” certain niches in the end consumer environment. The drivers of adaptation become the factors of interest in order to understand how markets shape and form supply chain networks which, in turn, also re-shape markets.

To take the importance of adaptation once step further, many products are now so complex in terms of the number of steps required to complete production and bring them to market that their value chains can be treated as ecological webs. Characterized by evolution and adaptation, in the ecological view, processes take precedence over outcomes. This is a dramatic shift from the traditional marketing research that focuses on outcomes.

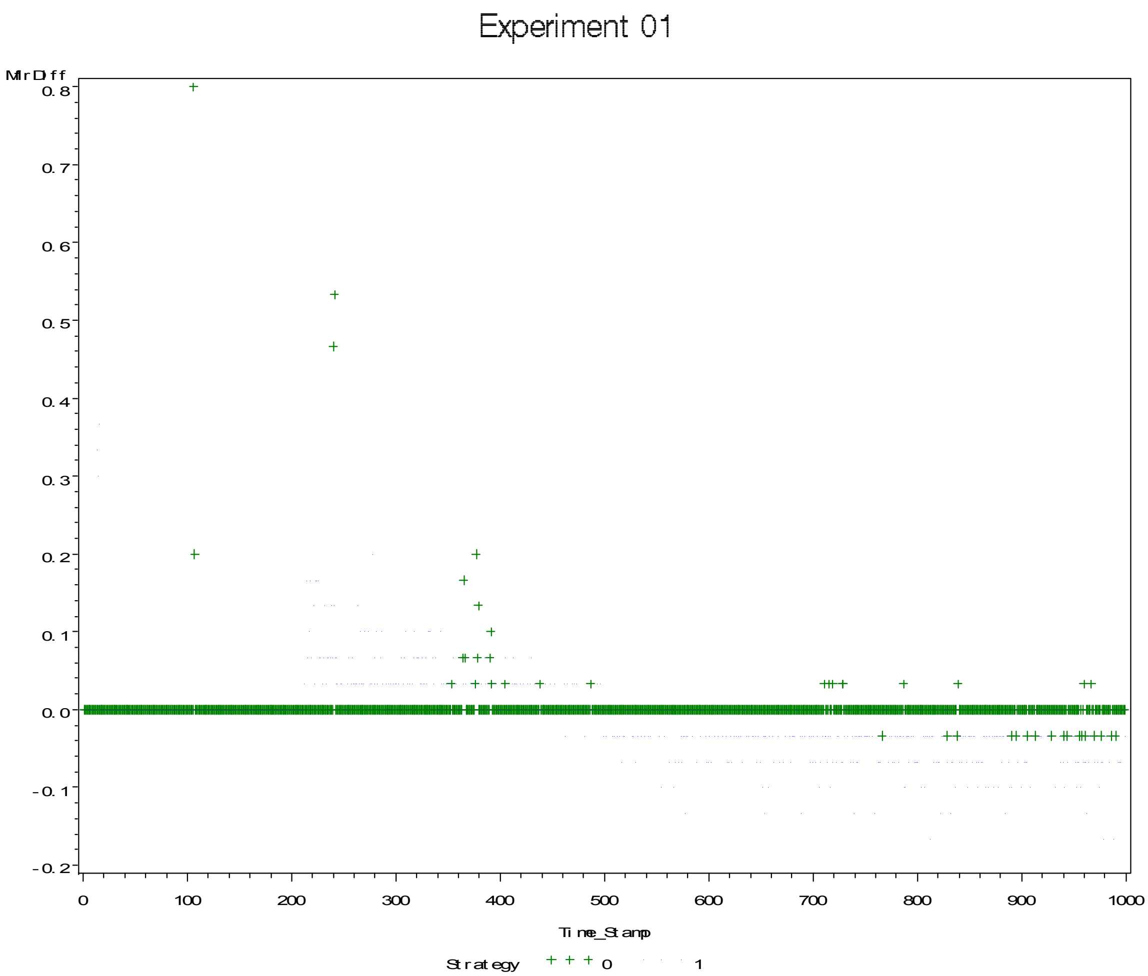
In the end, the theoretical insights garnered by this study creates more questions than it answers, but they open a door onto exchange as an organic and dynamic system that is in most senses of the word alive. As long as human exchanges retain the freedom to act like living organisms, scholars will never tire of studying them.

APPENDIX

DIFFERENCING PLOTS (VARIATION ANALYSIS)

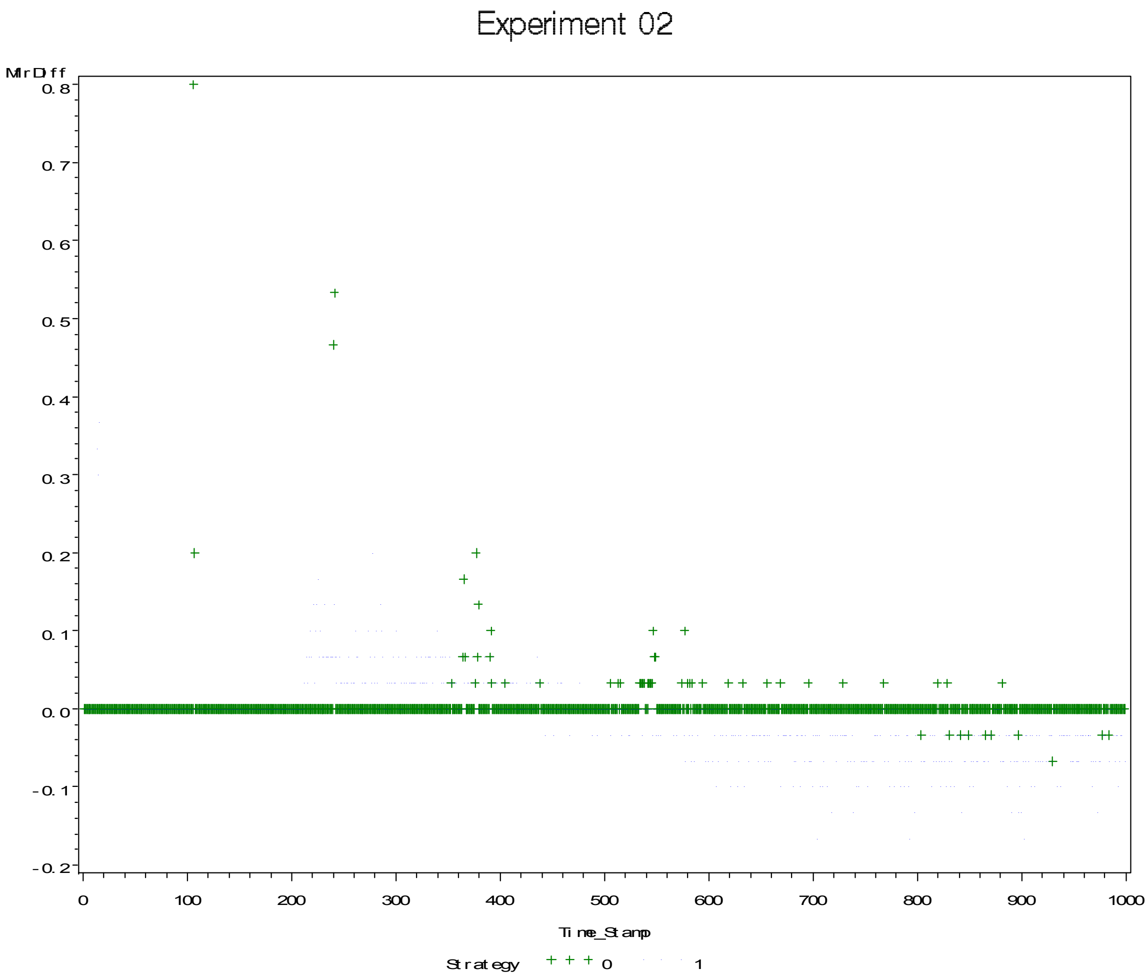
AVERAGE DIFFERENCING OF MANUFACTURERS

Heterogeneous End Market, Fast Rate of Technological Advance, and Rapidly Growing Economies of Scale



AVERAGE DIFFERENCING OF MANUFACTURERS

Heterogeneous End Market, Fast Rate of Technological Advance, and Slowly Growing Economies of Scale



AVERAGE DIFFERENCING OF MANUFACTURERS

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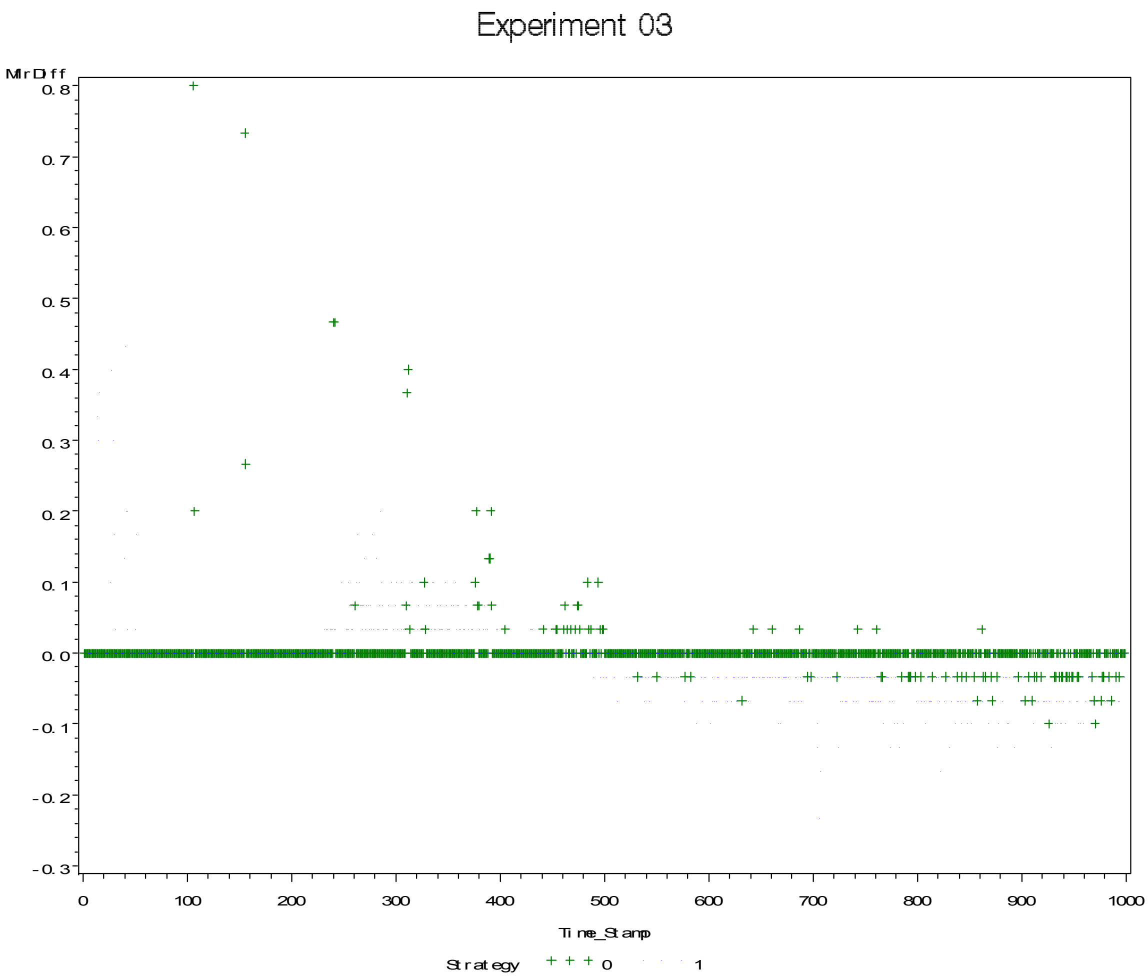
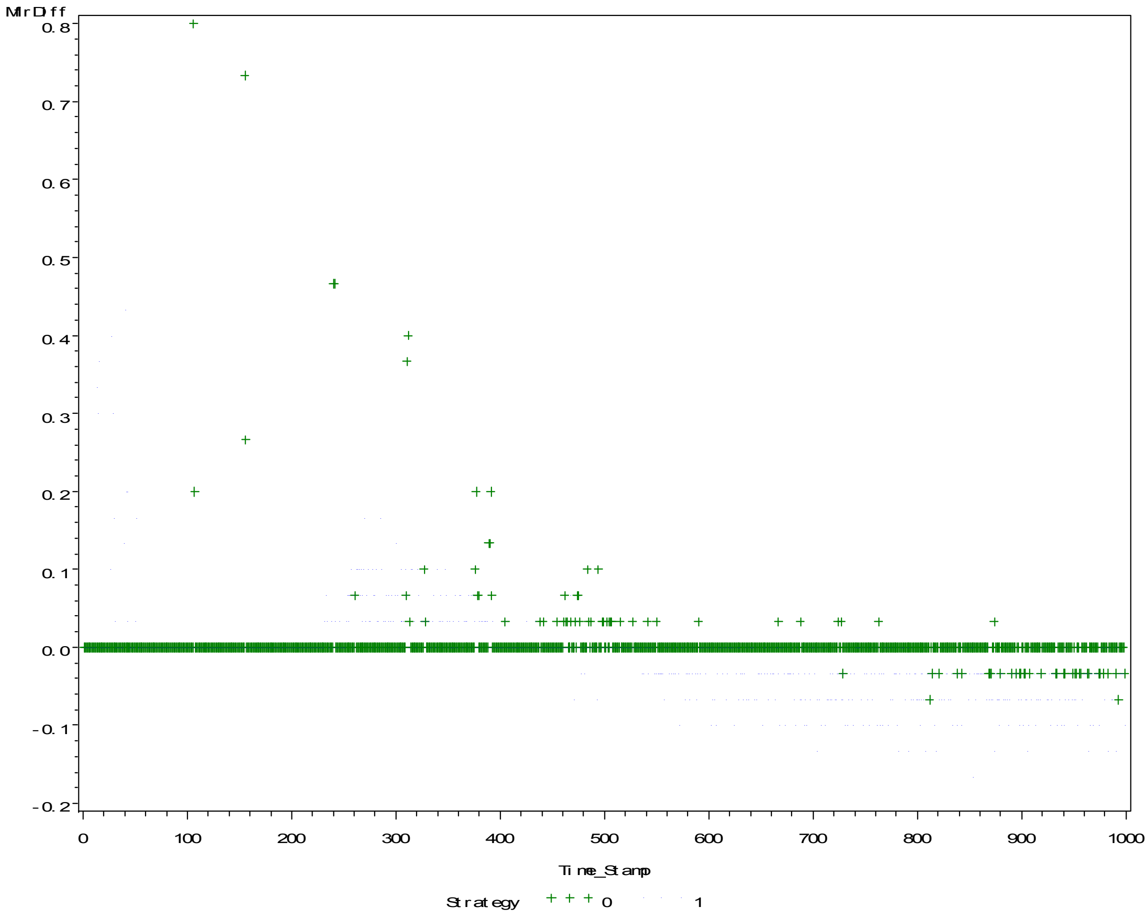


AVERAGE DIFFERENCING OF MANUFACTURERS

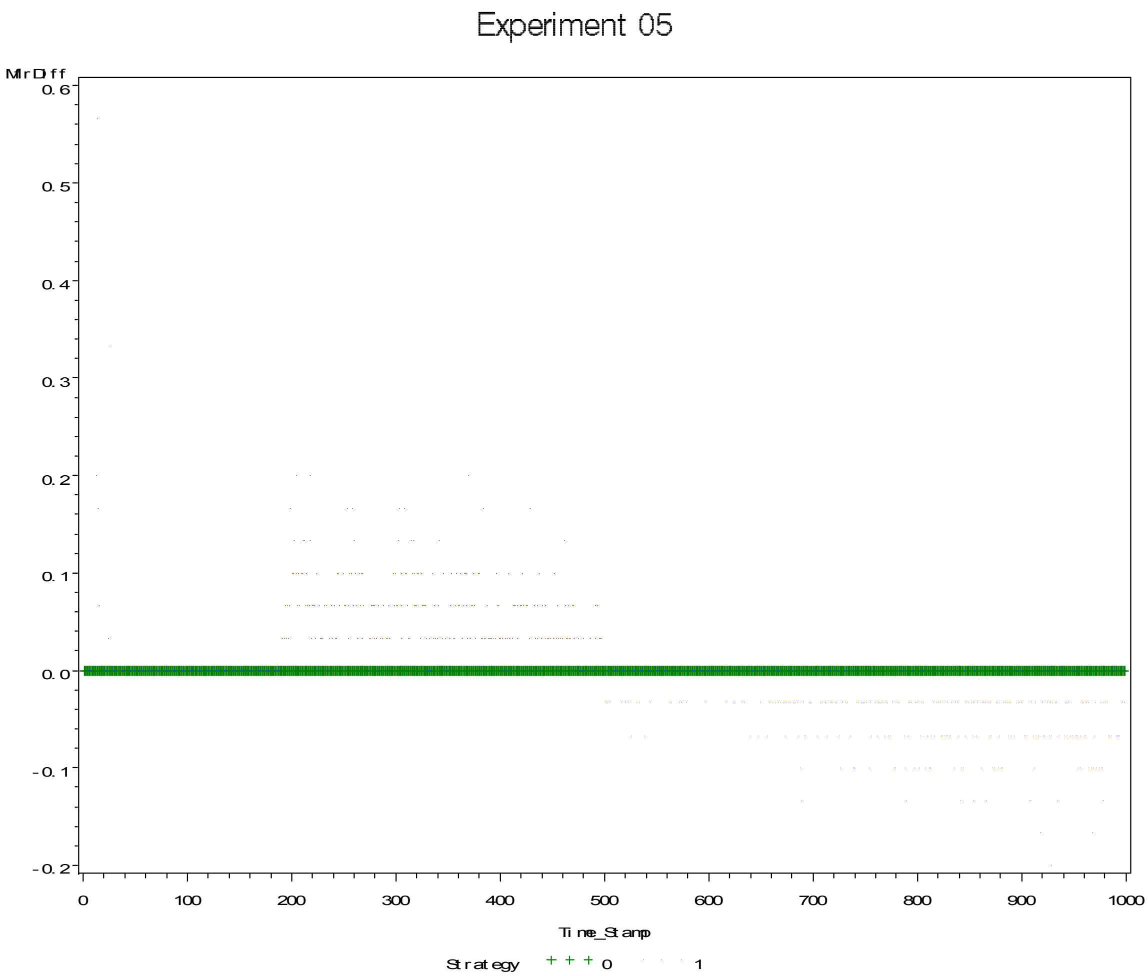
Heterogeneous End Market, Slow Rate of Technological Advance, and Slowly Growing Economies of Scale

Experiment 04



AVERAGE DIFFERENCING OF MANUFACTURERS

Homogeneous High End Market, Fast Rate of Technological Advance, and Rapidly Growing Economies of Scale



