ABSTRACT

Title of the Dissertation : EFFECT OF TRANSACTION COST AND COORDINATION MECHANISMS ON THE LENGTH OF THE SUPPLY CHAIN

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A drastic reduction in the cost of transmitting information has tremendously increased the flow and availability of information. Greater availability of information increases the firm's ability to manage its supply chain and, therefore, increases its operational performance. However, current literature is ambiguous about whether increased information flows leads to either a reduction or increase in transaction cost, which enable supply chains to migrate towards more market-based transactions or hierarchal-based transactions. This research empirically demonstrates that the governance structure of the supply chains changes towards market-based transactions due to a lowering of transaction costs after 1987. Much of the results is based on the theory of Transaction Cost Economics (TCE) and the role of asset specificity, uncertainty, and frequency in determining whether or not industries are moving towards markets or hierarchies. Unlike previous supply chain management literature that focuses on relatively short supply chains consisting of two or three supply chain members, Input-Output tables allow for analysis of supply chains with many more members. This paper uses the 1982, 1987, 1992, and 1997 U.S. Benchmark Input-Output tables published by the Bureau of Economic Analysis to analyze supply chains. In so doing, this dissertation not only provides insight into how supply chain structures are changing but also offers a sample methodology for other researchers interested in using Input-Output analysis for further supply chain management research.

The second part of the dissertation focuses on looking at the effect of different coordination mechanisms on supply chain length and supply chain performance using simulation. Three different heuristics that model ordering policies are used to simulate coordination mechanisms. Efficiency is measured on the basis of minimized total net stock for each heuristic used. The results are checked for robustness by using four different demand distributions. The results indicate that if a supply chain has minimized its net stock, then the heuristic used by various echelons in the supply chain need not be harmonized. Also, disintermediation helps in improving the performance of the supply chain.

EFFECT OF TRANSACTION COST AND COORDINATION MECHANISMS ON THE LENGTH OF THE SUPPLY CHAIN

by

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DEDICATION

To My Parents

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Chapter 1

Introduction

The goal of supply chain is to deliver a set of value-added products or services from its source to the final consumer. Value-added is an economic utility to satisfy a want or need. Value is added to a product or service by creating a combination of form utility, possession utility, time utility, and place utility (Lambert et al. (1998)).[1] Utility is in the form of acquiring raw materials, converting them to finished goods, and delivering them to the final customers (Beamon (1998)).

The main building blocks of the supply chain consists of physical entities. These entities are networks of suppliers, manufacturers, distributors, retailers, and customers (Akkermans et al. (2003); Lambert et al. (1998); Simchi-Levi et al. (2003); Beamon (1998)). These entities represent the main supply chain infrastructure and are assumed to be fixed (Harrison et al. (2003)). This is the design part of the supply chain and is strategic in nature. Supply chain execution consists of managing inventory policies, transportation schedules, and resource assignments and is more tactical and operational in nature.[2]

Managing supply chain execution within a given supply chain design is supply chain management (SCM). SCM improves the long term performance of the individual companies and the supply chain as a whole (Mentzer et al. (2001)). This improvement is possible due to an efficient flow of materials, information, and finances (Handfield and Nichols (1999); Mentzer et al. (2001); Chopra and Meindl (2001)). The flow of information precedes that of the flow of materials (Lambert et al. (1998)). The flow of information is in the form of actual demand in pull-based supply

[1] Form utility *creates* the basic goods or services. Possession utility enables the customer to take actual *delivery* of the product. Time utility ensures that the product is available *when* it is needed. Place utility ensures that the product is available *where* it is needed.

[2] Strategic decisions have a long time horizon for implementation and costs involved are substantial. Tactical and operational decisions are normally in terms of months,weeks or days and the costs involved are substantially low. Results are apparent in a substantially small period of time compared to results under strategic decisions.

chains or forecasted demand in push-based supply chains.[3] In traditional supply chains, no importance was given to the flow of information; while in today's supply chain, information plays a vital part in SCM. For successful SCM, three dimensions are needed : coordination, customer focus, and a holistic approach for the entire supply chain (Mentzer et al. (2001); Min and Mentzer (2004)).

A holistic approach is needed to reduce the amount of "Bullwhip effect"[4] in the supply chain. Bullwhip effect prevents the supply chain from running efficiently as each echelon [5] of the supply chain tries to optimize their own functional area without any regard to their downstream and upstream entities (Taylor (1999); Forrester (1958); Lee et al. (1997a)). The "Beer Game" illustrates the way demand is amplified throughout the supply chain even with information flowing through the supply chain. The main focus of reducing the "Bullwhip effect" is to minimize cost throughout the supply chain by reducing variable costs such as holding costs and also fixed costs like facility costs for the warehouses as well as to provide utility to the customer.

Coordination[6] between and among different echelons of the supply chain is possible due to the flow of information. Different echelons of the supply chain coordinate (Stock et al. (2000); Morash and Clinton (1998)) to enhance profitability (Kulp et al. (2004); Dyer (1997); Cachon and Lariviere (2001); Primo and Amundson (2002)). Most of these relationships are strategic in nature and on a long term basis (Clark and Fujimoto (1991); Sobrero and Roberts (2001); Ring and de Ven (1994)). Wal-Mart and Benetton have successfully increased the flow of information to coordinate with their suppliers and manufacturers to increase their profitability (Harrison et al. (2003)). An increase in the flow of information, however, does not mean that distortion does not

[3]See Simchi-Levi et al. (2003). Pull-based supply chains rely on actual customer demand to start manufacturing. e.g., Dell Computers. Push-based supply chains use forecasted demand to trigger their manufacturing operations. e.g., Coca-Cola.

[4]Taylor (1999). Also known as Demand Amplification. Small variations in demand from customers result in increasingly large variations as demand is transmitted upstream along a supply chain.

[5]Entity and echelon are used interchangeably.