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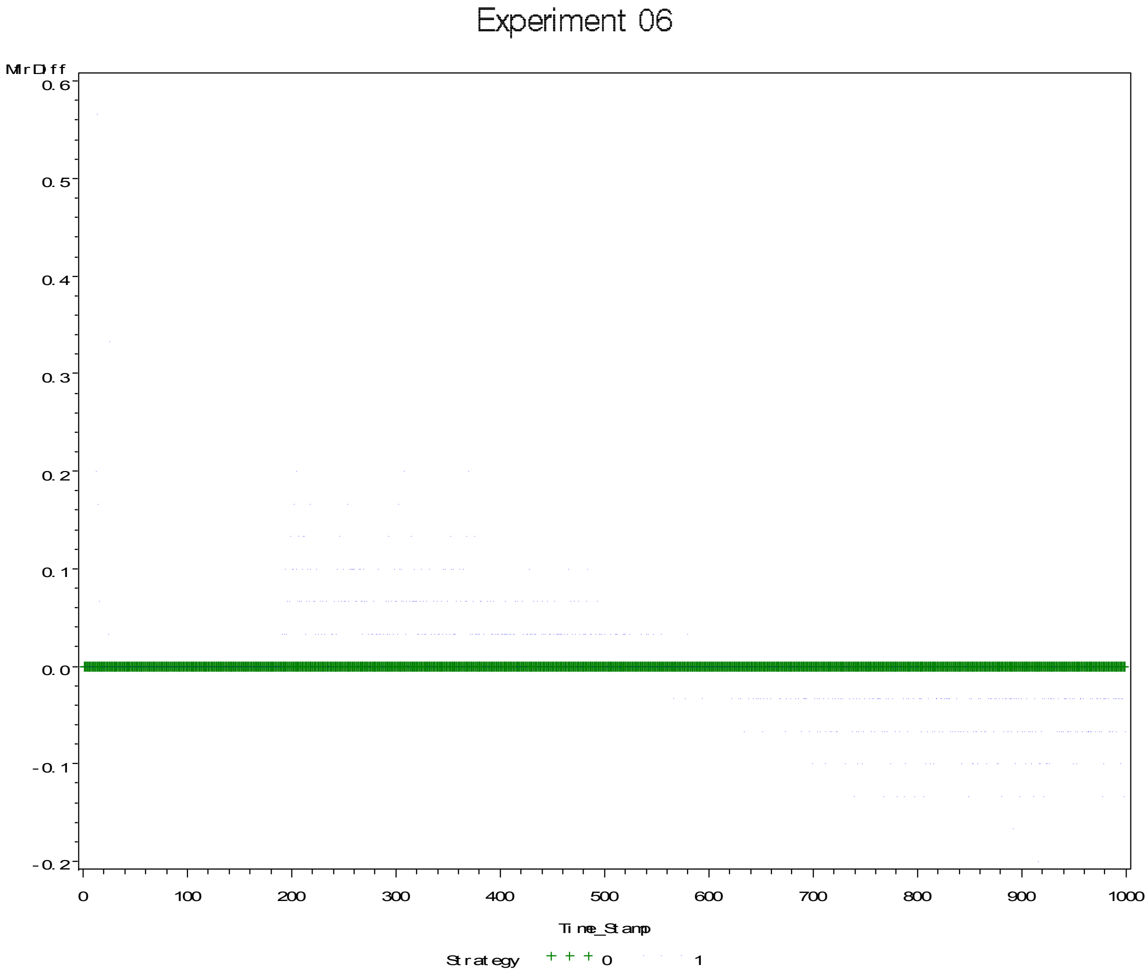

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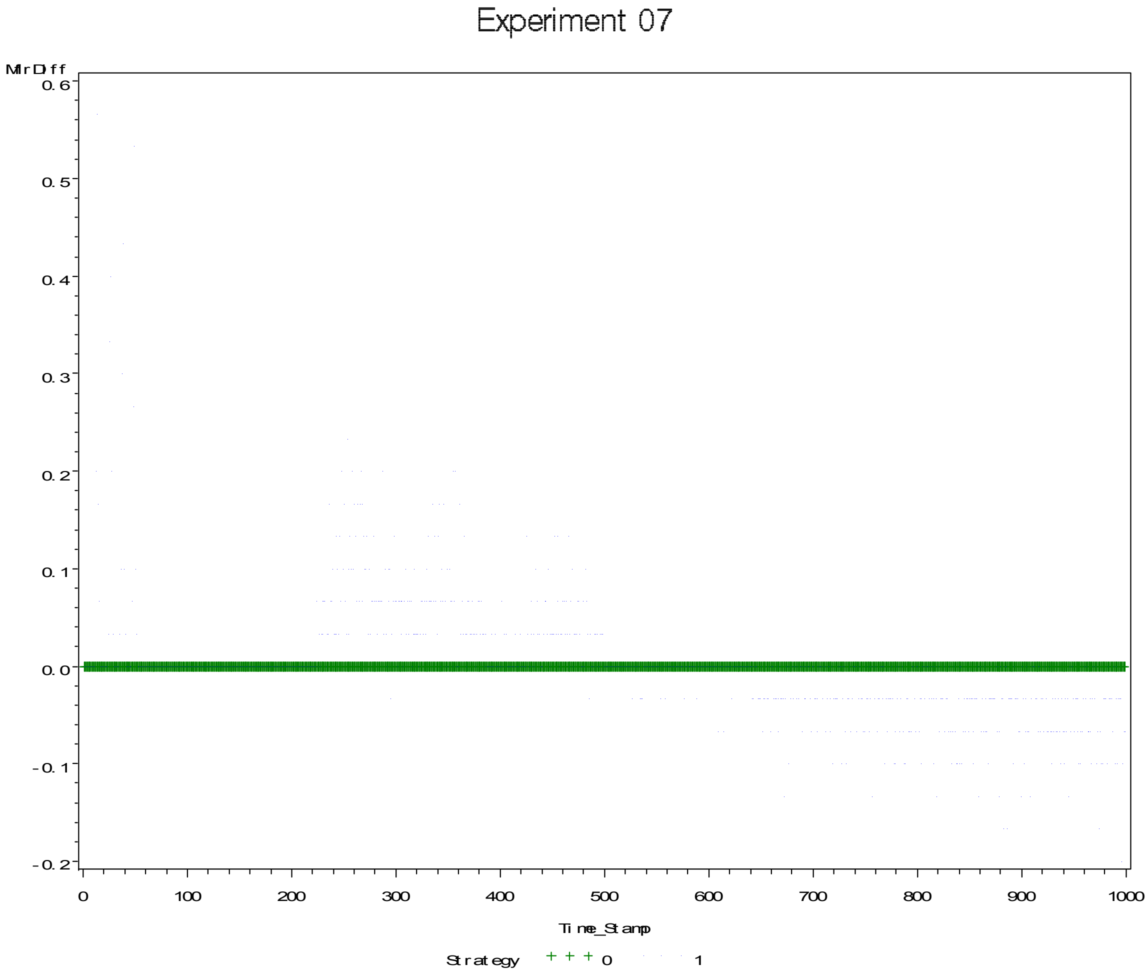

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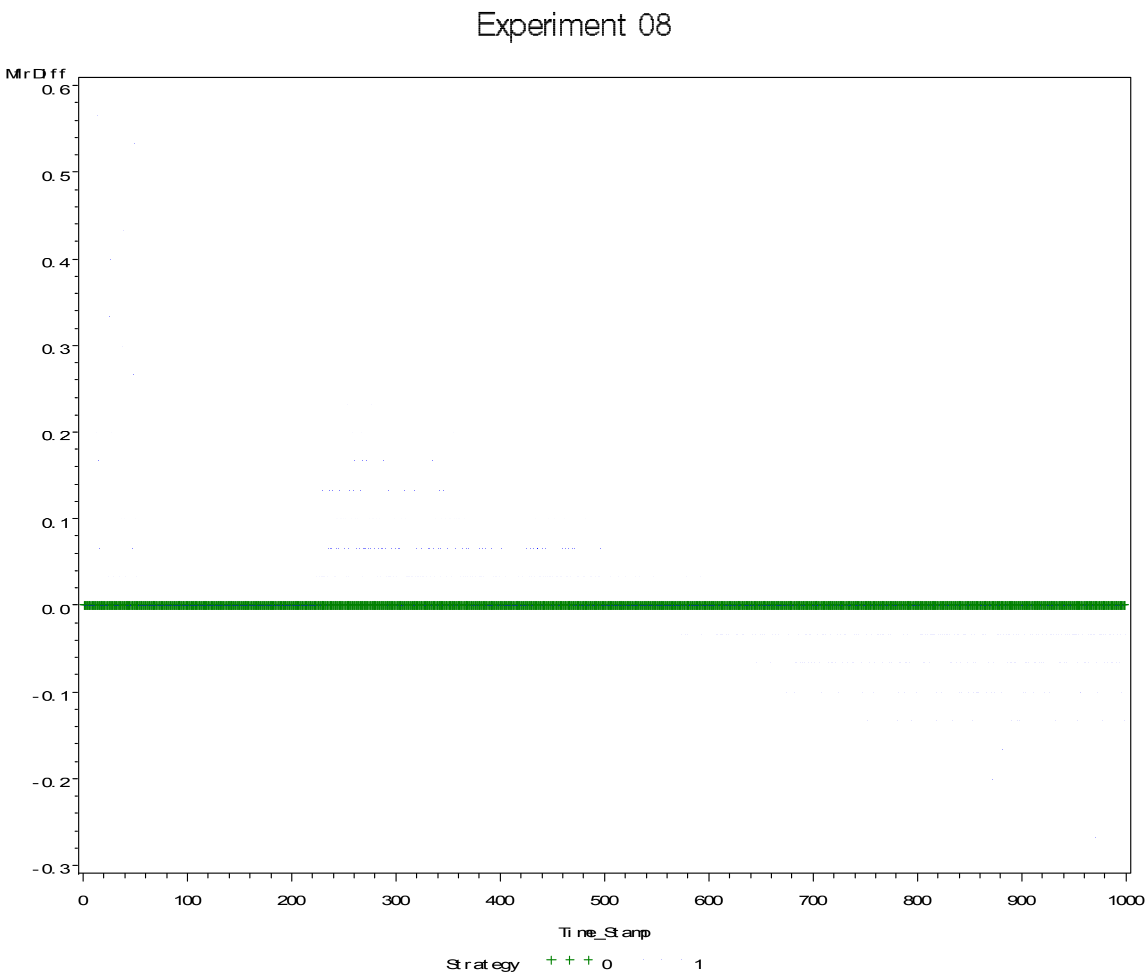

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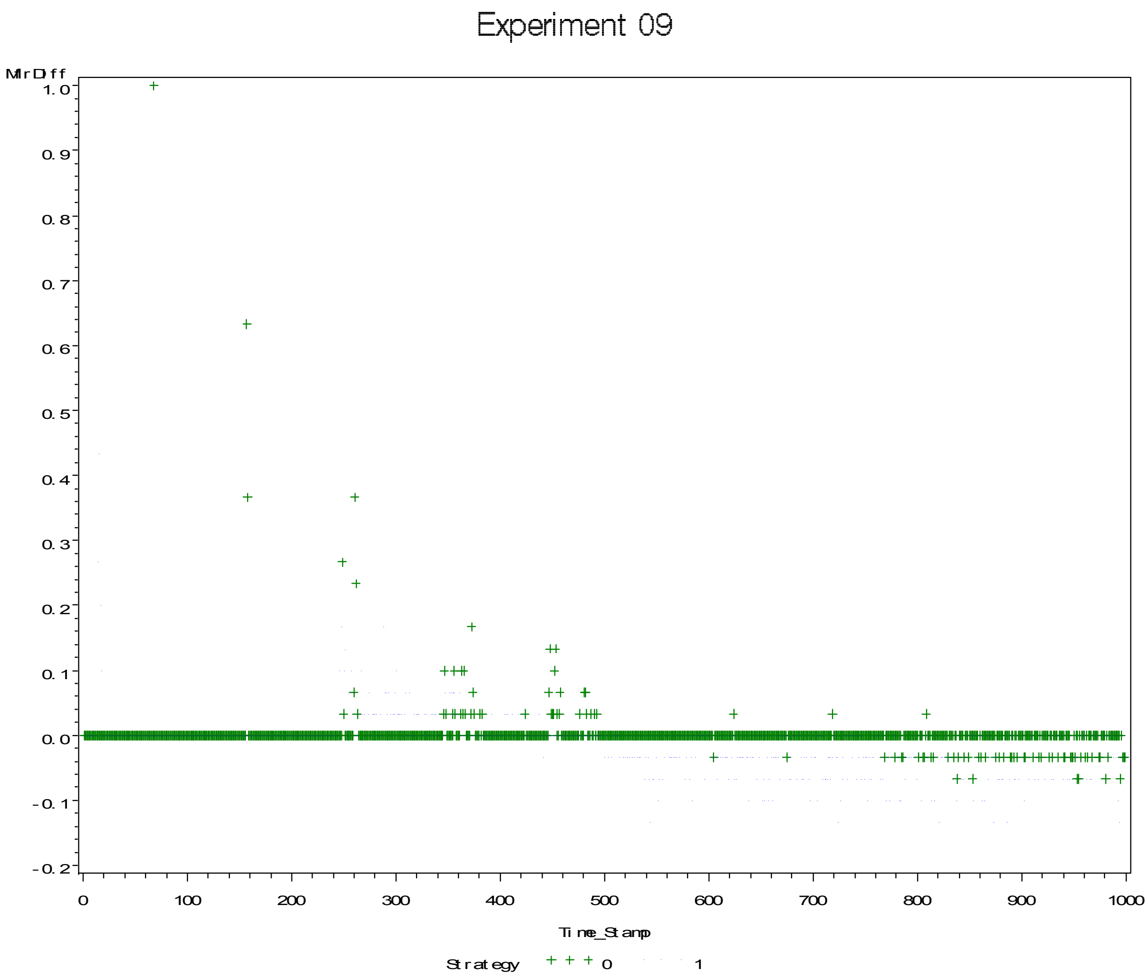

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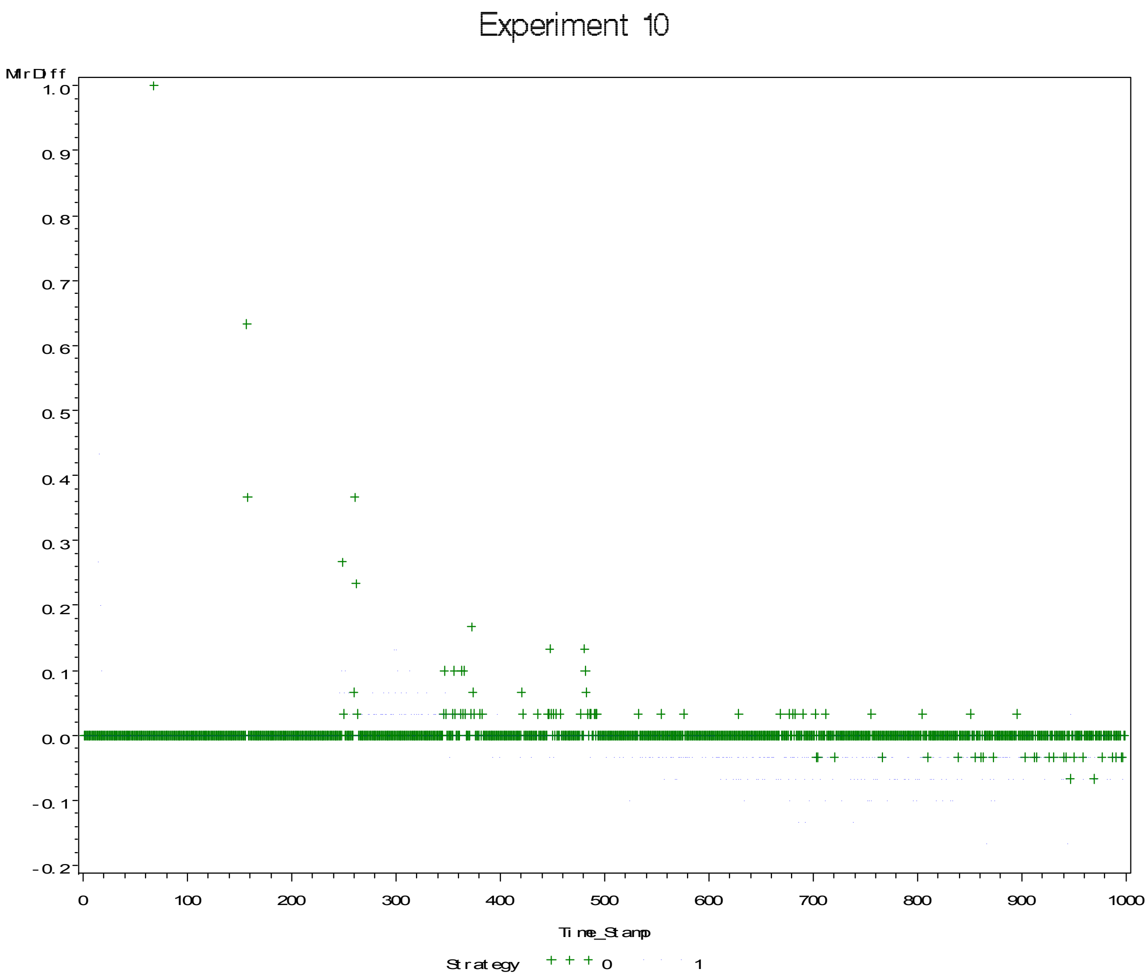

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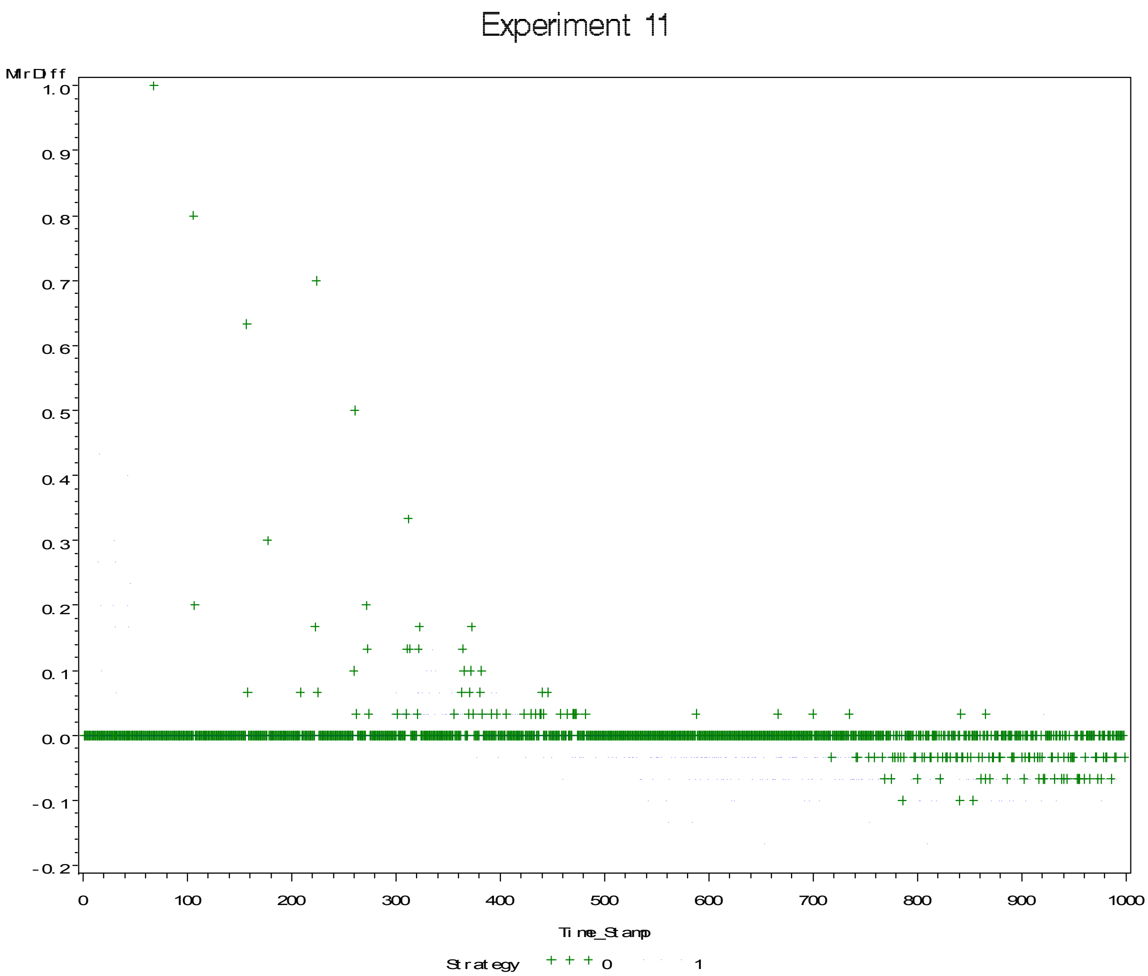

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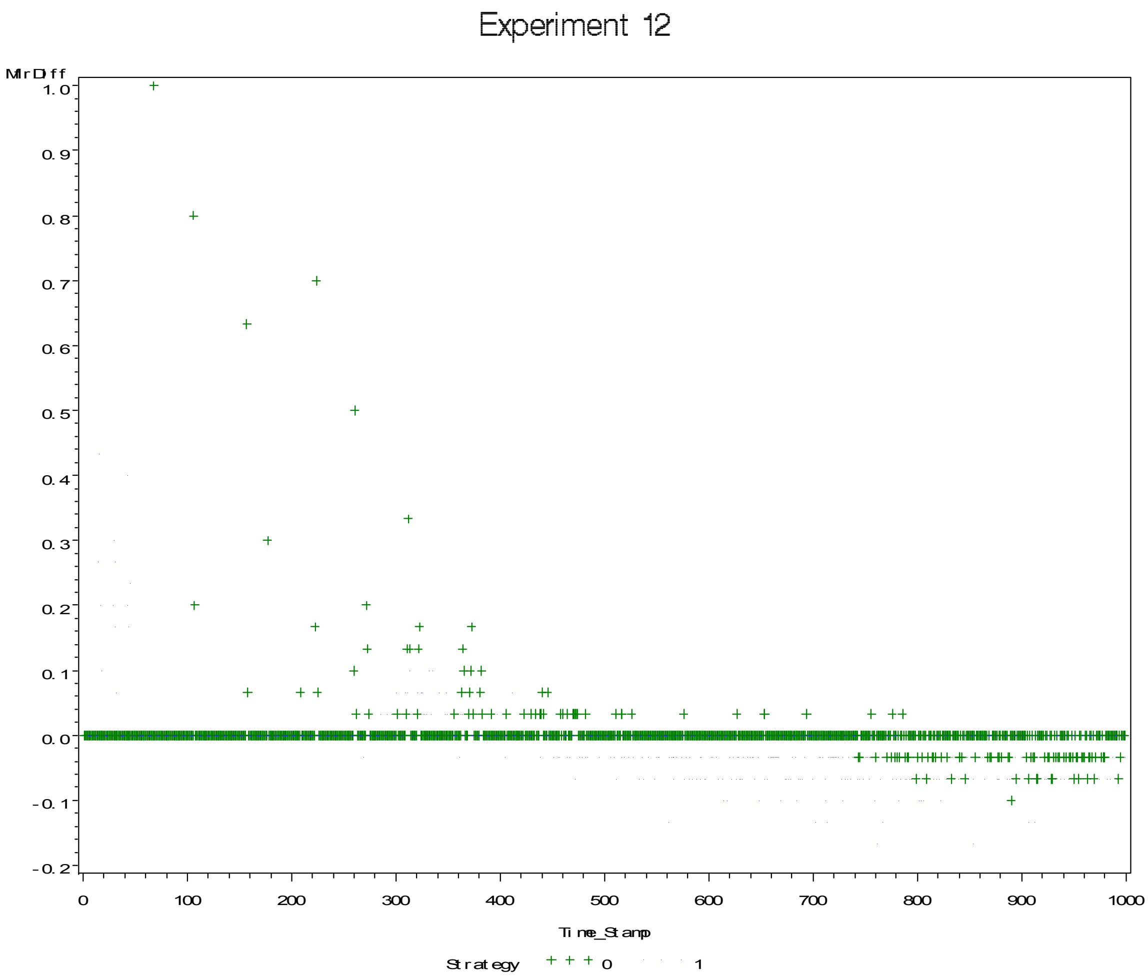
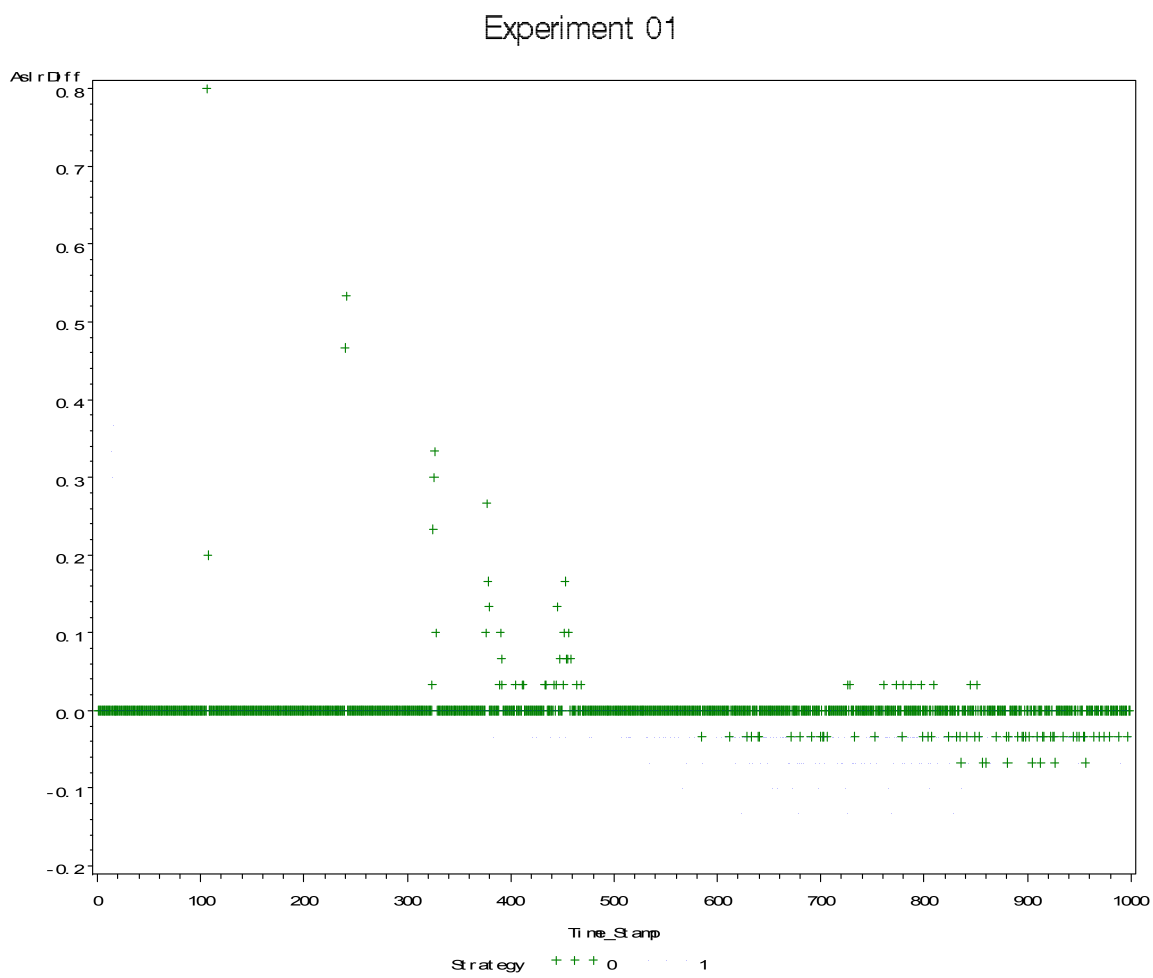


AVERAGE DIFFERENCING OF ASSEMBLERS

Heterogeneous End Market, Fast Rate of Technological Advance, and Rapidly Growing Economies of Scale



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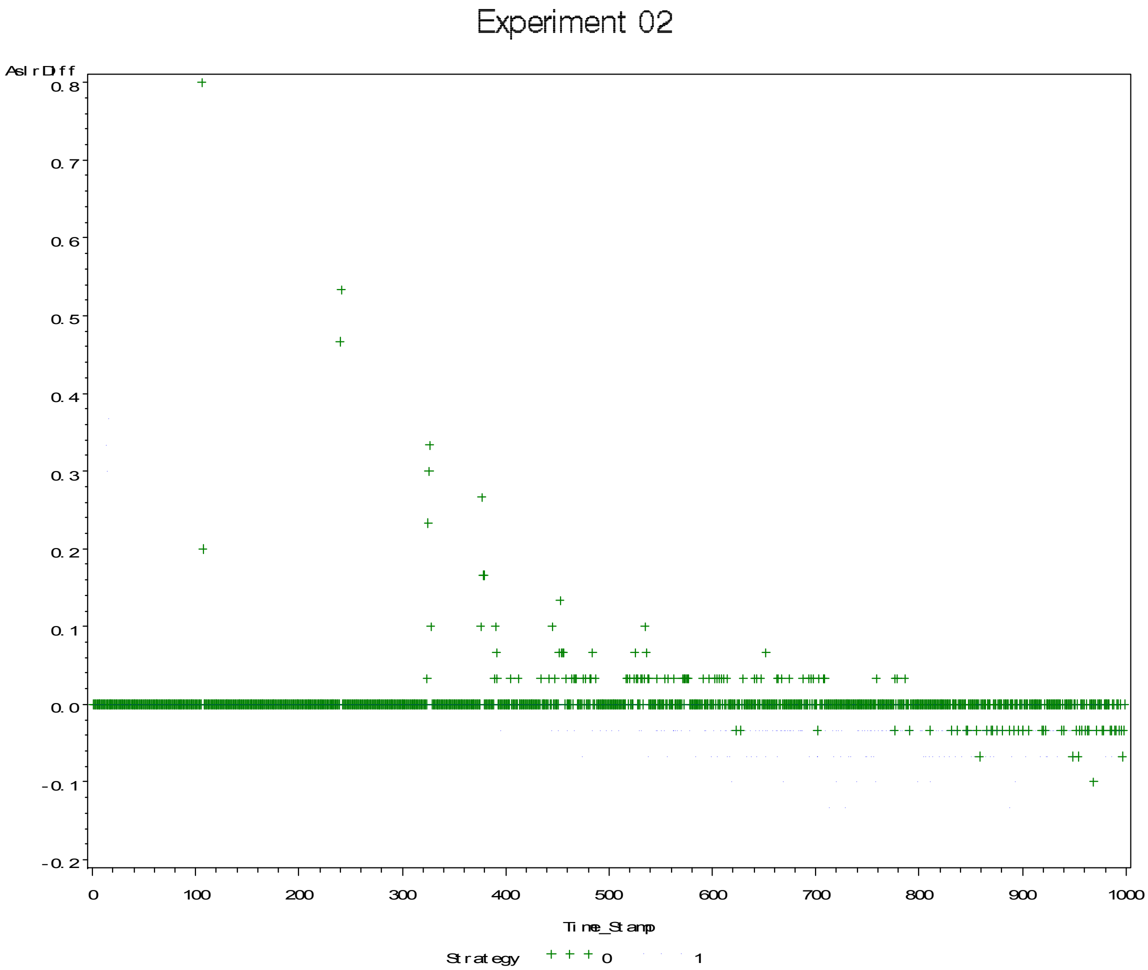

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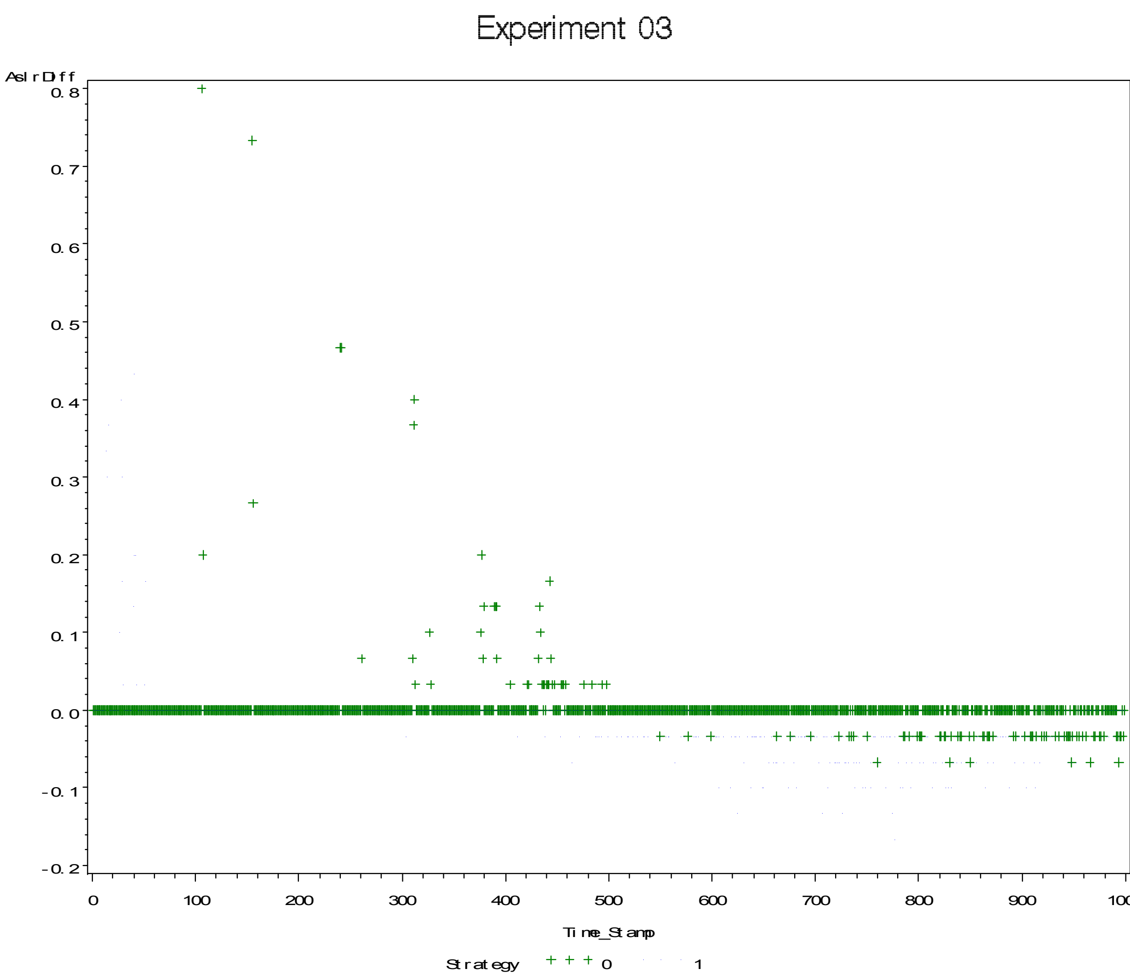

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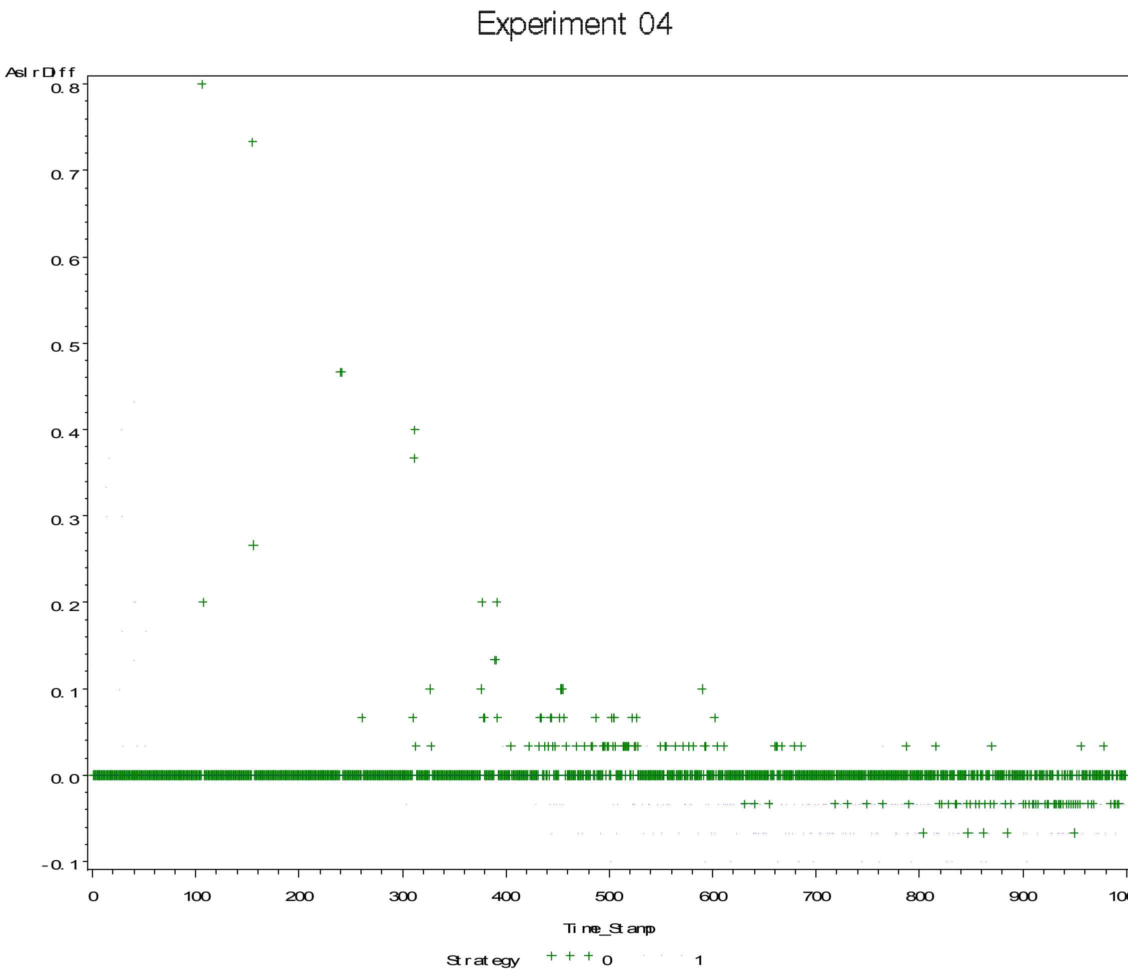