[6]Min and Mentzer (2004). Coordination involves sharing information, sharing risks and rewards, integrating processes, and integration among firms.

take place. If anything, the margin of error has reduced because various technologies like EDI and the Internet actually transmit information on real time, and any distortion in the information can easily be compounded by other users of the information. However, coordination in the form of information integration and collaboration among strategic partners can enhance the usefulness of the information (Harrison et al. (2003)). For example, Cisco had significant loses by not coordinating between their suppliers and buyers even though they had rich information flowing through their system (Berinato (2001)). One of the ways in which coordination occurs in a supply chain is when echelons within the supply chain harmonize their ordering policy (Zhao et al. (2002a); Khouja (2003); Simchi-Levi et al. (2003)). This dissertation looks at various harmonized ordering policies as a proxy for coordinated mechanisms.

As the flow of information increases over time, supply chains should perform more efficiently due to a decrease in transaction cost. The flow of information has increased tremendously in this century because transmission costs have fallen drastically. Governments and firms have used this flow of information to facilitate their objectives, which in turn has further boosted the growth of technology, which increases the flow of information (Temin (1999)). The flow of information is greatly facilitated by information-sharing devices and mechanisms such as fax, phone, EDI, Internet, VMI, MRP, Kanbhan, JIT, and ERP systems. The greater the flow of information, the lesser would be the chances of inefficiencies in the supply chain like excess inventories or stockouts (Simchi-Levi et al. (2003); Lee et al. (1997a)).

Past research has looked at the effects of flow of information and coordination on short supply chains, usually a dyadic relationship. A few studies have extrapolated the results of dyadic relationship[7] onto entire supply chains[8] (Shang and Song (2003); Khouja (2003); Williams et al. (2002)). Some research has been done on the length of entire supply chains, but most of them are

[7]Example : buyer–seller, manufacturer-buyer, etc.

[8]Supply chains are defined as starting from the raw material producer all the way through the end user. The length of the supply chain would be the number of echelons within the chain.

exploratory, case studies or simulated studies (Chen et al. (2004); Williams et al. (2002); Waller et al. (1999); Towill (1996); Towill and McCullen (1999)). This dissertation addresses the gap in the literature by proposing to study the entire length of the supply chains.

Empirically studying entire supply chains instead of looking at dyadic relationships enables researchers to analyze the way supply chains are configured and the effect of information and coordination mechanisms on them. In the absence of empirically analyzing entire supply chains, past research has normally used analytical approaches and case study methodologies to answer questions regarding the effect of transaction costs and coordination mechanisms on a dyadic relationship and then extending the results to entire supply chains (Lee et al. (1997b); Huggins and Olsen (2003); Ryu and Lee (2003); Raghunathan (2003)). This dissertation will help in filling this gap in the literature by empirically looking at the structure of entire supply chains in the U.S. economy and then trying to look at the effect that transaction cost and different coordination mechanisms have had on the length of the supply chain using the Transaction Cost Economics (TCE) [9] as a theoretical basis.

A new methodology is needed to empirically study entire supply chains. Due to the paucity of data, empirical studies have not been done on entire supply chains. The Input-Output table[10] of the U.S. will be used to construct supply chains based on North American Industrial Classification System (NAICS) codes. The NAICS system arranges industries in a specific manner starting with raw materials producers and ending with the service industries. This dissertation takes advantage of the way NAICS codes are logically arranged within the Input-Output table to construct entire supply chains: from raw material producers through service industries (defined here as end users).

Supply chains can either decrease or increase[11] in length depending on the nature of transac-

[9]See Williamson (1985).

[10]The Input-Output table show the production of commodities by each industry, the use of commodities by each industry, and the industry distribution of the value added (Lawson (1997)).

[11]The length of the supply chain is equivalent to the number of links between the echelons. Each echelon is

tion costs within the economy.[12] There are two opposing streams of literature within the framework of Transaction Cost Economics that describe the conditions in which supply chain lengths could shorten or lengthen. First, supply chains would be expected to decrease in length or vertically integrate if the uncertainty of conducting transactions between different echelons is high, the number of transactions between the entities is high, and if it is difficult to draw up complete contracts. An increase in asset specificity and incomplete contracts, due to bounded rationality, leads to firms preferring hierarchies[13] to market[14] based transactions (Bakos and Brynjolfsson (1993)). Secondly, another stream of research has argued that an increase in information should lead to increase in market-based transactions over hierarchy-based transactions (Malone et al. (1987)) due to an overall decrease in transaction costs. This dissertation would empirically investigate whether supply chains are increasing or decreasing in length and the conditions under which they do so.

Anecdotal evidence, however, suggests that even with increase in information, disintermediation may not occur on a large scale and even if it does, new intermediaries form (Jallat and Capek (2001)). In fact, with the drastic reduction in the cost of transmitting information and lowering of associated transaction cost, firms are outsourcing most of their activities other than their core competence (Heller (2000)). Hence, the length of the supply chain should continue to increase. Within the U.S. economy, at the level of analysis of the industry, new supply chains would be constantly formed with both intermediation and disintermediation taking place. However, with the overall transaction costs decreasing, the expectation would be to find the length of supply chains increasing. This dissertation will attempt to empirically confirm this result.

Information sharing among supply chain members through the use of information technology (IT) may lead to better operational performance, standardization of quality, reduction in

an industry with a specific NAICS code, i.e., starting with a raw material producer, a secondary industry, a manufacturing industry, transportation, wholesale and retail industries, and service industry.

[12] See Williamson (1985).

[13] Also called vertically integrated firms leading to decrease in the length of the supply chain.

[14] Also called outsourcing and leads to increase in the length of the supply chain.

lead-time, and overall cost savings in terms of inventory management. It has been estimated that the construction industry saves approximately 4 percent from the adoption of IT alone on its overall project cost and construction cost (Schwegler et al. (2001)). Bose Corporation has realized tremendous gains in terms of leadtime reduction and cost savings by implementing JIT II, a variant of the Just-In-Time (JIT) technique (HBR (1994)). Kuper et al. (2002) find that implementation of information technology in Hewlett-Packard's Gueltstein factory reduced cycle time from sixty days in 1993 to six days in 1998. Furthermore, inventory levels decreased by 30 percent, manufacturing costs were cut by 30 percent, and on-time delivery performance increased by 100 percent.