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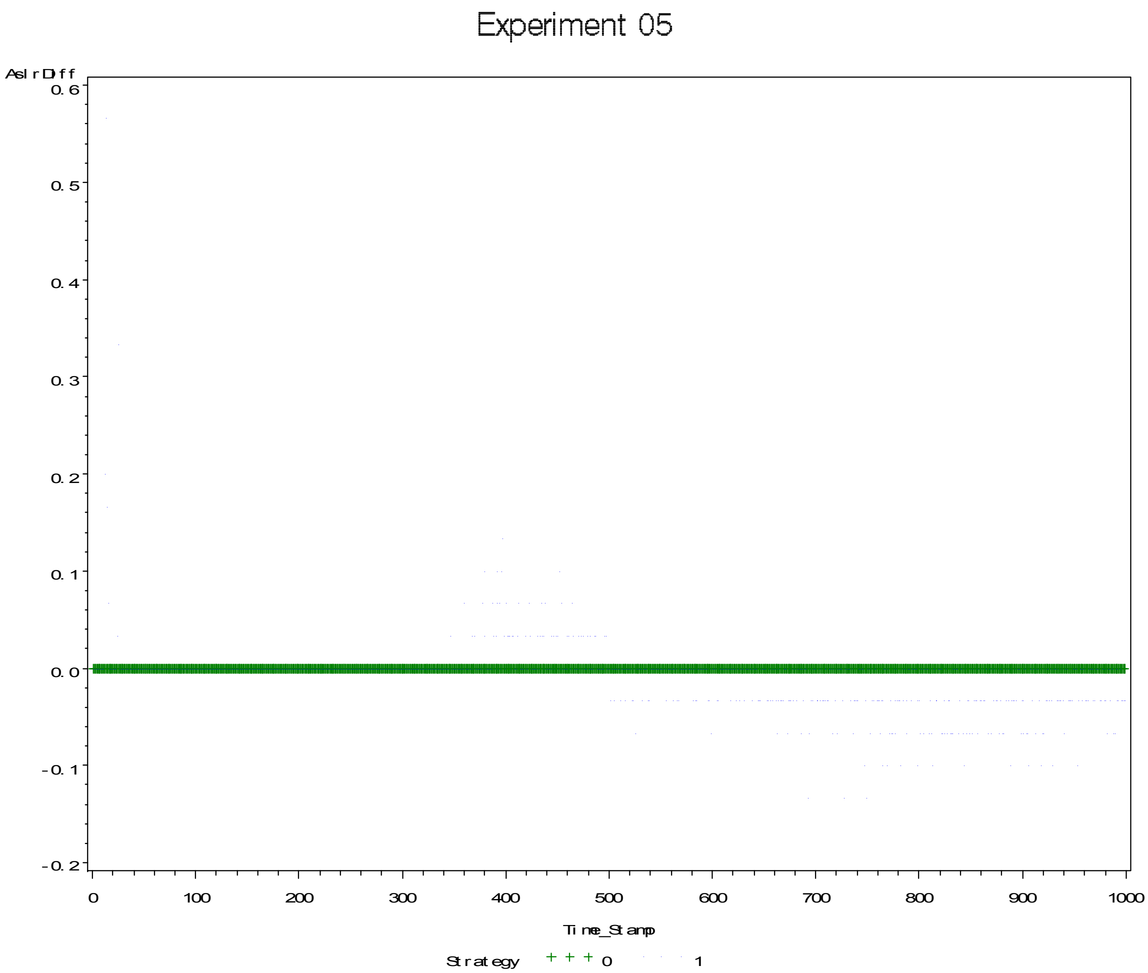

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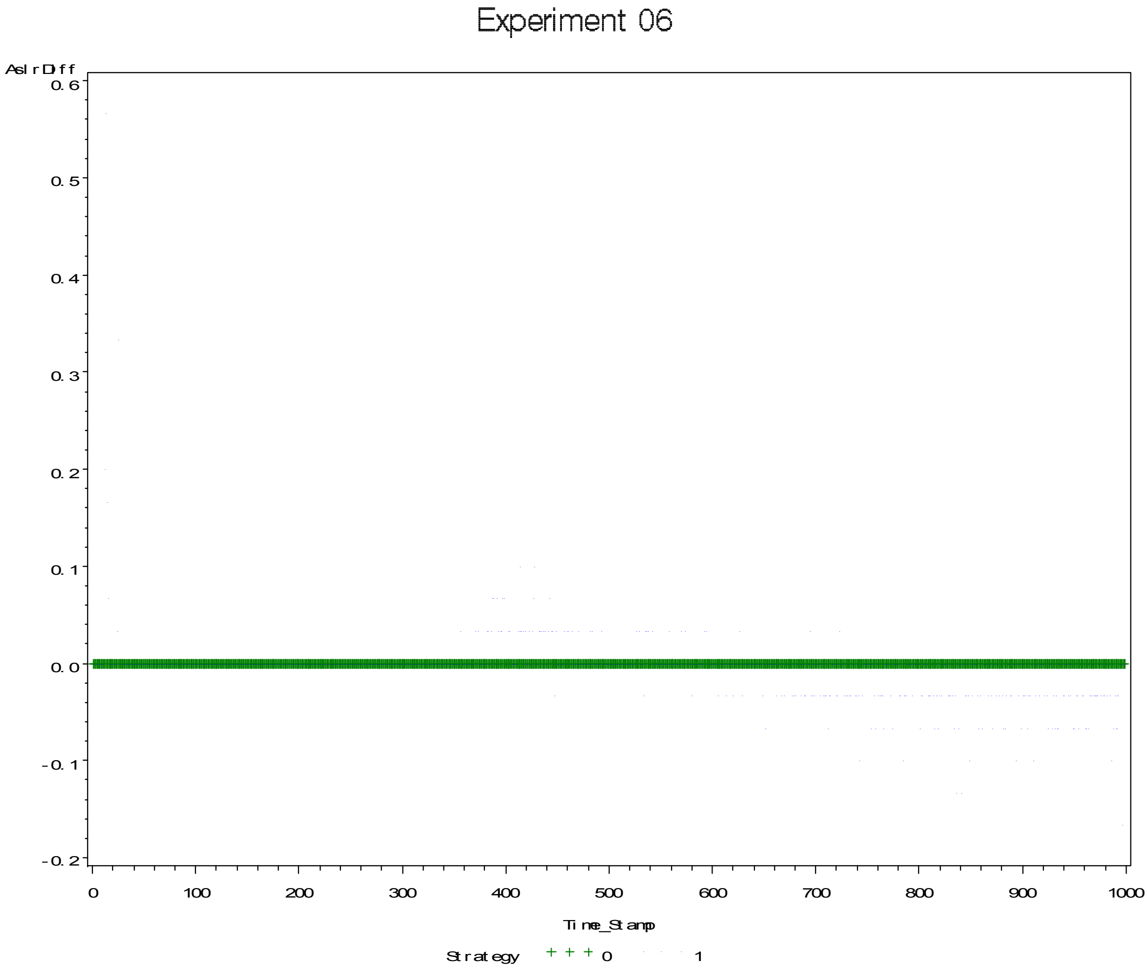

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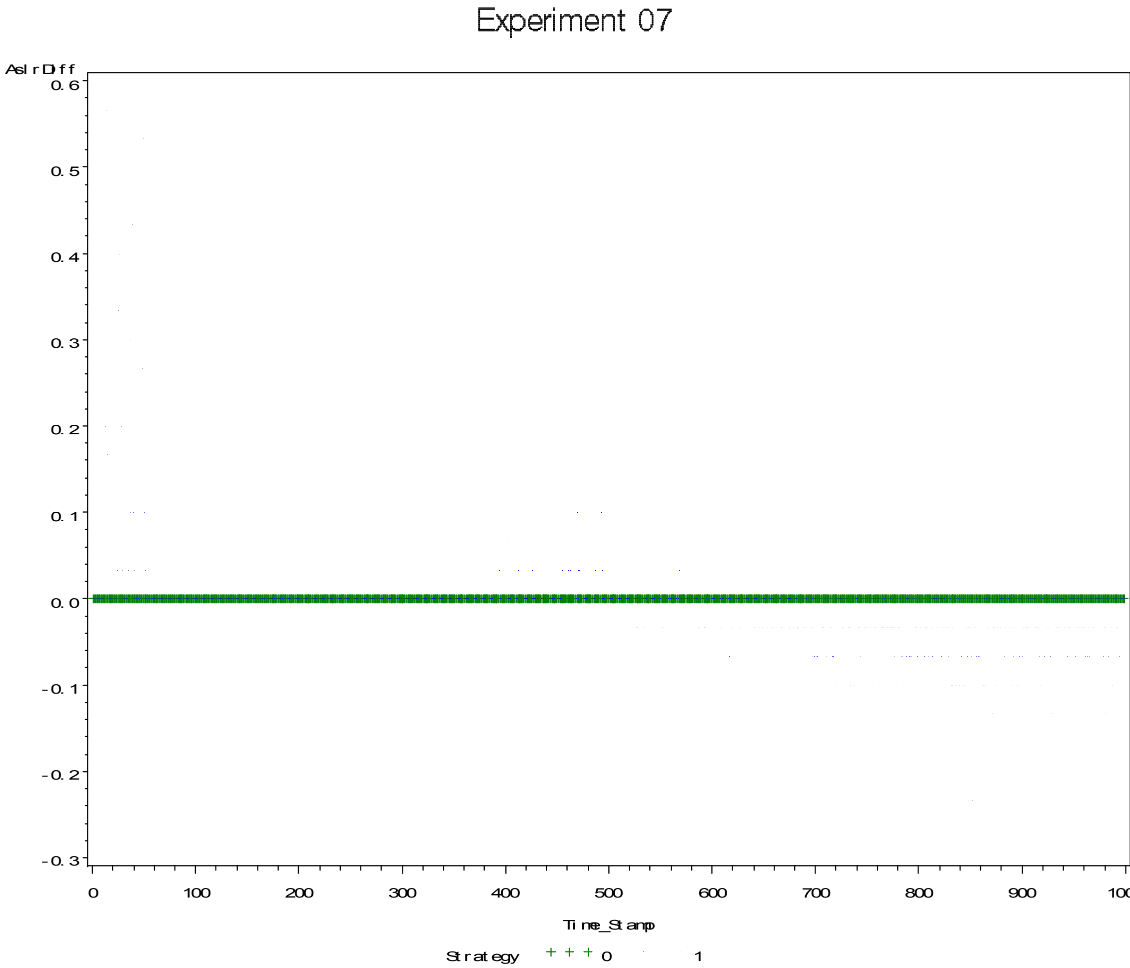

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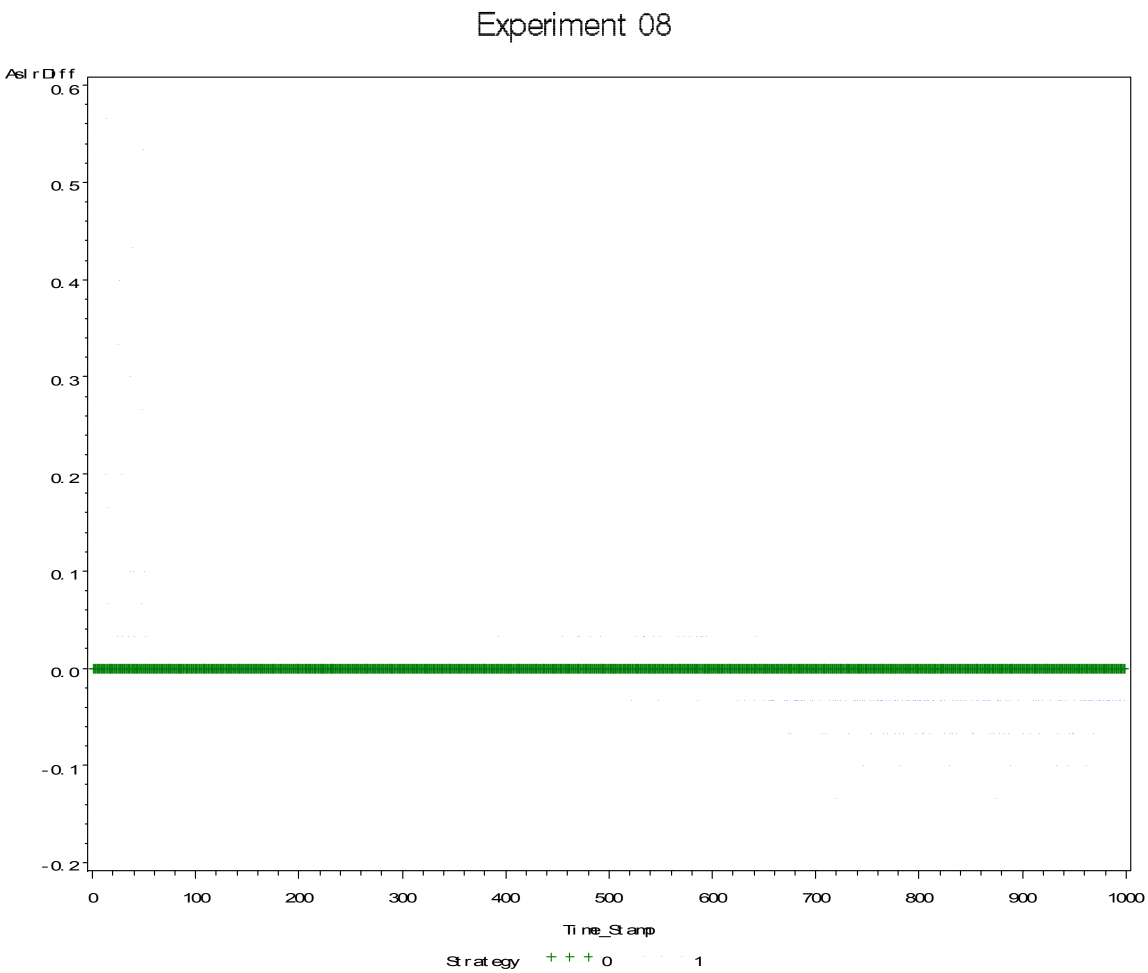

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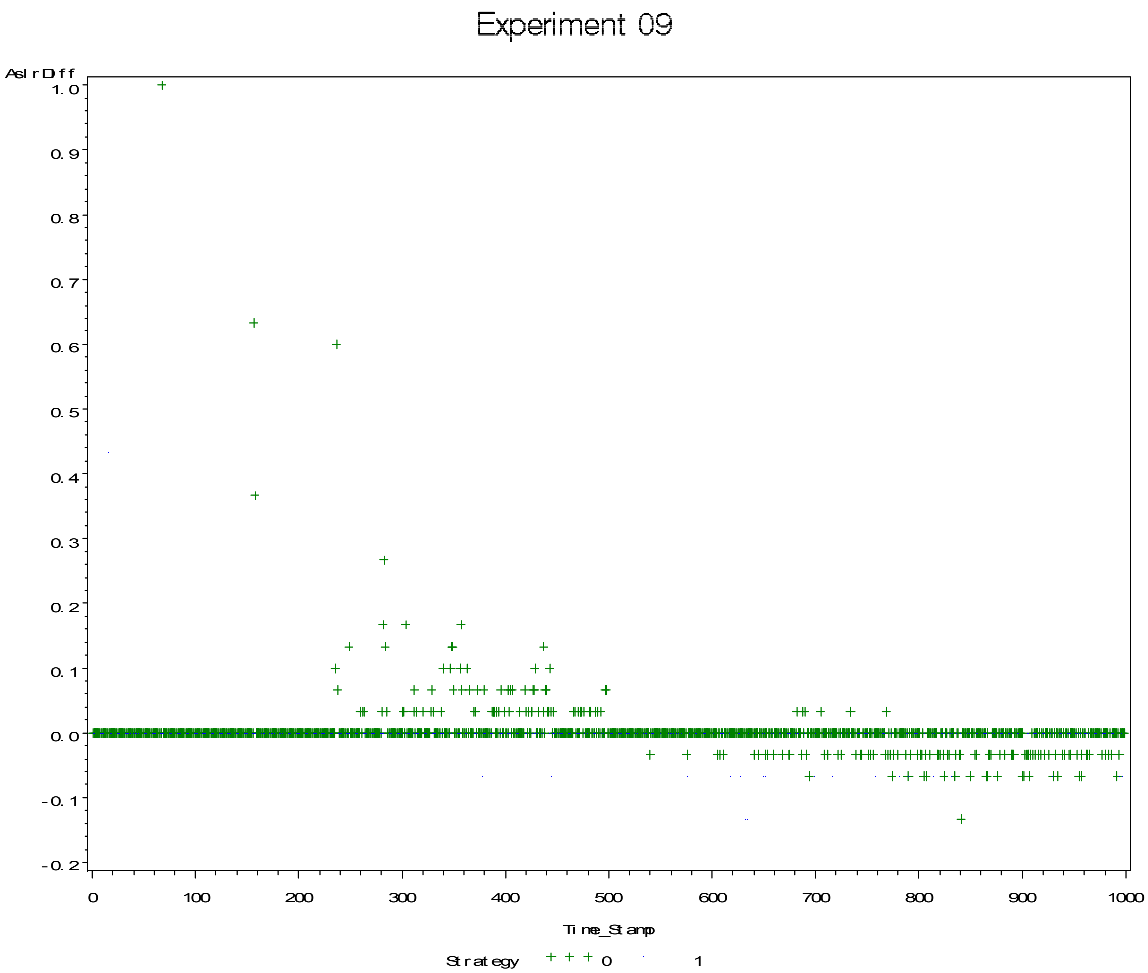

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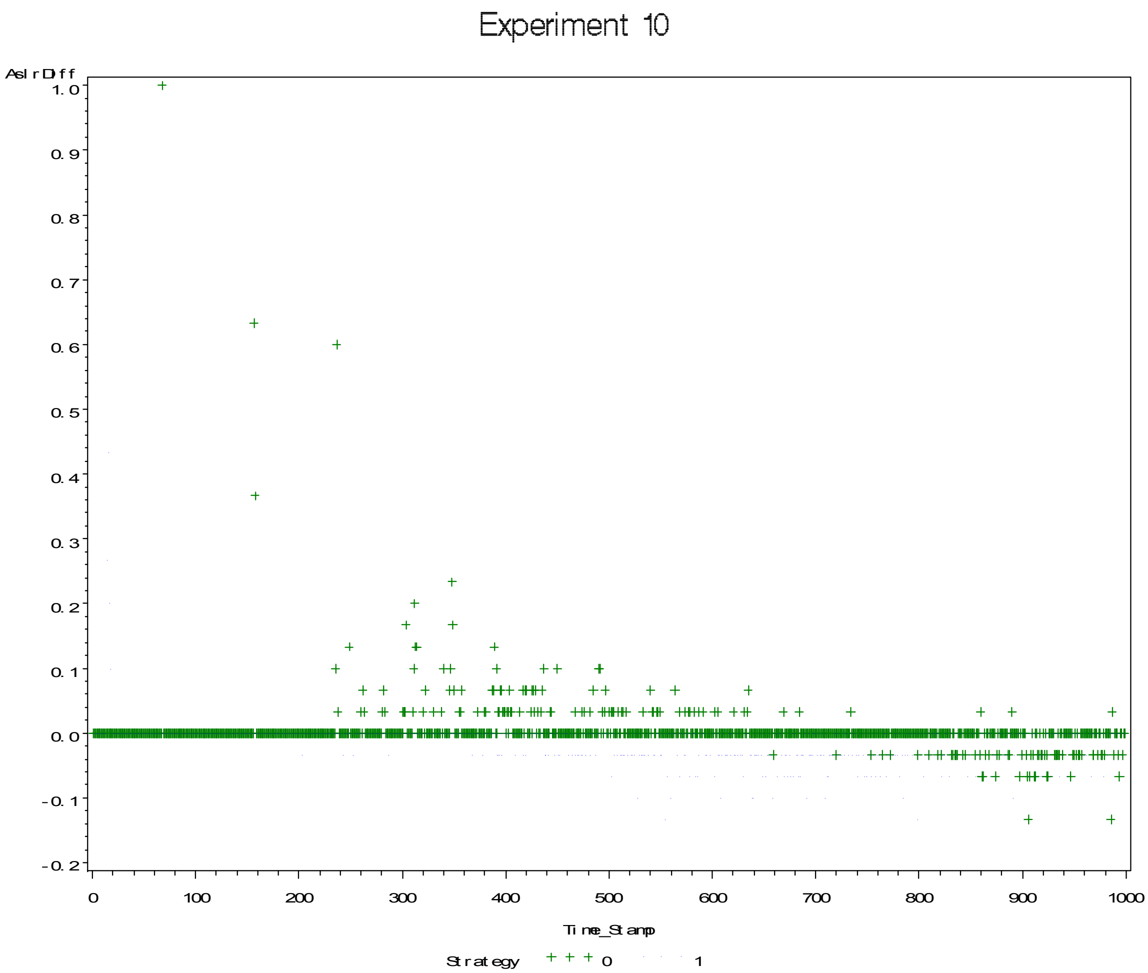

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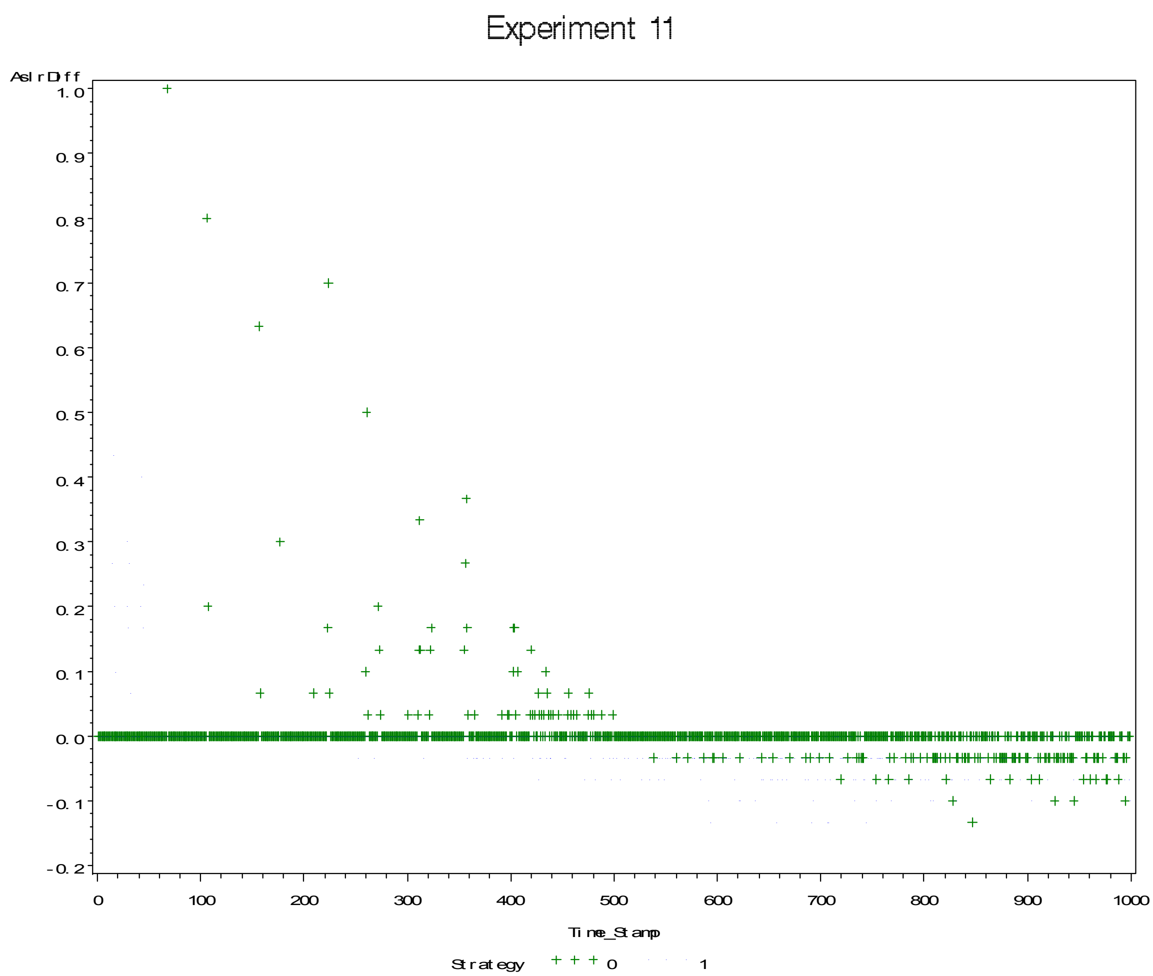

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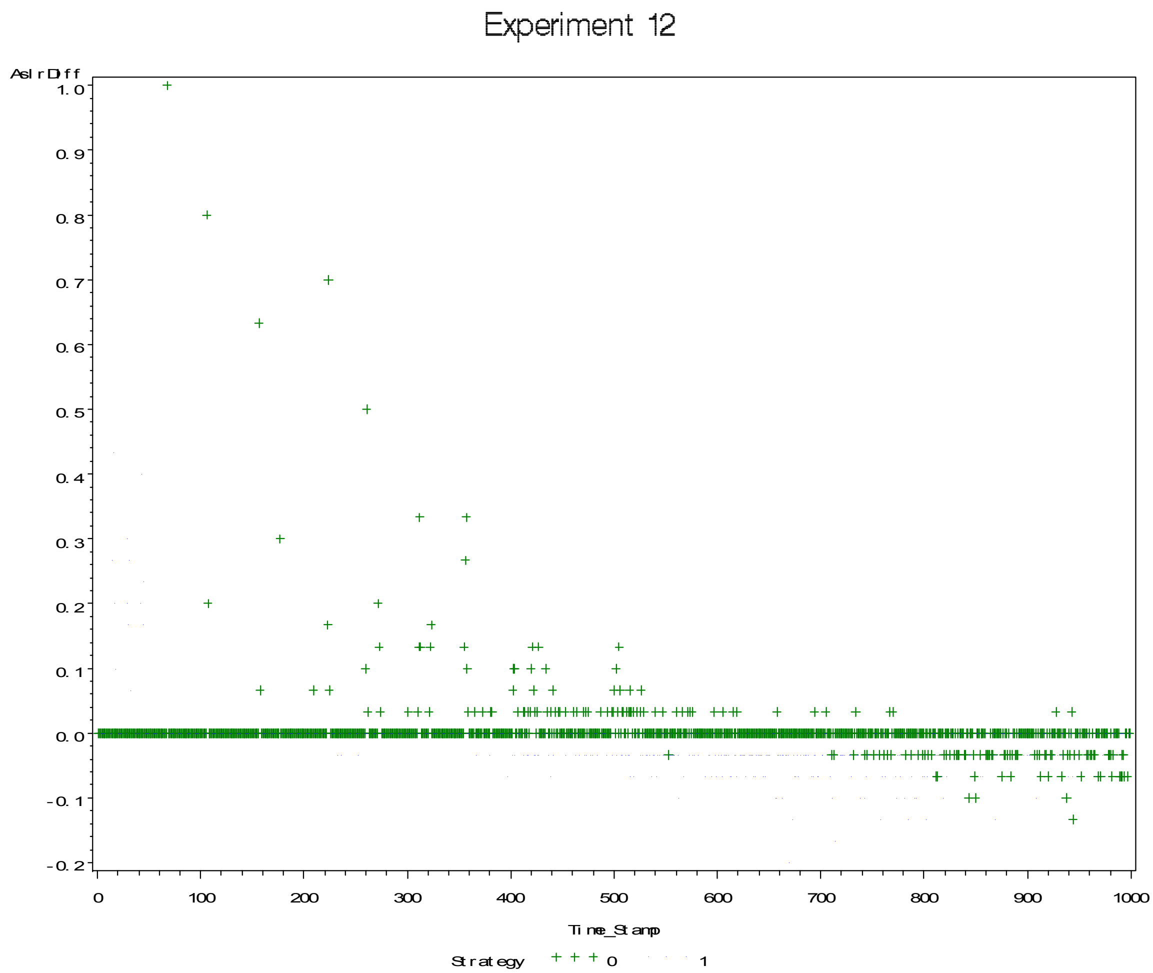
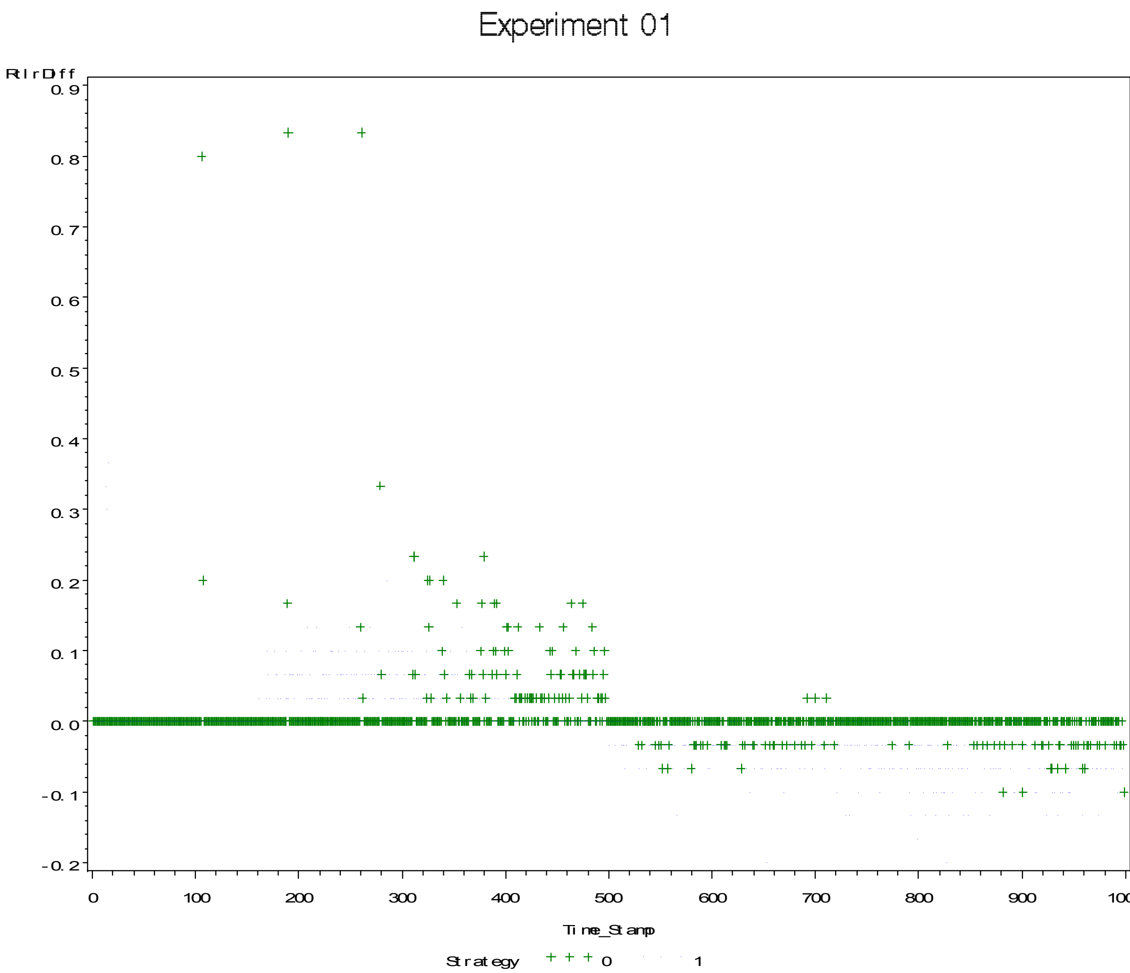


AVERAGE DIFFERENCING OF RETAILERS

Heterogeneous End Market, Fast Rate of Technological Advance, and Rapidly Growing Economies of Scale



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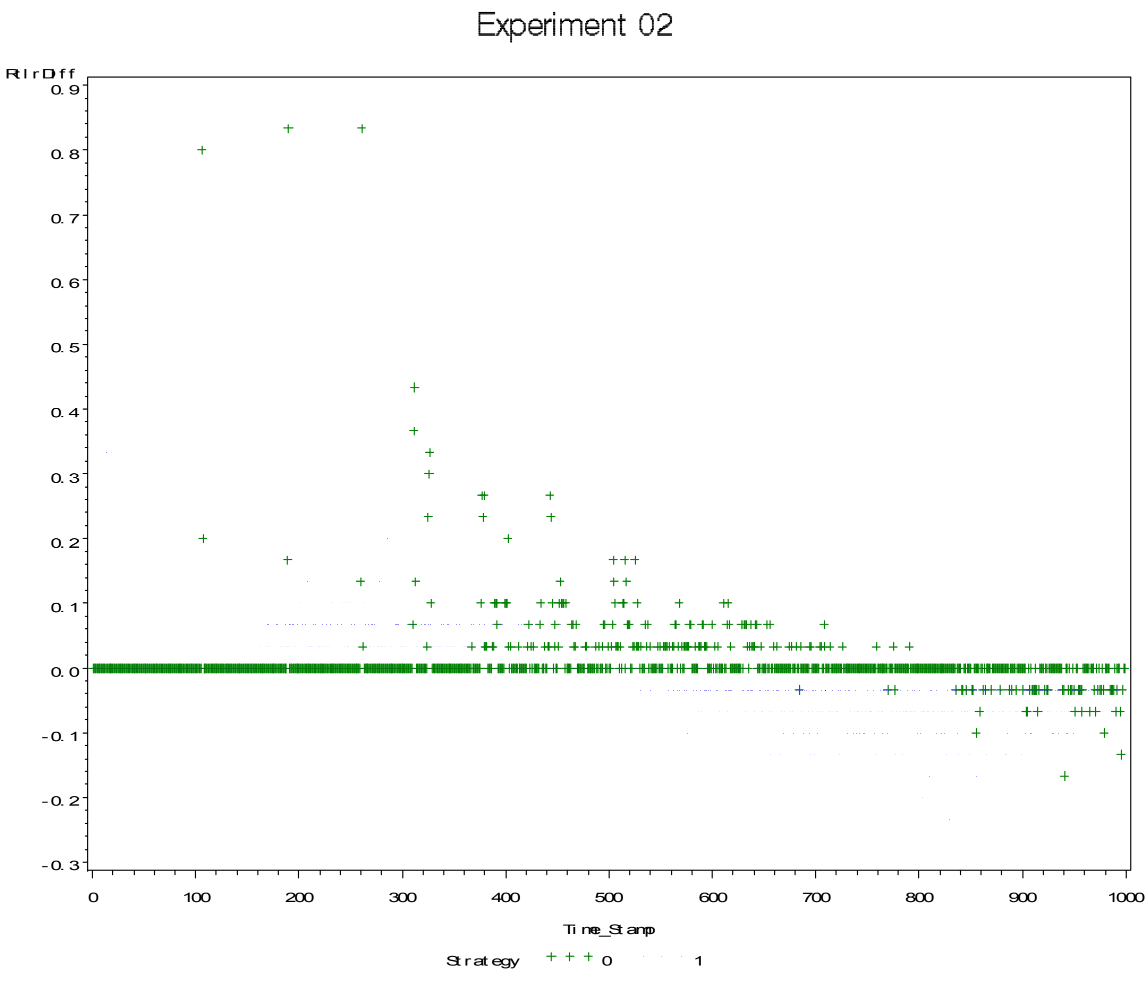

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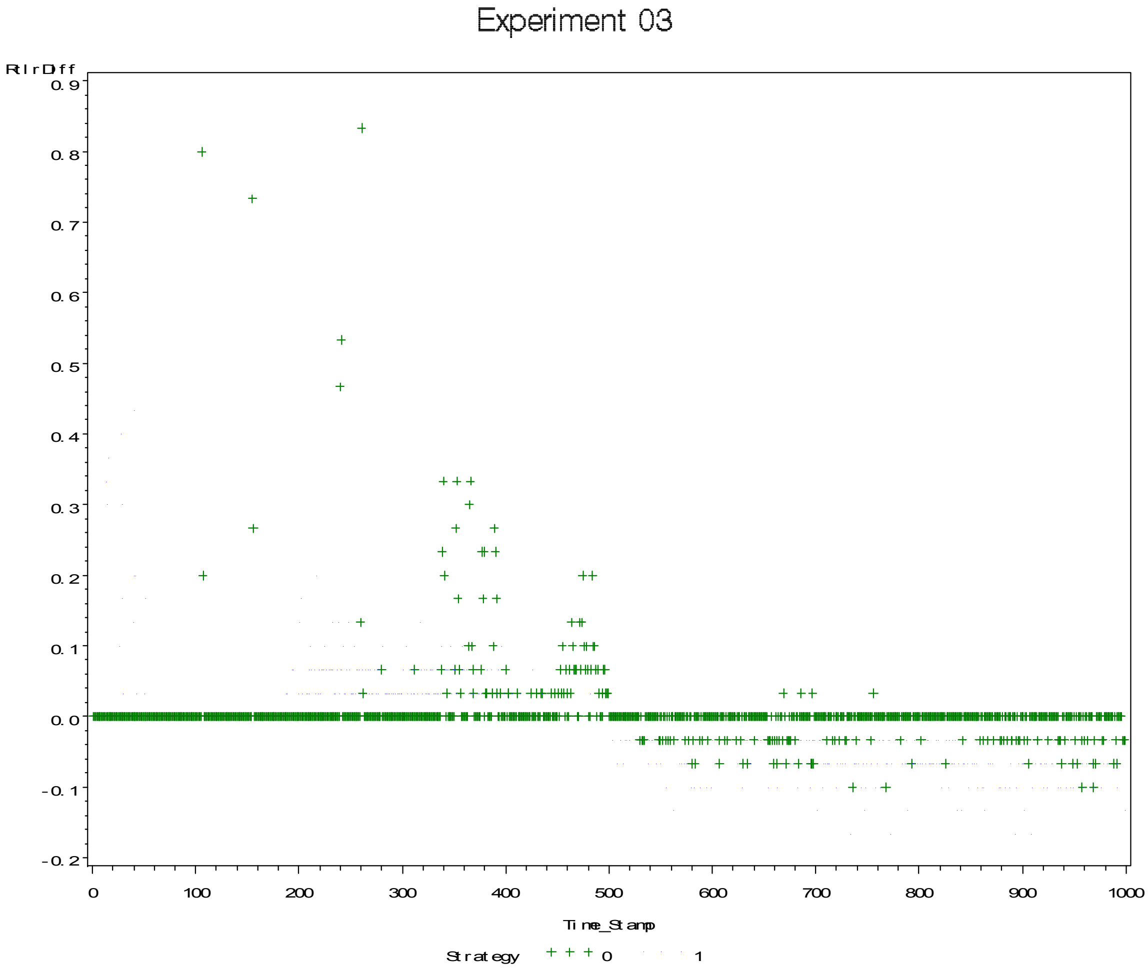