There are some firms, though, that have not realized the benefit of information sharing in their overall profitability. Drug makers like FoxMeyer became bankrupt while trying to implement an ERP system. "Confirm," a reservation system developed by Hilton Hotels Corp. and Budget Rent A Car Corp., turned out to be one of the biggest IT disasters. Tri Valley spent nearly $22 million on a failed Oracle ERP software package (Nash (2000)).

The implicit assumption in all the examples (success as well as failures) cited above is that increases in the availability of information should lead to members[15] of the supply chain to harmonize their coordination mechanism and optimize their inventory in terms of net stock,[16]thereby increasing their efficiency. Due to lack of data at the firm level, simulation is used as the desired methodology in this dissertation to test whether a change in the length of supply chain (intermediation or disintermediation) improves the efficiency of the supply chain given different coordination mechanisms or ordering policies.

Also, standard textbooks (Simchi-Levi et al. (2003); Lambert et al. (1998)) talk about harmonization of ordering policies along the entire supply chain to gain maximum efficiencies. This viewpoint is true in most cases (Stock et al. (2000); Morash and Clinton (1998); Simchi-Levi et al.

[15] Also called echelons.

[16] $NetStock = ExcessStock + Stockouts$.

(2003); Xu and Dong (2004); Angulo et al. (2004); Kent and Mentzer (2003); Childerhouse et al. (2003)), but consider the following example in which Intel provides chips to both Sony and Dell. The expectation is that Intel, Dell, and Sony each use different ordering policies [17] but still have efficient supply chains. Indeed, one analytical study shows that complete harmonization need not necessarily lead to optimal performance among various echelons of the supply chain (Khouja (2003)). This dissertation will look at conditions under which different echelons of the supply chain can have non-harmonized coordination mechanisms but still operate efficiently.

Two distinct methodologies are used in the analysis of the above mentioned hypotheses:

1. An empirical analysis looks at the supply chain structure at the level of analysis of the industry using the Input-Output table of the U.S. economy.
2. A simulation study on the effect of change in the supply chain length on the efficiency of the supply chain is analyzed at the level of analysis of a firm. This dissertation also analyzes the conditions under which non-harmonized supply chains coordinate optimally.

The dissertation is organized in the following order. Chapter Two summarizes the research problem and presents the background under which the research problem is studied. Chapter Three examines the literature review and presents the hypotheses. Chapter Four describes the research methodology of empirically using the Input–Output table to derive the structure of supply chains. Chapter Five describes the simulation methodology used in discovering the effects of different coordination mechanisms on supply chain performance. Chapter Six presents the results of structure of supply chain using Input–Output tables. Chapter Seven presents the results of the simulation study at the level of analysis of the firm, and Chapter Eight presents the conclusions, implications, limitations, and future research opportunities arising out of this research.

[17] Proxy for coordinating mechanisms.

Chapter 2

Research Question

2.1 Length of the Supply Chain and Transaction Costs

As per past literature, an increase in information flowing through the supply chain could have two different effects on the total transaction cost and hence on the overall length of the supply chain. First, lowering of transaction costs will enable supply chains to get longer, since firms within the supply chain will go in for market-based transactions instead of hierarchy-based transactions (Malone et al. (1987); Brown and Goolsbee (2002)). Second, an increase in transaction costs could occur within a supply chain due to a firm's investment in assets like the EDI, human resources, and other costly-to-imitate resources. Also, due to bounded rationality, the contractual obligation between members of the supply chain would be incomplete and hence would make it extremely difficult for firms within the supply chain to exit a relationship. In this scenario, supply chains would tend to get shorter or remain the same over time (Bakos and Brynjolfsson (1993)).

For this dissertation, the view taken is that the length of the supply chain would tend to increase with a decrease in transaction costs. This is consistent with the view of Electronic Market Hypotheses (EMH), where there is evidence in the literature that points to an overall decrease in transaction costs over time (Hitt (1999); Clemons et al. (1993); Atkinson (2001)). Literature from work done on intermediation also argues that reduction in transaction costs could lead to the intermediaries redefining their roles, which would prevent them from being disintermediated (Bailey and Bakos (1997); Spulber (1996)).

2.1.1 Using the Input-Output Table for the Analysis

Past literature has concentrated on exploratory studies, analytical studies, empirical studies, and case-based studies to study supply chains. However, most of the work in supply chains have been studied as a dyadic relationship whose results were then extrapolated to the entire supply chain. The reason for this is not hard to imagine as gathering and analyzing data for the entire supply chain is extremely time consuming and costly. In most cases, firms within the supply chain will not have visibility more than an echelon below and above them. This dissertation fills this gap in the literature by empirically studying the entire supply chain starting from the raw material producer and going to the service industries at the level of the industry using the Input-Output table.

The Input-Output table, in brief, is a summary of all the producing industries and the consuming industries. Hence, at the level of the industry, the dissertation uses this feature of the Input-Output table to map out entire supply chains within the U.S. economy.

Leontief (1936, 1941) formalized the structure of the Input-Output table based on the Leontief production function. The Input-Output table has been extensively used in macroeconomics to look at problems like pollution, employment, technological change, distribution of income, and education (Sohn (1986); Hoen (2002); Miller et al. (1989)). In the business field, marketing has used the Input-Output table in benchmarking competitors and exploring new market segments of a firm (Matthews and Lave (2003); Rothe (1972)). This dissertation aims to extend the scope the Input-Output table in analyzing entire supply chains within the U.S. economy.

2.2 Length of the Supply Chain and Coordination Mechanism

Coordination in ordering policies among different echelons of the supply chain are implicit assumptions in most standard text books for successful supply chain management and inventory management. However, some analytical studies have found that complete coordination may not necessarily be the optimum strategy for the entire supply chains (Khouja (2003)). This dissertation studies the effect of change in the supply chain length on the efficiency of the supply chains, at the level of analysis of a firm. This dissertation also analyzes the performance of non-harmonized supply chains relative to harmonized supply chains.

Simulation methodology is used to answer the questions at the level of the firm to complement the industry-level analysis of the Input–Output tables. The findings from this dissertation will improve the understanding of various coordination mechanisms on supply chain performance. Specifically, it will help management in identifying where their supply chains lie with respect to their competitors supply chain and will help in analyzing whether or not harmonization of ordering policies increase efficiencies within the supply chain. Also, it will enable practitioners to determine under what conditions non-harmonized supply chains work as well as harmonized supply chains.

Chapter 3

Literature Review and Theory

To study the impact of transaction costs and coordination mechanisms on the length of the supply chain, the areas of supply chain management, transaction cost economics, information sharing, coordination mechanisms, and market microstructure must be studied in detail.

3.1 Supply Chain Management

A supply chain is "*a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, and/ or information from a source to a customer*" (Mentzer et al. (2001)).

For a supply chain to exist, there must be entities that are either organizations or individuals. A simple supply chain is one in which each entity involved in the flow of materials and information to another interconnected entity is connected to just one entity below and / or above it. A complex supply chain has more than one entity connected to others (Figure 3.1). These organizations or individuals must be networked[1] together and should be interdependent and cooperate with each other to attain their objective of efficiently moving information and materials (Christopher (1998)). These entities are involved in the design of new products and services and represent an "end-to-end"[2] process (Swaminathan and Tayur (2003)).

The goal of supply chain management (SCM) is to deliver superior customer value at a lower cost. This can be done by matching demand and supply with the focus being on inventory management to reduce inefficient use of capital and extra associated costs (Cachon (2004)). Another indicator of an efficient supply chain is its ability to match the flow of information and materials. Inefficient management in supply chains is usually due to the poor flow of information across the various entities or echelons Simchi-Levi et al. (2003)). Past literature that focused primarily on

[1] Networked firms normally consist of a focal firm with lots of suppliers and buyers.

[2] "End-to-end process starts with design of a service or product and ends with consumption by the consumer.

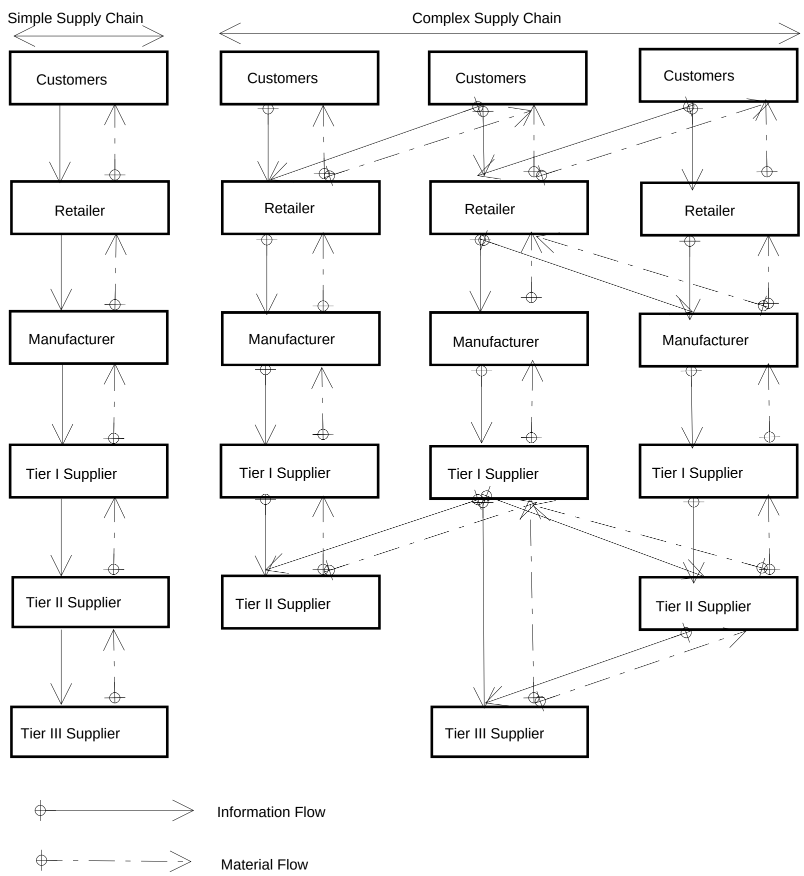

Figure 3.1: Simple and Complex Supply Chains

Adapted from Khouja (2003); Handfield and Nichols (1999) the flow of materials did not discount the role of the flow of information, but saw it more as an enabler(Khouja (2003); Shapiro (2001); Chopra and Meindl (2001); Simchi-Levi et al. (2003)). Recently, authors have given equal or more importance to the flow of information in achieving an efficient supply chain (Stank et al. (1999); Handfield and Nichols (1999); Steckel et al. (2004)). For example, computers were traditionally distributed through wholesalers and retailers. Dell started selling computers directly to the customer, thereby reducing the overall lead-time in delivering the product as well as reducing the overall cost of the product. This was achieved through better management of information flow that enabled a better materials flow (Christopher (1998)).

Coordination within the supply chain is essential for the efficient flow of goods and information. Coordination helps in improving the long term performance of individual companies as well as the supply chain as a whole across and within business functions (Mentzer et al. (2001)). It helps the firm achieve a competitive advantage vis-a-vis other firms (Handfield and Nichols (1999)). Toyota uses coordination effectively as a competitive advantage to decrease its overall cost of manufacture as well as to hold down inventory to a minimum (Simchi-Levi et al. (2003)). One of the ways suppliers and buyers coordinate their activities is by implementing a harmonized[3] ordering policy. Global competition, increased use of information, and emergence of new inter-organizational relationships[4] have contributed to the efficiency of supply chains (Handfield and Nichols (1999)).

The key issues in supply chain management are primarily based on the decisions made and their effects on the firm. Simchi-Levi et al. (2003) break down these issues in terms of strategic level,[5] tactical level,[6] and operational level.[7] This dissertation examines the strategic level changes that manifest as changes in the length of the supply chain over time.

[3]Harmonized comes from the word harmony which in turn means "compatibility in opinion and action." (www.wordreference.com/definition/harmonized).

[4]An example of coordination.

[5]Decisions that have a significant effect on the firm whose results are normally felt for a long time.

[6]Decisions taken a number of times in a year whose affects are felt for a short period of time.