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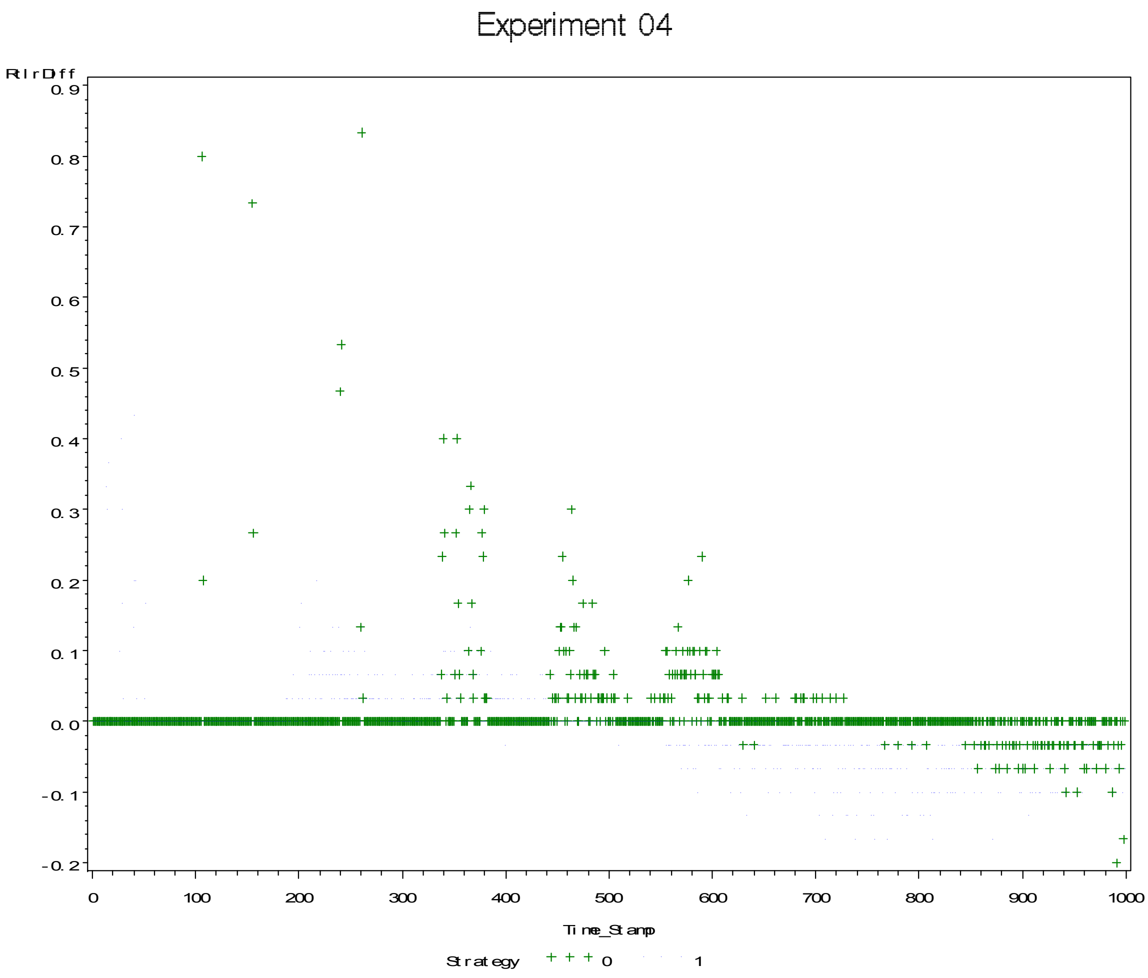

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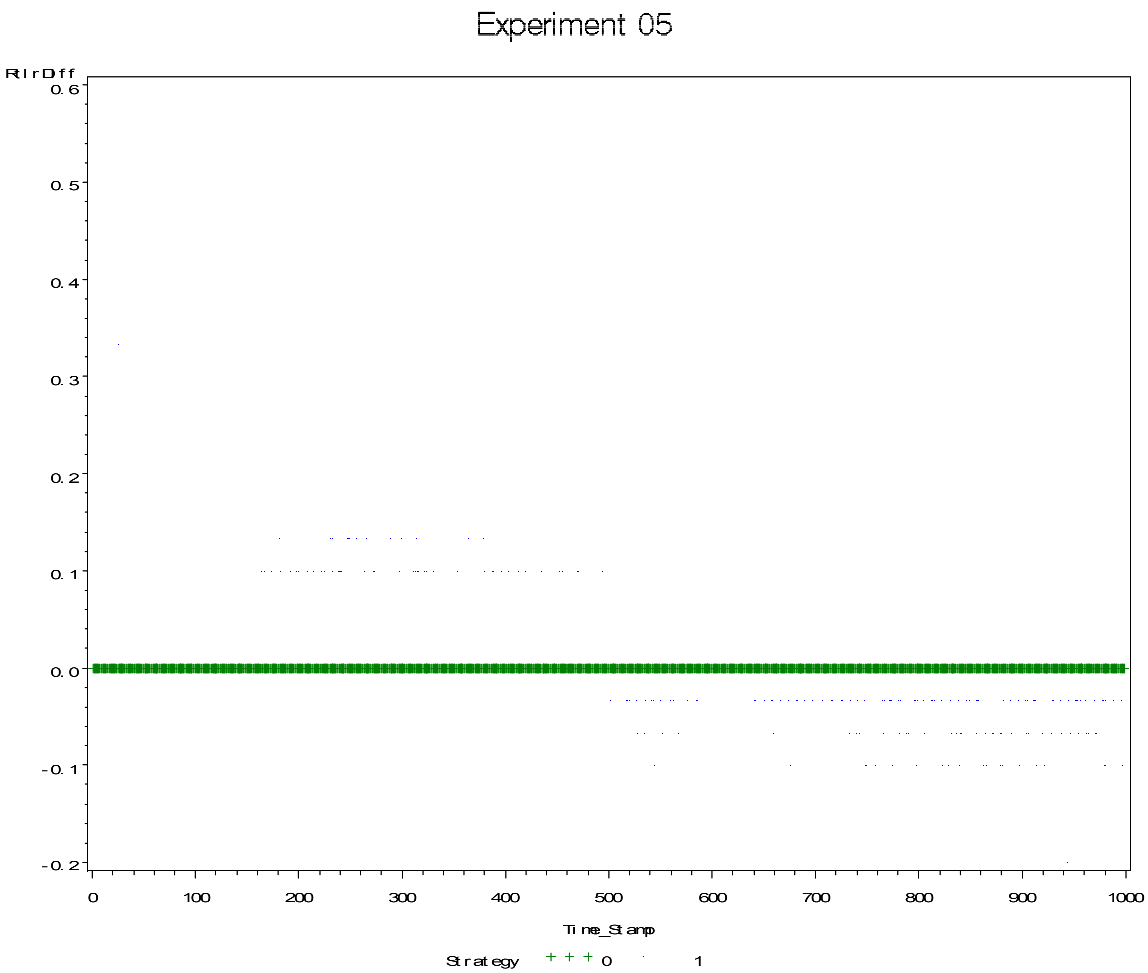

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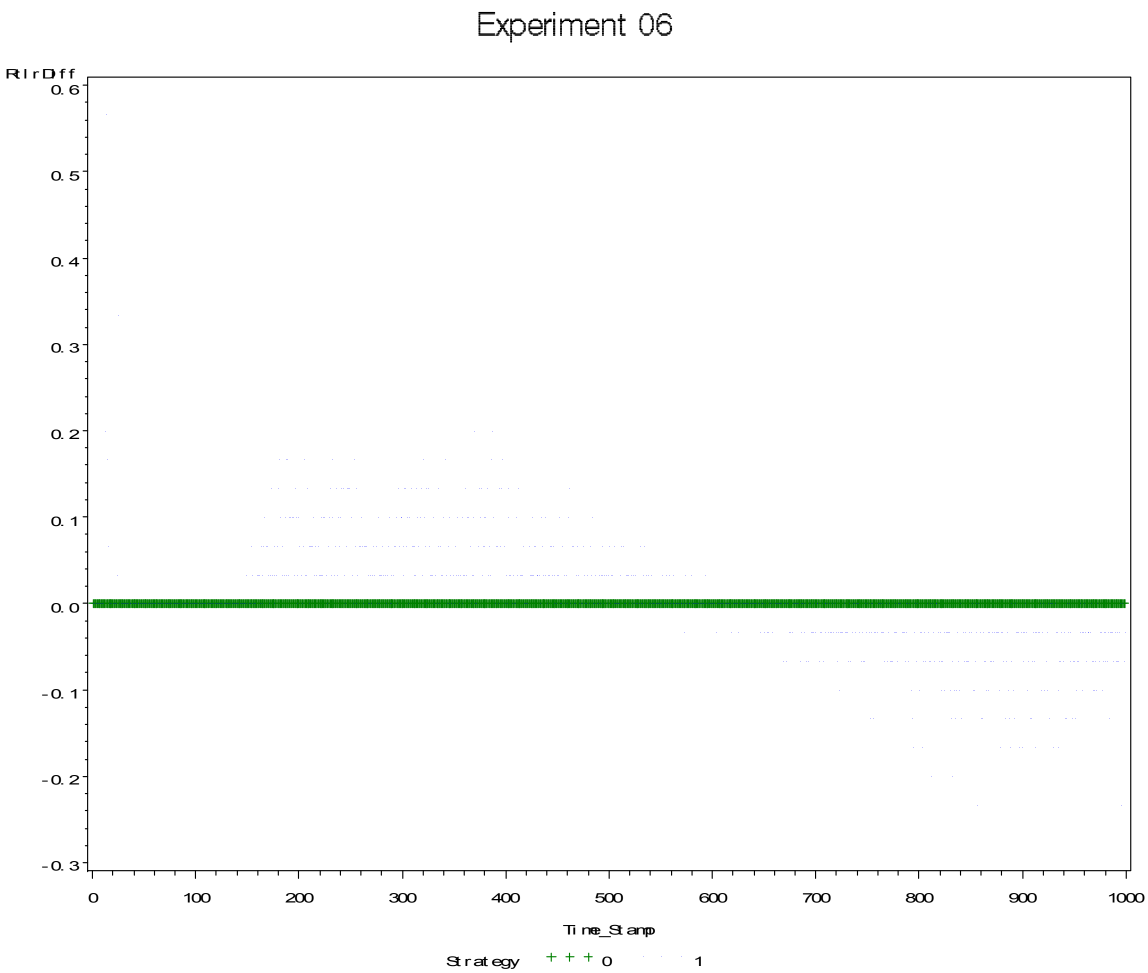

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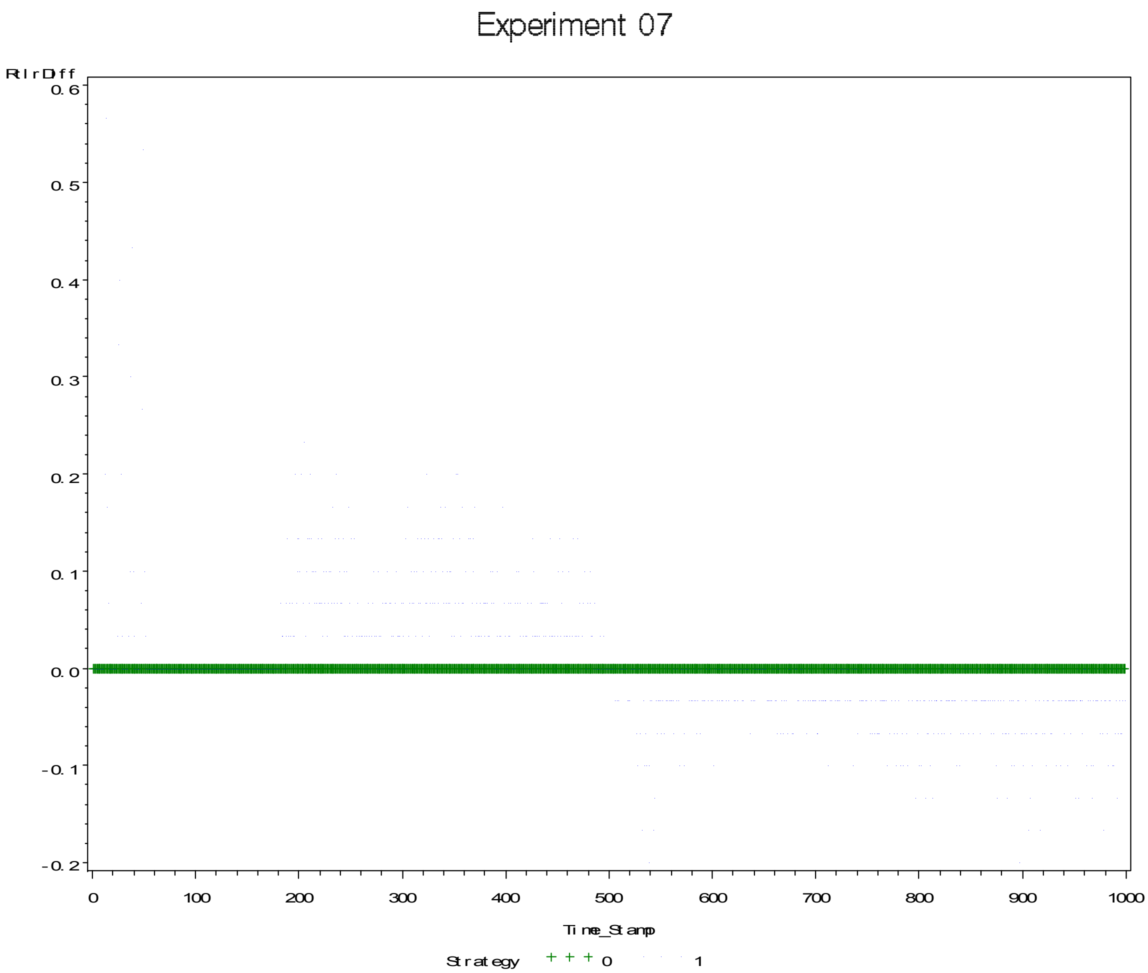

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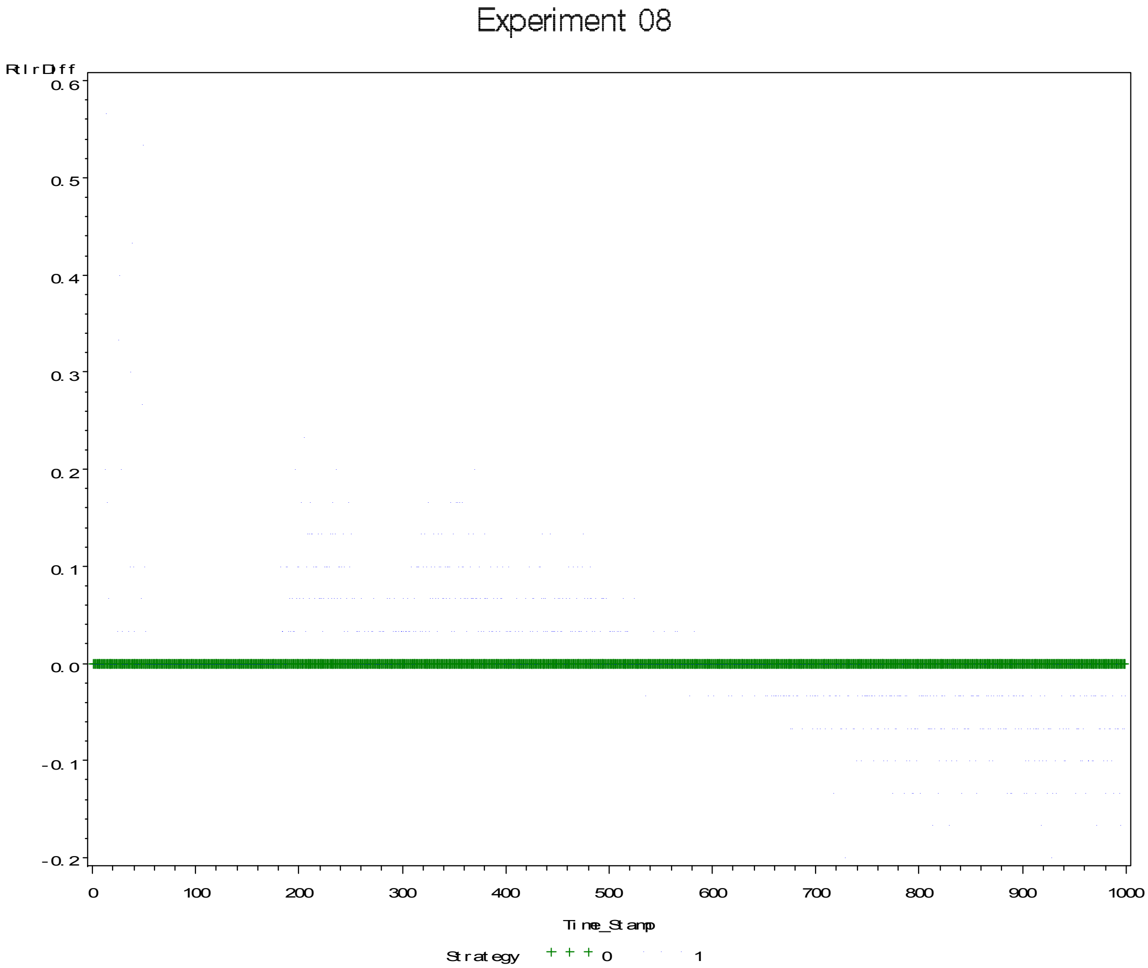

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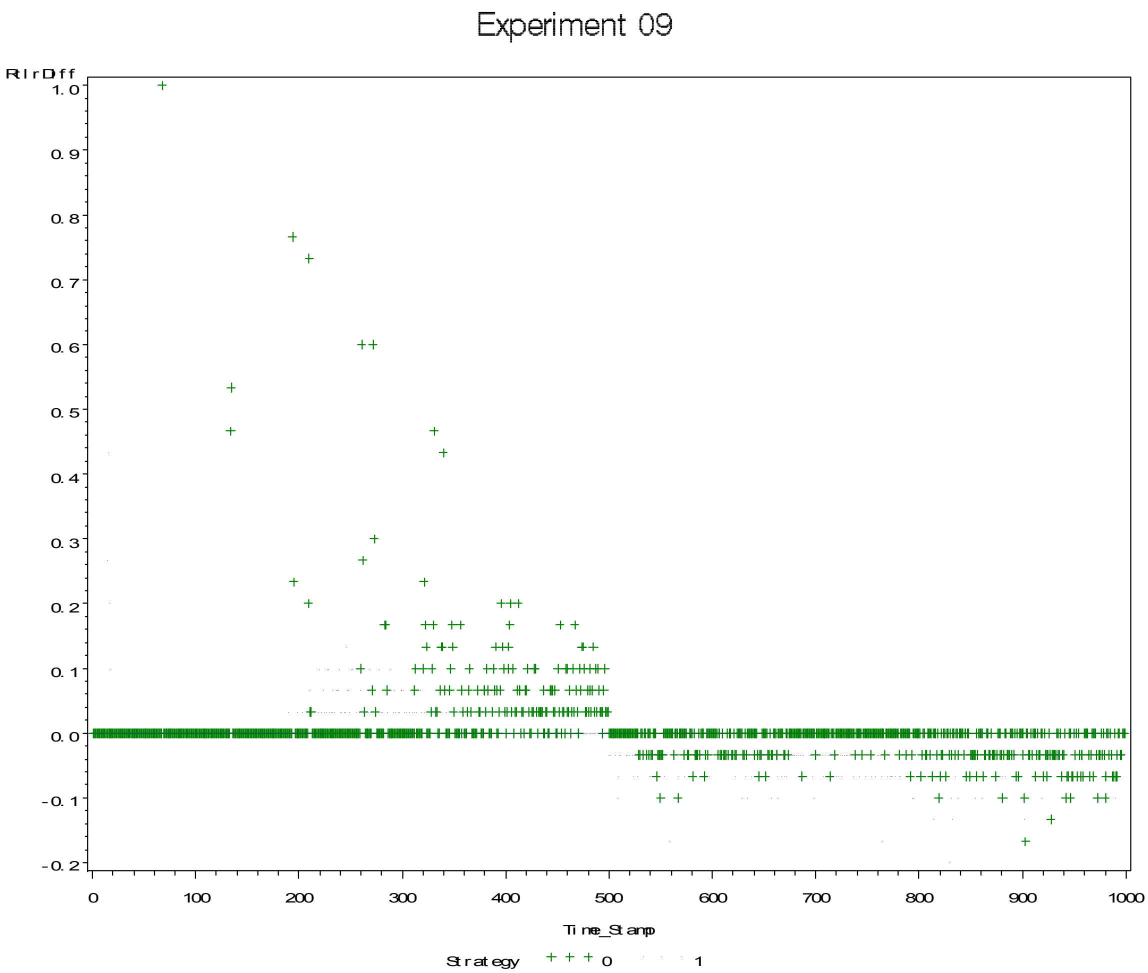