[7]Decisions taken on a daily basis whose effects last for a very short period.

Other ways to think of the primary issues surrounding supply chain management are as configuration issues and coordination issues. Configuration-based issues arise due to the very structure of the supply chain, while coordination issues arise due to the interaction of the various echelons or players of the Supply Chain (Swaminathan and Tayur (2003)). The "3S" framework developed by Giannakis and Croom (2004) consists of *synthesis, synergy,* and *synchronization*. Among other things, *synthesis* involves the structural aspects of the supply chain and talks about the scope and extent of vertical integration and the various choices of channels open to customers. *Synergy* looks at the inter- and intra-organizational relationships within the supply chains, and *synchronization* is mainly concerned with coordination, information management, and material flow analysis.

There are different measures to gauge the performance of the supply chain. In the systems dynamics literature,[8] the popular performance metrics are capacity utilization, cumulative inventory level, stock-outs, and time lags. In the operations research area, the metrics used are logistics cost-per-unit, service level, and time-to-deliver. The logistics field generally tends to evaluate the performance of the supply chains in terms of lead-times, order-cycle-times, and inventory levels. Marketing tends to evaluate efficiency in terms of customer satisfaction and market shares (Otto and Kotzab (2003)). The common thread running through each of these measures is the coordination between various entities or echelons within the supply chain and the flow of information amongst these echelons for the success of the supply chain.

In this dissertation, the issue of coordination as well as configuration will be studied with respect to the length of the supply chain. The consequences of implementing a successful supply chain management by optimizing the configuration and coordination issues are lower costs, improved customer value and satisfaction, and an increased competitive advantage of the supply chain vis-a-vis other supply chains.

[8] This views the supply chain as fulfilling its objectives through consecutive, interdependent, and local transactions (Otto and Kotzab (2003)).

3.1.1 Study of Complete Supply Chains

Anecdotal evidence suggests that supply chains are typically long[9] and complex. In the literature, though, there has been a paucity in research on the complete supply chain. The prime reason for the neglect of studying complete supply chains, has been the absence of adequate data and sources of data (Lee et al. (1997b)). Many studies have looked at dyadic relationships between firms and two or three echelon supply chains, but very few studies have looked at supply chains that are more than three echelons long. The few studies that have been performed on partially complete supply chains have mostly been done as case studies. The results of these case studies are not easily generalizable. In reality, supply chains typically consist of at least one raw material supplier, one manufacturer, one wholesaler or retailer, and finally the customer.

Most studies extrapolate the results of a dyadic relationship or a three-echelon supply chain to the entire supply chain due to the limitation of collecting data. Analytical and empirical analysis on supply chains, with a focus on inventory management, typically involve a manufacturer and one or more retailers (Evers (2001); Moinzadeh (2002); Chen et al. (2000); Iyer and Jain (2003); Lee et al. (2000); Raghunathan (2003); Xu et al. (2003); Slikker et al. (2005)). Inventory is assumed to be residing only at the stages of the manufacturer and the retailer. There is no provision for a wholesaler, warehouse, or transporter to hold and store goods. The complexities normally associated with supply chains, like the "Bullwhip effect" are normally lost when studying such short supply chains. Most researchers do, however, acknowledge the need to extend their studies to the entire supply chains (Lee et al. (1997b); Huggins and Olsen (2003); Ryu and Lee (2003); Raghunathan (2003)).

An increase in the amount of information flowing through a firm produces two different kinds of effects. In the first case, an increase in the amount of information flowing through a firm creates more market-based transactions (Malone et al. (1987)) due to a decrease in transaction,[10]

[9] Complete supply chains typically are more than a dyadic relationship between two echelons.

[10] Williamson (1975)

coordination, and switching costs.[11] In the second case, an increase in information leads to an increase in vertical integration or hierarchy-based transactions (Bakos and Brynjolfsson (1993)) due to an increase in transaction, coordination, and switching costs. These two apparent contradictory effects will be resolved in the following sections when the topic of Transaction Cost Economics (TCE) is examined. In the context of complete supply chains, if supply chains move towards more market-based transactions, it would show up as an increase in the length of the overall supply chains. If supply chains move towards hierarchial-based transactions, it would show up as a decrease in the length of supply chains. Depending on the nature of the industry, supply chains could shorten, lengthen, or remain stable over time. However, there have been no empirical studies that have confirmed either of these effects on complete supply chains. This dissertation empirically answers the question on the direction[12] supply chains take in the context of the overall economy or within individual industries within the economy.

Another reason to study complete supply chains is in the area of coordination and coordination mechanisms. While current literature talks about an increase in coordination increasing the efficiency of dyadic relationships (Cheung and Lee (2002); Ross (2002); Zhao et al. (2002a); Yu et al. (2002); Rabinovich et al. (2003)), it is silent on the effects of coordination and coordination mechanisms on complete supply chains. The coordination mechanisms in a dyadic relationship are implicitly assumed to be uniform. However, in the case of Intel supplying chips to both HP and Sony, Intel may have different coordination mechanisms[13] with both HP and Sony and still may be efficient in its dealings. In this case, the assumption of a harmonized coordination mechanism being followed by Intel breaks down. Studying complete supply chains will help in analyzing situations where coordination mechanisms may differ but the overall supply chains may be running efficiently. One analytical paper has found that for some supply chains, harmonization of coordination mechanisms may actually not be efficient (Khouja (2003)). This dissertation stud-

[11]Switching cost is the cost borne by the firm when it replaces its suppliers or buyers.

[12]The direction of the supply chain may be to shorten, lengthen, or remain stable.

[13]ordering policies.

ies coordination mechanisms and efficiency due to coordination on complete supply chains using simulation. The reason simulation is chosen as the methodology is due to the absence of data on entire supply chains.

The length of the supply chain is dependent on whether different coordination mechanisms are efficient or not. In case supply chains with different coordination mechanisms are inefficient, the lengths of these supply chains would then show a significant negative relationship with the coordination mechanism. Disintermediation of the supply chain would occur[14] to bring the supply chain back towards efficiency. This dissertation tests the effects of different coordination mechanisms on different lengths of the supply chains.