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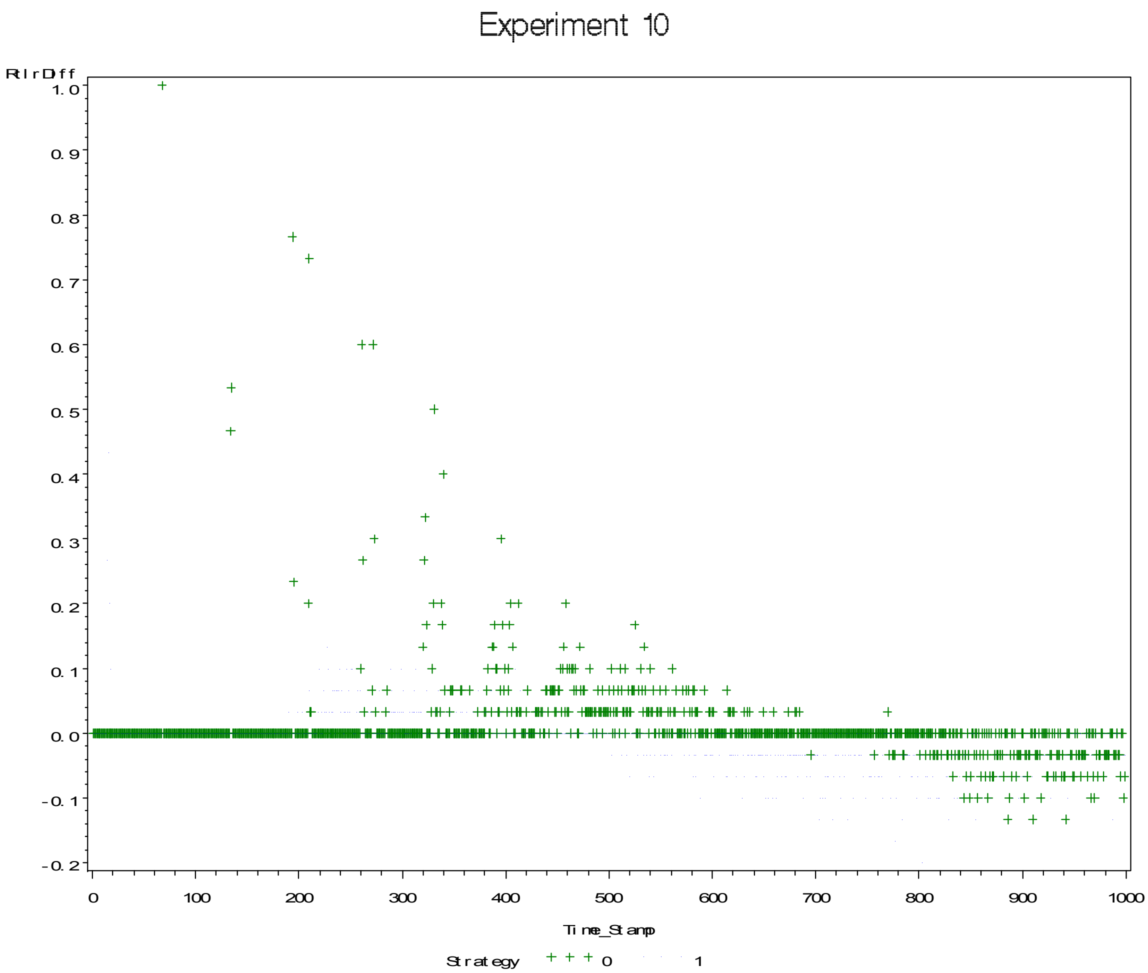

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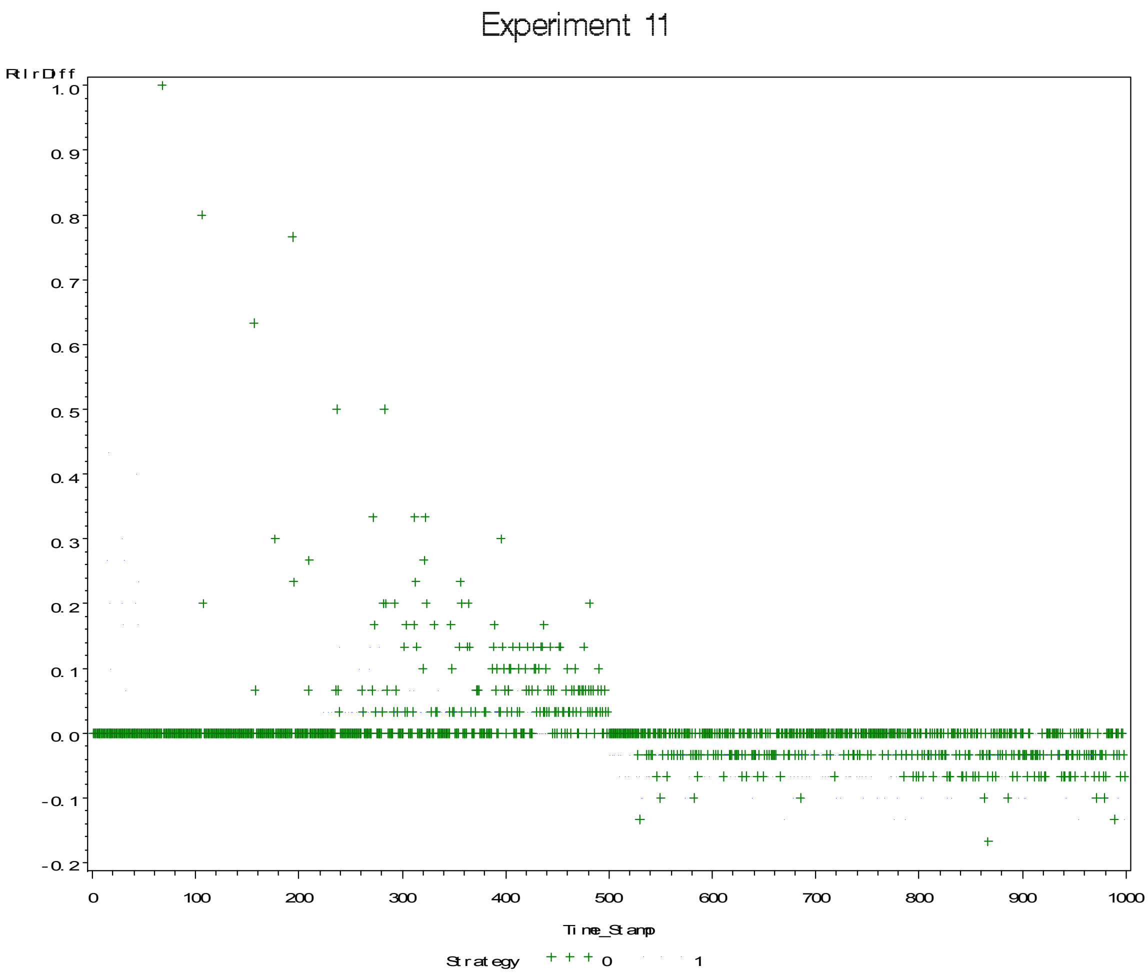

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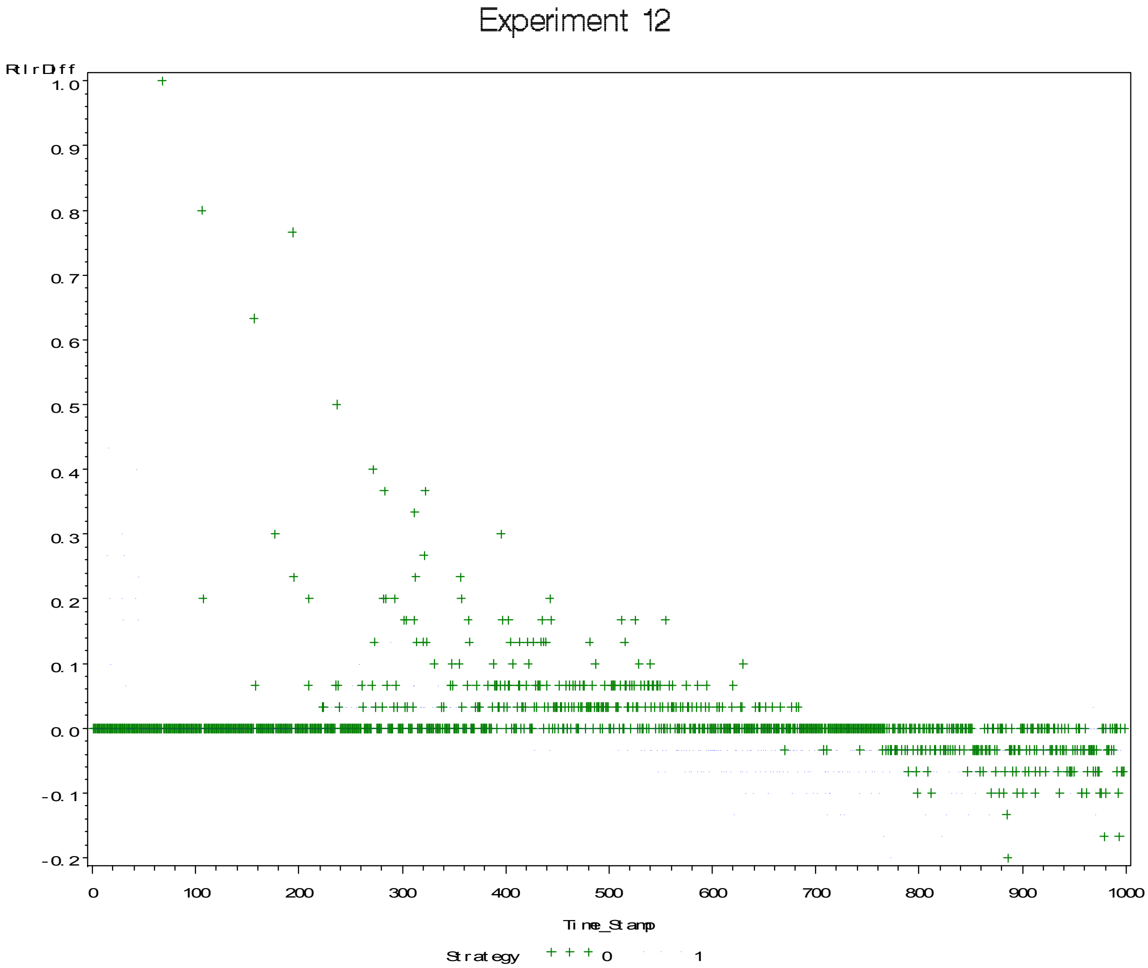

REFERENCES

Abel, T. (1998). Complex adaptive systems, evolutionism, and ecology within anthropology: Interdisciplinary research for understanding cultural and ecological dynamics. *Georgia Journal of Ecological Anthropology, 2*, 6-29.

Achrol, R. S. (1997). Changes in the theory of interorganizational relations in marketing: Toward a network paradigm. *Journal of the Academy of Marketing Science, 25*(1), 56-71.

Achrol, R. S., & Kotler, P. (1999). Marketing in the network economy. *Journal of Marketing, 63*(Special Issue), 146-163.

Adner, R. (2002). When are technologies disruptive? *Strategic Management Journal, 23*, 667-688.

Adner, R., James M., & Zemsky, P., William J. (2006a). A demand-based perspective on sustainable competitive advantagedynamic model of process and product innovation. *StrategicOMEGA, The International Journal of Management JournalScience, 273*(36), 215-239639-239656.

Adner, R., & Levinthal, D. (1996). Value-based business strategy. *Management Science, 5*(1), 5-24.

Adner, R., & Levinthal, D. (2001). Demand heterogeneity and technology evolution: Implications for product and process innovation. *Management Science, 47*(5), 611-628.

Adner, R., & Zemsky, P. (2006b). A demand-based perspective on sustainable competitive advantage. *Strategic Management Journal, 27*(3), 215-239.

Agresti, A. (1990). *Categorical data analysis*. New York: John Wiley and Sons.

Aitken, J., Childerhouse, P., Christopher, M., & Towill, D. (2005). Designing and managing multiple pipelines. *Journal of Business Logistics, 26*(2), 73-96.

Akkermans, H. (2001). *Emergent supply networks: System dynamics simulation of adaptive supply agents.* Paper presented at the 34th Hawaii International Conference on System Sciences, Hawaii.

Anderson, J. C., Håkansson, H., & Johanson, J. (1994). Dyadic business relationships within a business network context. *Journal of Marketing, 58*(4), 1-15.

Anderson, P. (1999). Complexity theory and organization science. *Organization Science, 10*(3), 216-232.

Antia, K. D., & Frazier, G. L. (2001). The severity of contract enforcement in interfirm channel relationships. *Journal of Marketing, 65*(4), 67-81.

Banks, J., II, J. S. C., & Nelson, B. L. (1999). *Discrete-event system simulation* (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall.

Barney, J. B. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*(1), 99-120.

Barney, J. B. (1992). Integrating organizational behavior and strategy formulation research: A resource-based view. *Working paper, Texas A&M University, College Station, TX.*

Bass, F. M., Krishnan, T. V., & Jain, D. C. (1994). Why the bass model fits without decision variables. *Marketing Science, 13*(3), 203-223.

Bello, D. C., & Lohtia, R. (1995). Export channel design: The use of foreign distributors and agents. *Journal of the Academy of Marketing Science, 23*(2), 83.

Berkowitz, L., & Donnerstein, E. (1982). External validity is more than skin deep: Some answers to criticism of laboratory experiments. *American Psychologist, 37*, 245-257.

Bettis, R. A., & Prahalad, C. K. (1995). The dominant logic: Retrospective extension. *Strategic management journal, 16*(1), 5-14.

Borgatti, S. P., & Foster, P. C. (2003). The network paradigm in organizational research: A review and typology. *Journal of Management, 29*(6), 991-1013.

Borrus, M. (1997). Left for dead: Asian production networks and the revival of us electronics: Berkeley Roundtable on the International Economy (BRIE).

Brandenburger, A. M., & Stuart Jr., H. W. (1996). Value-based business strategy. *Journal of Economics & Management Strategy, 5*(1), 5-24.

Browning, L. D., Beyer, J. M., & Shetler, J. C. (1995). Building cooperation in a competitive industry: Sematech and the semiconductor industry. *The Academy of Management Journal, 38*(1), 113-151.

Bureau, U. S. C. (2005). Survey of plant capacity: 2005. In E. a. S. Administration (Ed.): U.S. Government Printing Office.

Chandy, R. K., & Tellis, G. J. (1998). Organizing for radical product innovation: The overlooked role of willingness to cannibalize. *Journal of Marketing Research, 35*(4), 474-487.

Chandy, R. K., & Tellis, G. J. (2000). The incumbent's curse? Incumbency, size, and radical product innovation. *Journal of Marketing, 64*(3), 1-17.

Chesbrough, H. W., & Teece, D. J. (1996). When is virtual virtuous? Organizing for innovation. *Harvard Business Review, 74*(1), 65-73.

Chiva-Gomez, R. (2003). The facilitating factors for organizational learning: Bringing ideas from complex adaptive systems. *Knowledge and Process Management, 10*(2), 99-114.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. *Journal of Operations Management, 19*, 351-366.

Christopher, M. G. (1992). *Logistics and supply chain management: Strategies for reducing costs and improving services*. London: Pitman.

Coase, R. H. (1937). The nature of the firm. *Economica, 4*(16), 386-405.

David, R. J., & Han, S.-K. (2004). A systematic assessment of the empirical support for transaction cost economics. *Strategic Management Journal, 25*, 39-58.

Davis, J. P., Bingham, C. B., & Eisenhardt, K. M. (2007). Developing theory through simulation methods. *Academy of Management Review, 32*(2), 480-499.

Day, G. S. (2000). Managing market relationships. *Journal of the Academy of Marketing Science, 28*(1), 24-30.

Desarbo, W. S., Grewal, R., & Wind, J. (2006). Who competes with whom? Perspectives for identifying and representing asymmetric competition. *Strategic Management Journal, 27*(2), 101-129.

Dooley, K. J. (1997). A complex adaptive systems model of organization change. *Nonlinear Dynamics, Psychology, and Life Sciences, 1*(1), 69-97.

Dutta, S., Heide, J. B., & Bergen, M. (1999). Vertical territorial restrictions and public policy: Theories and industry evidence. *Journal of Marketing, 63*(4), 121-134.

Dwyer, F. R., Schurr, P. H., & Oh, S. (1987). Developing buyer-seller relationships. *Journal of Marketing, 51*(April), 11-27.

Dyer, J. H. (1996). Does governance matter? *Keiretsu* alliances and asset specificity as sources of japanese competitive advantage. *Organization Science, 7*(6), 649-666.

Dyer, J. H. (1997). Effective interfirm collaboration: How firms minimize transaction costs and maximize transaction value. *Strategic Management Journal, 18*(7), 535-556.

Dyer, J. H., & Hatch, N. W. (2006). Relation-specific capabilities and barriers to knowledge transfers: Creating advantage through network relationships. *Strategic Management Journal, 27*, 701-719.

Dyer, J. H., & Nobeoka, K. (2000). Creating and managing a high-performance knowledge-sharing network: The toyota case. *Strategic Management Journal, 21*(3), 345-367.

Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review, 23*(4), 660-679.

Economic Census. (1992). Semiconductor and related device manufacturing. In U. S. C. Bureau (Ed.).

Economic Census. (1997). Semiconductor and related device manufacturing. In U. S. C. Bureau (Ed.).

Economic Census. (2002). Economic census: Semiconductor and related device manufacturing. In U. S. C. Bureau (Ed.).

Eisenhardt, K., & Tabrizi, B. N. (1995). Accelerating adaptive processes: Product innovation in the global computer industry. *Administrative Science Quarterly, 40*(1).

Eisenhardt, K. M., & Brown, S. L. (1998). *Competing on the edge: Strategy as structured chaos*: Harvard Business School Press.

Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: What are they? *Strategic Management Journal, 21*(10/11), 1105.

Eisenhardt, K. M., & Schoonhoven, C. B. (1996). Resource-based view of strategic alliance formation: Strategic and social effects in entrepreneurial firms. *Organization Science, 7*(2), 136-150.

El-Ansary, A. I., & Stern, L. W. (1972). Power measurement in the distribution channel. *Journal of Marketing Research, 9*(1), 47-52.

Ernst, D. (1997). *From partial to systemic globalization: International production networks in the electronics industry* (No. BRIE Working Paper #98): University of California at Berkeley.