Table 3.1 delineates the previous studies that have looked at complete supply chains. Even though this list is not exhaustive, the majority of research is based on a dyadic relationship with the analytical approach being the preferred methodology. Quite a few analytical papers (Kalchschmidt et al. (2003); Lee and Billington (1993); Shang and Song (2003)) do extend their dyadic model to "N" member supply chains, but fail to take into account the complexities of complete supply chains in their model. Most papers call for extending their results to entire supply chains. This dissertation gives a methodology to generate complete supply chains, with some limitations, which future researchers could use to empirically test their analytical models.

3.2 Transaction Cost Economics

3.2.1 Why Transaction Cost Economics?

Neoclassical economics would not be an appropriate theory to understand supply chain length because of some of its fundamental assumptions. Neoclassical economics assumes that within per-

[14] Either due to a decision made by the firms within the supply chain, or due to a cessation of activities by the firm.

Authors	No. of Echelons	Type of Research
Lee et al. (1997b)	2	Analytical
Cachon (2004)	2	Analytical
Steckel et al. (2004)	3	Simulation
Krishnan et al. (2004)	2	Analytical
Huggins and Olsen (2003)	2	Analytical
Sakaguchi et al. (2004)	1	Empirical
Huang and Gangopadhyay (2004)	4	Simulation
Chen et al. (2004)	3	Exploratory
Svoronos and Zipkin (1987)	3	Analytical
Metters (1997)	1	Analytical
Shang and Song (2003)	N	Analytical
Khouja (2003)	N	Analytical
Williams et al. (2002)	N	Case Study
Waller et al. (1999)	4	Simulation
Ryu and Lee (2003)	2	Analytical
Raghunathan (2003)	2	Analytical
Lee et al. (2000)	2	Analytical
Gavirneni et al. (1999)	2	Analytical
Kaminsky and Simchi-Levi (2003)	2	Analytical
Kalchschmidt et al. (2003)	N	Simulation
Lee and Billington (1993)	N	Analytical
Xu et al. (2003)	N	Analytical
Evers (2001)	N	Analytical
Slikker et al. (2005)	N	Analytical

Table 3.1: Previous Research on Supply Chains

fectly competitive markets, transactions are coordinated by a unique price, that is determined by analyzing the equilibrium of large number of buyers and sellers. Perfect information is a prerequisite, and there are no transaction costs. There are no barriers to exit or entry, and both consumers and producers are price takers (Smith (1976)). The "invisible hand" of the market establishes the price that clears the market. However, one of the drawbacks of the classical theory is that buyers and sellers have limited knowledge and therefore cannot assume to acquire information in a costless manner (Stigler (1961)). Businesses, however, do not always go in for market-based transactions but coordinate among and between themselves to produce goods and to manage and coordinate the flow of goods and information (Galbraith (1973)). Contracts are normally drawn between businesses to produce goods in direct contravention to market-based transaction to find a price equilibrium (Milgrom and Roberts (1992)). With respect to the length of the supply chain, neoclassical economics favors market-based transactions.

Resource Based View (RBV) Theory looks at firms as a bundle of resources that creates a competitive edge to the firms if these resources are economically valuable, relatively scarce, difficult to imitate, or imperfectly mobile (Barney (1991), Peteraf (1993)). The flow of information can also be thought of as a scarce resource. The disadvantage of using RBV as a theoretical base is that it is difficult to operationalize the variables of "bundle of resources that create a competitive edge." Under the framework of RBV, firms would tend to go in for hierarchy-based transactions compared to market-based transaction to preserve their competitive advantage and to protect their scarce resources. Hence, the length of supply chains should decrease under this viewpoint.

Structure-Conduct-Performance (SCP) Paradigm was first propounded by Mason and Bain in the 1950s where the basic hypothesis was that there is a direct relationship between market structure, market conduct, and market performance. Efficiency comes about when all the three elements work in synchronization (Waldman and Jensen (1998)) for a firm. Looking at it from the point of view of a supply chain, the length of the supply chain comes under the market structure.

The underlying assumption is that the length of the supply chain will adjust according to the underlying supply and demand conditions and after receiving feedback from the performance of the entire supply chain. However, it is difficult to establish a relationship between the length of the supply chain (market structure) and a move towards market or hierarchial based transactions under this theoretical viewpoint.

Due to the inability of the previous theories to fully explain the way a supply chain behaves, and to reconcile the various predictions on how a supply chain should behave with regard to its length, we look into the Transaction Cost Economies (TCE) to provide a comprehensive answer.

3.2.2 Elements of Transaction Cost Economics

Production can be carried out by various market intermediaries or by a firm. A firm would keep expanding its range of activities in producing goods so long as the internal costs of undertaking these transaction equals the costs of using the market to handle the very same individual transactions (Coase (1937, 1984); Waldman and Jensen (1998); Williamson (1985)). These transaction costs are "frictions" in conducting a transaction (Williamson (1985)). There are various reasons why individuals would seek to organize themselves into firms despite these "costs and frictions." Conducting market-based transactions can reduce bureaucracies, increase incentives, and reduce risk, but there are certain costs associated with these activities. To reduce these costs, individuals tend to come into a contractual agreement with others to produce economic goods. However, each individual is also constrained by certain behaviors, i.e., bounded rationality and opportunism. Bounded rationality, from neoclassical economics, regards human beings as a rational entities. However, transaction cost economics recognizes that not all contingencies can be anticipated and can be included in a contract due to humans' limited capabilities to solve complex problems. Opportunism suggests that bounded rationality by itself would not hamper market-based transaction if people did not have the propensity to be "self-interest seeking with guile." Incomplete transmission or distorting of information is often used to mislead people to appropriate resources.

Hence, market-based transactions would eventually fail as the costs would tend to be too high (Williamson (1985)). The factors, according to Transaction Cost Economics, which set the limits of the boundaries of a firm are asset specificity,[15] uncertainty,[16] and frequency.[17]

Firms that come together to form a complete supply chain exhibit characteristics of such a vertically integrated firm. Since firms in a supply chain exhibit high frequency of transactions coupled with high asset specificity, they tend to behave like a vertically integrated firm and do not go in for market-based transactions (Bakos and Brynjolfsson (1993); Hitt (1999); Subramani (2004)).

The relationship between the length of the supply chain, information flow among the members of the supply chain, and the complexity of the supply chain with relation to the various theories are as follows. Neoclassical economics would predicts that firms would adopt more market-based transactions. Hence, we would expect more supply chains to be as short as possible. Both Resource-Based view and Transaction Cost Economics predict large or small supply chains depending on their underlying elements.

3.2.3 Transaction Cost Economics and Supply Chain Length

The three main elements of Transaction Cost Economics (TCE) are asset specificity, frequency of transaction, and uncertainty within each transaction. TCE was primarily developed to explain

[15] Assets that are of primary value to one firm compared to another and create unique value to the firm. This value cannot be easily transplanted to other firms and can be in the form of geographic location, physical characteristics, human capital, or specific tools. The more the assets specificity, the greater the chances that the firm would tend to go in for vertical integration compared to market-based transaction.

[16] Due to bounded rationality and opportunism, there is a greater probability that a complete contract can never be written. Firms tend to vertically integrate to get around the problem of uncertainty and the risks and costs associated with it.

[17] In case firms go in for a one-time transaction, they would tend to prefer market-based transactions. In case the frequency of transaction is great, firms would tend to try to reduce their overall costs of going to the market repeatedly by vertically integrating (Williamson (1985); Waldman and Jensen (1998)).

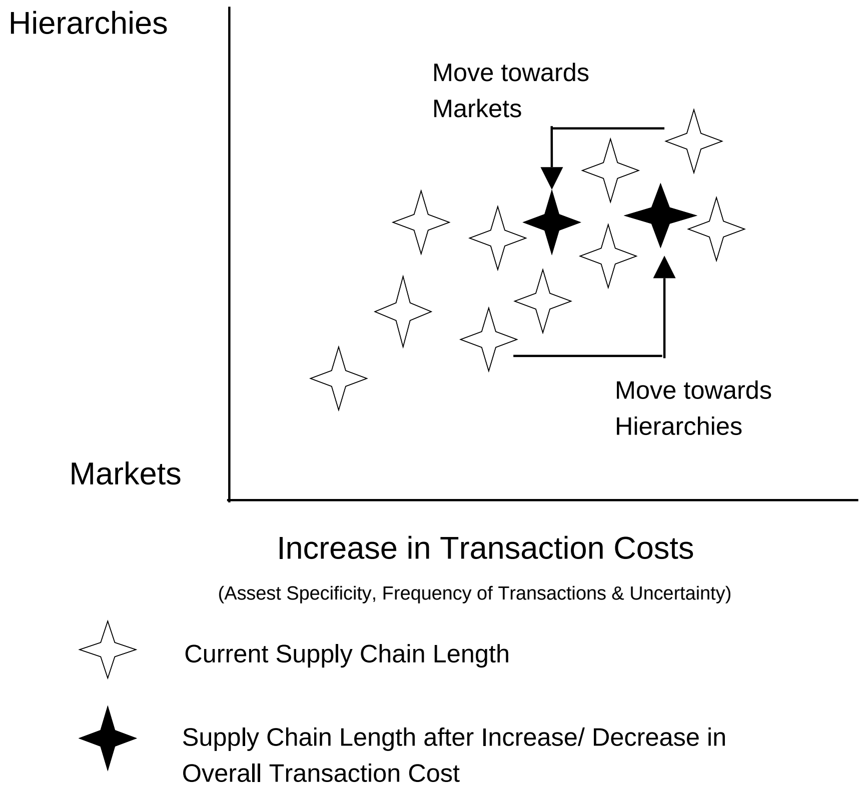

Figure 3.2: Graphical Representation of Effect of Overall Transaction Cost on Governance Structure

why firms' governance structures tend to be market-based, hierarchial-based or some combination of both (Williamson (1975)).

This theory could be used to explain whether entire supply chains tend towards market-based transactions or hierarchial-based transactions, using the length of the supply chains as a way to measure the overall effect of transaction costs. A decrease in overall transaction costs,[18] would decrease coordination and switching costs and hence would lead to market-based transactions.[19] This would manifest itself as an increase in the length of the supply chain. An increase in overall transaction costs would increase coordination and switching costs, which would lead to

[18]Elements of transaction costs are frequency of transactions, uncertainty in external environment, and asset specificity.

[19]Also called outsourcing.

hierarchial-based transactions.[20] This would lead to an overall decrease in the length of the supply chain. Figure 3.2 gives a graphical illustration on the effect of transaction costs to the governance structure of the supply chain or firm.

Neoclassical economics makes the a priori assumption that full information is available to all the players without any cost. Transaction Cost Economics assumes that a cost is attached in obtaining information. These costs could be in terms of search costs or coordination costs. An increase in information should reduce the likelihood of bounded rationality and decrease the chances of opportunism among individual firms in a supply chain. If each element of the transaction cost is viewed individually, then supply chains with high *frequency* of transactions would reduce the costs associated with coordination by being more hierarchial in nature. Supply chains with low frequency of transactions would tend to have more market-based transaction. A decrease in *uncertainty* in the overall supply chain pushes supply chain towards more market-based transactions. On the other hand, an increase in uncertainty in the external environment would push supply chains to vertically integrate and hence would reduce the overall length of the supply chain. An increase in *asset specificity*, in terms of dedicated EDI systems and technology resources, would push firms within a supply chain to hierarchial-based transactions. Supply chains with low asset specificity would not have a lot of resources tied up as assets[21] and could go towards market-based transactions.

When all the three elements of TCE are taken together in a supply chain, then the interplay between these various elements determine whether supply chains move towards markets or hierarchies. In case of an increase in uncertainty, frequency, and asset specificity, then the supply chain would lean towards hierarchial-based transactions and hence a decrease in the length of the supply chain. In a situation where any of the two elements of transaction costs increase, then the supply chains would tend to have hierarchial-based transactions. In cases where all the three elements

[20] Also called vertical integration.

[21] Assets could be both tangible and intangible.

show a decreasing trend, then the supply chains would tend towards market-based transactions.