Farmer, D. (1997). Purchasing myopia--revisited. *European Journal of Purchasing and Supply Chain Management, 3*(1), 1-8.

Ferguson, R., J., Paulin, M., & Bergeron, J. (2005). Contractual governance, relational governance, and the performance of interfirm service exchanges: The influence of boundary-spanner closeness. *Journal of the Academy of Marketing Science, 33*(2), 217-234.

Fernie, J., & Arnold, S. J. (2002). Wal-mart in europe: Prospects for germany, the uk and france. *International Journal of Retail & Distribution Management, 30*(2), 92–102.

Fine, C. H. (1998). *Clockspeed*. Reading, Massachusetts: Perseus Books.

Fokianos, K., & Kedem, B. (2003). Regression theory for categorical time series. *Statistical Science, 18*(3), 357-376.

Foote, P. S. (2001). Forecasting using data warehousing model: Wal-mart's experience. *The Journal of Business Forecasting Methods & Systems, 20*(3), 13-17.

Fornell, C. (1992). A national customer satisfaction barometer: The swedish experience. *Journal of Marketing, 56*(1), 6-21.

Forrester, J. W. (1958). Industrial dynamics: A major breakthrough for decision makers. *Harvard Business Review*, 37-66.

Forrester, J. W. (1961). *Industrial dynamics*: MIT Press.

Fromkin, H. L., & Steufert, S. (1976). Laboratory experimentation. In M. D. Dunnette (Ed.), *Handbook of industrial and organizational psychology* (pp. 415-465). Chicago: Rand McNally.

Fuller, J. B., O'Conor, J., & Rawlinson, R. (1993). Tailored logistics: The next advantage. *Harvard Business Review*, 87-98.

Gharajedaghi, J. (1999). *Systems thinking: Managing chaos and complexity*. Boston: Butterworth-Heinemann.

Goldstone, R. L., & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46*(4), 414-466.

Golicic, S. L., Foggin, J. H., & Mentzer, J. T. (2003). Relationship magnitude and its role in interorganizational relationship structure. *Journal of Business Logistics, 24*(1), 57-75.

Goodall, R., Fandel, D., Allan, A., Landler, P., & Huff, H. R. (2002). Long term productivity mechanisms of the semiconductor industry. *ECS PV, 2*, 125–143.

Granger, C. W. J., & Newbold, P. (1977). *Forecasting economic time series*. New York: Academic Press.

Granovetter, M. (1985). Economic action and social structure: The problem of embeddedness. *American Journal of Sociology, 91*(3), 481-510.

Grewal, R., & Dharwadkar, R. (2002). The role of the institutional environment in marketing channels. *Journal of Marketing, 66*(3), 82-97.

Gulati, R. (1998). Alliances and networks. *Strategic Management Journal, 19*(4), 293-317.

Han, J. K., Kim, N., & Srivastava, R. K. (1998). Market orientation and organizational performance: Is innovation a missing link? *Journal of Marketing, 62*, 30-45.

Harland, C., Zheng, J., Johnsen, T., & Lamming, R. (2004). A conceptual model for researching the creation and operation of supply networks. *British Journal of Management, 15*, 1-21.

Harrell, F. E. (2001). *Regression modeling strategies: With applications to linear models, logistic regression, and survival analysis*. New York: Springer-Verlag.

Heide, J. B. (1994). Interorganizational governance in marketing channels. *Journal of Marketing, 58*(1), 71-85.

Heide, J. B., & John, G. (1988). The role of dependence balancing in safeguarding transaction-specific assets in conventional channels. *Journal of Marketing, 52*(1), 20-35.

Heide, J. B., & John, G. (1990). Alliances in industrial purchasing: The determinants of joint action in buyer-supplier relationships. *Journal of Marketing Research, 27*(1), 24-36.

Heide, J. B., & John, G. (1992). Do norms matter in marketing relationships? *Journal of Marketing, 56*(2), 32-44.

Hobbs, J. E. (1996). A transaction cost approach to supply chain management. *Supply Chain Management, 1*(2), 15-27.

Holland, J. H. (1995). Hidden order: How adaption builds complexity. *Reading: Addison-Wesley*.

Holland, J. H., & Miller, J. H. (1991). Artificial adaptive agents in economic theory. *The American Economic Review, 81*(2), 365-370.

Hosmer, D. W., & Lemeshow, S. (1999). *Applied survival analysis: Regression modeling of time to event data*. New York: John Wiley and Sons, Inc.

Houlihan, J. B. (1987). International supply chain management. *International Journal of Physical Distribution & Materials Management, 17*(2), 51-66.

Hult, G. T. M., Ketchen, D. J., & Slater, S. F. (2004). Information processing, knowledge development, and strategic supply chain performance. *Academy of Management Journal, 47*(2), 241-253.

Hunt, S. D. (1992). Marketing is. *Journal of the Academy of Marketing Science, 20*(4), 301-311.

Hunt, S. D. (2000). *A general theory of competition*. Thousand Oaks, California: Sage Publications.

Hunt, S. D., & Morgan, R. M. (1995). The comparative advantage theory of competition. *Journal of Marketing, 59*(2), 1-15.

Hunt, S. D., & Nevin, J. R. (1974). Power in a channel of distribution: Sources and consequences. *Journal of Marketing Research, 11*(2), 186-193.

Ilachinski, A. (2000). Irreducible semi-autonomous adaptive combat (isaac): An artificial-life approach to land combat. *Military Operations Research, 5*(3), 29–46.

Ilgen, D. R. (1986). Laboratory research: A question of when, not if. In E. A. Locke (Ed.), *Generalizing from laboratory of field settings* (pp. 3-9). Lexington: Lexington Books.

Inkpen, A. C., & Tsang, E. W. K. (2005). Social capital, networks, and knowledge transfer. *Academy of Management Review, 30*(1), 146-165.

Innis, D. E., & La Londe, B. J. (1994). Customer service: The key to customer satisfaction, customer loyalty, and market share. *Journal of Business Logistics, 70*(4), 1-28.

Intel Corporation. (2005). Microprocessor hall of fame. Retrieved September 17, 2005, from http://www.intel.com/museum/online/hist_micro/hof/index.htm

Ishimatsu, H., Sugasawa, Y., & Sakurai, K. (2004). Understanding innovation as a complex adaptive system: Case studies from shimadzu and nec. *Pacific Economic Review, 9*(4), 371-376.

Jap, S. D. (1999). Pie-expansion efforts: Collaboration processes in buyer-seller relationships. *Journal of Marketing Research, 36*(3), 461-475.

Jarillo, J. C. (1988). On strategic networks. *Strategic Management Journal, 9*(1), 31-41.

Jaworski, B. J., & Kohli, A. K. (1993). Market orientation: Antecedents and consequences. *Journal of Marketing, 57*.

Johnson, J. L., Lee, R. P.-W., Saini, A., & Grohmann, B. (2003). Market-focused strategic flexibility: Conceptual advances and an integrative model. *Journal of the Academy of Marketing Science, 31*(1), 74-89.

Johnson, M. D., & Selnes, F. (2004). Customer portfolio management: Toward a dynamic theory of exchange relationships. *Journal of Marketing, 68*(2), 1-17.

Jones, C., Hesterly, W. S., & Borgatti, S. P. (1997). A general theory of network governance: Exchange conditions and social mechanisms. *Academy of Management Review, 22*(4), 911-945.

Joshi, A. W., & Campbell, A. J. (2003). Effect of environmental dynamism on relational governance in manufacturer-supplier relationships: A contingency framework and an empirical test. *Journal of the Academy of Marketing Science, 31*(2), 176-188.

Kahn, B. E. (1998). Dynamic relationships with customers: High-variety strategies. *Journal of the Academy of Marketing Science, 26*(1), 45-53.

Kauffman, S. A. (1990). Requirements for evolvability in complex systems: Orderly dynamics and frozen components. In W. H. Zurek (Ed.), *Complexity, entropy and the physics of information* (pp. 151-192). Redwood City, CA: Addison-Wesley Publishing Company.

Kaufman, A., Wood, C. H., & Theyel, G. (2000). Collaboration and technology linkages: A strategic supplier typology. *Strategic Management Journal, 21*(6), 649-663.

Kim, D., Cavusgil, S. T., & Calantone, R. J. (2006). Information system innovations and supply chain management: Channel relationships and firm performance. *Journal of the Academy of Marketing Science, 34*(1), 40-54.

Kim, K. (2001). On the effects of customer conditions on distributor commitment and supplier commitment in industrial channels of distribution. *Journal of Business Research, 51*, 87-99.

Kim, S. W. (2003). *An investigation of information technology investments on buyer-supplier relationship and supply chain dynamics.* Michigan State University, East Lansing, Michigan.

Kirby, S. (2000). Syntax without natural selection: How compositionality emerges from vocabulary in a population of learners. *The evolutionary emergence of language: Social function and the origins of linguistic form*, 185–215.

Kirca, A. H., Jayachandran, S., & Bearden, W. O. (2005). Market orientation: A meta-analytic review and assessment of its antecedents and impact on performance. *Journal of Marketing, 69*, 24-41.

Klein, S., Frazier, G. L., & Roth, V. J. (1990). A transaction cost analysis model of channel integration in international markets. *Journal of Marketing Research, 27*, 196-208.

Kotler, P. (1972). A generic concept of marketing. *Journal of Marketing, 36*, 46-54.

Kotler, P., & Levy, S. J. (1969). Broadening the concept of marketing. *Journal of Marketing, 33*, 10-15.

Langley, C. J., Jr., & Holcomb, M. C. (1992). Creating logistics customer value. *Journal of Business Logistics, 13*(2), 1.

Langlois, R. N. (2002). Modularity in technology and organization. *Journal of Economic Behavior and Organization, 49*(1), 19-37.

Langlois, R. N., & Steinmueller, W. E. (2000). Strategy and circumstance: The response of american firms to japanese competition in semiconductors, 1980-1995. *Strategic Management Journal, 21*, 1163-1173.

Law, A. M., & Kelton, W. D. (2000). *Simulation modeling and analysis* (3rd ed.): McGraw-Hill Higher Education.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997a). The bullwhip effect in supply chains. *Sloan Management Review, 38*(3), 93-102.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997b). Information distortion in a supply chain: The bullwhip effect. *Management Science, 43*(4), 546-558.

Leiblein, M. J. (2003). The choice of organizational governance form and performance: Predictions from transaction cost, resource-based, and real options theories. *Journal of Management, 29*(6), 937-961.

Levitt, R. E., Thomsen, J., Christiansen, T. R., Kunz, J. C., Jin, Y., & Nass, C. (1999). Simulating project work processes and organizations: Toward a micro-contingency theory of organizational design. *Management Science, 45*(11), 1479-1495.

Lewis, B., Middleton, P., & Donovan, J. (2006). *Semiconductor consolidation continues with lsi/agere merger* (No. G00145251): Gartner, Inc.

Limburg, K. E., O'Neill, R. V., Costanza, R., & Farber, S. (2002). Complex systems and valuation. *Ecological Economics, 41*(3), 409-420.

Limburg, K. E., & Wichmann, K. E. (2003). Complex systems and valuation. *Ecological Economics*.

Lin, F.-r., Huang, S.-h., & Lin, S.-c. (2002). Effects of information sharing on supply chain performance in electronic commerce. *IEEE Transactions on Engineering Management, 49*(3), 258- 268.

Liu, Y. (2001). *A strategic study of technological innovations in the fiber optical communications industry.* Massachusetts Institute of Technology.

Lloyd, S., & Slotine, J. J. E. (1996). Information theoretic tools for stable adaptation and learning. *International journal of adaptive control and signal processing, 10*, 499-530.

Lusch, R. F., & Vargo, S. L. (2006). *The service dominant logic of marketing*. Armonk, New York: M.E. Sharpe.

Macher, J. T. (2006). Technological development and the boundaries of the firm: A knowledge-based examination in semiconductor manufacturing. *Management Science, 52*(6), 826-843.

Macher, J. T., Mowery, D. C., & Hodges, D. A. (1998). Reversal of fortune? The recovery of the u.S. Semiconductor industry. *California Management Review, 41*(1), 107-136.

MacNeil, I. R. (1974). The many futures of contracts. *Southern California Law Review, 47*, 691—816.

Mahajan, V., Muller, E., & Bass, F. M. (1990). New product diffusion models in marketing: A review and directions for research. *Journal of Marketing, 54*(January), 1-26.

Maisel, H., & Gnugnoli, G. (1972). *Simulation of discrete stochastic systems*. Chicago: Science Research Associates, Inc.

Markose, S. M. (2005). Computability and evolutionary complexity: Markets as complex adaptive systems (cas). *The Economic Journal, 115*(504), F159.

Mateos de Cabo, R., Olmedo Fernández, E., & Valderas Jaramillo, J. M. (2002). The new complex perspective in economic analysis and business management. *Emergence, 4*(1/2), 147-163.

Mayo, D. D., & Wichmann, K. E. (2003). *Tutorial on business and market modeling to aid strategic decision making: System dynamics ni perspective and selecting appropriate analysis approaches.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

McElroy, M. W. (2000). Integrating complexity theory, knowledge management and organizational learning. *Journal of Knowledge Management, 4*(3), 195-203.

Monteverde, K., & Teece, D. J. (1982). Supplier switching costs and vertical integration in the automobile industry. *The Bell Journal of Economics, 13*(1), 206-213.

Morel, B., & Ramanujam, R. (1999). Through the looking glass of complexity: The dynamics of organizations as adaptive and evolving systems. *Organization Science, 10*(3), 278-293.

Nardi, A., & Schemper, M. (2003). Comparing cox and parametric models in clinical studies. *Statistics in Medicine, 22*, 3597-3610.

Narver, J. C., & Slater, S. F. (1990). The effect of market orientation on business profitability. *Journal of Marketing, 54*(October), 20-35.

Nelson, C. R. (1973). *Applied time series analysis for managerial forecasting*. San Francisco: Holden-Day, Inc.

Ouchi, W. G. (1979). A conceptual framework for the design of organizational control mechanisms. *Management Science, 25*(9), 833-848.

Papadakis, I. S. (2003). On the sensitivity of configure-to-order supply chains for personal computers after component market disruptions. *International Journal of Physical Distribution & Logistics Management, 33*(10), 934-950.

Parunak, H. V. D. (1998). The dasch experience: How to model a supply chain.

Pathak, S. D. (2005). *An investigative framework for studying the growth and evolution of complex supply networks.* Vanderbilt University, Nashville, Tennessee.

Pathak, S. D., Dilts, D. M., & Biswas, G. (2003). *A multi-paradigm simulator for simulating complex adaptive supply chain networks.* Paper presented at the Winter Simulation Conference.

Porter, M. E. (1980). *Competitive strategy*. New York: The Free Press.

Porter, M. E. (1985). *Competitive advantage*. New York: The Free Press.

Prahalad, C. K., & Hamel, G. (1990). The core competence and the corporation. *Harvard Business Review*, 71-90.

Rangan, V. K., Corey, E. R., & Cespedes, F. (1993). Transaction cost theory: Inferences from clinical field research on downstream vertical integration. *Organization Science, 4*(3), 454-477.

Ren, C., Ren, S., Chai, Y., Liu, Y., & Tian, C. (2002). Modeling agile supply chain dynamics: A complex adaptive system perspective. *Systems, Man and Cybernetics, 2002 IEEE International Conference on, 3*.

Rindfleisch, A., & Heide, J. B. (1997). Transaction cost analysis: Past, present, and future applications. *Journal of Marketing, 61*(4), 30-54.

Rindfleisch, A., & Moorman, C. (2001). The acquisition and utilization of information in new product alliances: A strength-of-ties perspective. *Journal of Marketing, 65*(2), 1-18.

Roy, S., Sivakumar, K., & Wilkinson, I. F. (2004). Innovation generation in supply chain relationships: A conceptual model and research propositions. *Academy of Marketing Science. Journal, 32*(1), 61-79.

Sahin, F., & Robinson, E. P. (2002). Flow coordination and information sharing in supply chains: Review, implications, and directions for future research. *Decision Sciences, 33*(4), 505.

Sanchez, R., & Mahoney, J. T. (1996). Modularity, flexibility, and knowledge management in product and organization design. *Strategic Management Journal, 17*, 63-76.

Sawhney, M., & Zabin, J. (2002). Managing and measuring relational equity in the network economy. *Journal of the Academy of Marketing Science, 30*(4), 313-332.

Semiconductor Industry Association. (2005). *2020 is closer than you think.*

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2004). *Designing and managing the supply chain: Concepts, strategies, and case studies* (2nd ed.). New York: MGraw-Hill Publishing Company.

Sood, A., & Tellis, G. J. (2005). Technological evolution and radical innovation. *Journal of Marketing, 69*(3), 152.

Steckel, J. H., Gupta, S., & Banerji, A. (2004). Supply chain decision making: Will shorter cycle times and shared point-of-sale information necessarily help? *Management Science, 50*(4), 458-464.

Sterman, J. D., Henderson, R., Beinhocker, E. D., & Newman, L. I. (2007). Getting big too fast: Strategic dynamics with increasing returns and bounded rationality. *Management Science, 53*(4), 683-696.

Stump, R. L., & Heide, J. B. (1996). Controlling supplier opportunism in industrial relationships. *Journal of Marketing Research, 33*(4), 431-441.

Sturgeon, T. J. (1997). *Turnkey production networks: A new american model of industrial organization?* (No. BRIE Working Paper 92A). Berkeley, CA: University of California at Berkeley.

Sturgeon, T. J. (2002). Modular production networks: A new american model of industrial organization. *Industrial and Corporate Change, 11*(3), 451-496.

Sturgeon, T. J. (2003). What really goes on in silicon valley? Spatial clustering and dispersal in modular production networks. *Journal of Economic Geography, 3*, 199-225.

Surana, A., Kumara, S., Greaves, M., & Raghavan, U. N. (2005). Supply-chain networks: A complex adaptive systems perspective. *International Journal of Production Research, 43*(20), 4235-4265.

Swann, G. M. P. (1985). Product competition in microprocessors. *Journal of Industrial Economics, 34*(1), 33-53.

Tan, K. C. (2001). A framework of supply chain management literature. *European Journal of Purchasing and Supply Chain Management, 7*, 39-48.

Taylor III, L. A., Goodwin, V. L., & Cosier, R. A. (2003). Method myopia. *Journal of Management Inquiry, 12*(3), 255-263.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509-533.

Tewary, A., & Wang, N. (2005). Semiconductors. On *Standard and Poor's Industry Surveys*.

Thorelli, H. B. (1986). Networks: Between markets and hierarchies. *Strategic Management Journal, 7*(1), 37-51.

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *OMEGA, The International Journal of Management Science, 3*(6), 639-656.

Van De Ven, A. H., & Poole, M. S. (1995). Explaining development and change in organizations. *Academy of Management Review, 20*(3), 510-540.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. *Journal of Marketing, 68*(1), 1-17.

Wathne, K. H., & Heide, J. B. (2004). Relationship governance in a supply chain network. *Journal of Marketing, 68*(January), 73-89.

Williamson, O. E. (1975). *Markets and hierarchies: Analysis and antitrust implications*. New York: The Free Press.

Williamson, O. E. (1986). *Economic organization*. New York: New York University Press.

Williamson, O. E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. *Administrative Science Quarterly, 36*(2), 269-296.

Zurek, W. H. (Ed.). (1990). *Complexity, entropy and the physics of information*. Redwood City, CA: Addison-Wesley Publishing Company.