In all other cases, it would depend on the interplay of cost increases of certain elements versus the cost decreases of the other elements to decide whether the supply chain tends towards market-based or hierarchial-based transactions. If the transaction cost increases of a certain element are much more than the cost of the other elements, then the supply chain would tend towards hierarchy-based transactions.[22] If the transaction cost increases of a certain element are less than the in transaction costs of the other elements, then the supply chain would tend towards more market-based transactions.[23] Depending on the the nature of the industry and the dominating elements in terms of asset specificity, uncertainty, or frequency in those industries, we would see supply chains within those industries going towards either market-based or hierarchial-based transactions.

Past empirical studies of firms have shown that a decrease in transaction costs due to increased use of information decreases overall cost of the product. The use of the Internet cut the prices of books and CDs by over 33 percent over the prices charged by conventional retailers. This was possible because of the substantial decrease in the cost of changing the menu cost online compared to physically changing them in the stores (Brynjolfsson and Smith (2000)). Conventional retailers cannot be as efficient as online players because of the transaction cost associated with higher frequencies of changing the menu costs. It costs about 5 percent less to buy a CD online, and around 15 percent less to buy life insurance online due to the reduction in coordination and search costs. Drawing up simple contracts costs 80 percent less if done online (Atkinson (2001)). All these costs savings are possible due to the elimination of middlemen based on lower menu costs, fixed costs, and transaction costs (Berthon et al. (2003)). Consumers have found larger transaction efficiency in terms of "list price discount"[24] due to economies of scale when dealing with pure net

[22] Decrease in overall supply chain lengths.

[23] Increase in overall supply chain lengths.

[24] See Sobel (1984).

players rather than with brick-and-mortar firms (Rabinovich et al. (2003)).

This dissertation will use Transaction Cost Economics (TCE) as a theoretical basis to study the lengths of supply chains in the context of the U.S. economy and also to look into the lengths of supply chains in specific industries within the U.S. economy.

3.2.4 Coordination and Supply Chain Length

The flow of information is as important as the flow of materials in efficiently managing the forecasts within supply chains (Mentzer et al. (2001); Stank et al. (1999); Handfield and Nichols (1999); Steckel et al. (2004)). Due to globalization and a drop in the prices of the carriers of information, there is a lot more flow of information over time (Temin (1999)). The flow of information precedes the flow of materials in the form of either actual demand or demand forecast (Lambert et al. (1998)). Since a perfect pull-based supply chain does not exist, the use of forecasting techniques is still paramount in the inventory management. In the "Beer Game," it has been repeatedly seen that each participant or echelon within the supply chain use their own ordering policy and end up performing inefficiently as a whole (Sterman (1992); Chen and Samroengraja (2000); Taylor (1999)).

To achieve efficiency along with the flow of information, different echelons in the supply chains need to coordinate among and within themselves. Coordination in a supply chain is achieved when decisions are synchronized to achieve a given set of objectives (Sahin and Robinson (2002)). One set of objectives is the reduction of overall inventory;[25] both in terms of stockouts and excess stock. According to standard textbooks, harmonization of ordering policies is essential to reduction in net stock. Efficiency can be noticed in terms of better inventory allocation, reduced overhead costs, and decrease in administrative expenses. One example of where coordination increases the efficiency of the supply chain is in the reduction of the "Bullwhip effect."[26] Distortion in the sup-

[25]Also called net stock.

[26]The Bullwhip effect, sometimes know as "Demand Amplification," is a situation whereby small variations in

ply chain results in inefficiencies of inventory, capital, transportation, capacity utilization, and sales generation (Lee et al. (1997a)). Typically, the distortion or variability is more pronounced at upstream sites when compared with downstream sites even in cases where consumer demand is evenly distributed throughout the year (Lee et al. (1997b); Taylor (1999)). Some of the main causes of "Bullwhip effect" (Taylor (1999); Forrester (1958); Lee et al. (1997a)) are impact of time lag in transmission of both information and materials along the supply pipeline, reduced short-term random fluctuations, decreased bounded rationality[27] of individuals and organizations, and reduced variability in machine reliability and process and quality capabilities. Better coordination in terms of undistorted flow of information and use of consistent heuristics tends to reduce the phenomena of demand amplification.

Coordination along with the flow of information leads to better performance of the supply chain. Information spending, which is often used as a proxy for the flow of information in a firm, has also been found to be positively related to sales of a company (Brynjolfsson and Hitt (1996); Ross (2002)). The increase in information technology spending in systems like EDI and Internet is to achieve a higher degree of coordination and undistorted flow of information. Suppliers always benefit due to increase in coordination irrespective of their capacity tightness,[28] while retailers tend to benefit if their capacity tightness is high (Zhao et al. (2002a)). Logistics synchronization, information sharing, and incentive alignment are some of the drivers of coordination that increase customer service and speed of responsiveness and decrease lead-times. This in turn leads to lower inventory in the supply chain and its associated costs (Simatupang et al. (2002); Ozer (2003); Zhao et al. (2002a)).

Uncoordinated supply chains tend to under-perform. When information is not centralized, and forecasts are made without taking into consideration subsequent echelons of the supply chains,

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demand from customers result in increasingly large variations as demand is transmitted upstream along a supply chain (Taylor (1999)).

[27]See Williamson (1985) The inability of individuals to forecast all possible scenarios.

[28]Refers to supplier's or retailer's capacity relative to the demand.

the whole supply chain starts under-performing (Munson et al. (2003)). Decrease in the flow of information leads to a loss of coordination that could lead to increase in inventory levels and costs (Yu et al. (2002)). Increase in investment in information technology leads to increased coordination that improves trust between the echelons and also increases logistics efficiencies and other factors of production (Kent and Mentzer (2003); Kudyba and Diwan (2002); Dewan and Min (1997)).

Various inventory management policies have taken advantage of the fact that an increase in coordination among and between the echelon members increases the efficiency of the entire supply chain. Under JIT,[29] suppliers of automotive parts gained significant cost advantages over suppliers who were not part of the JIT program (Scannell et al. (2000)). JIT is a process that heavily relies on information flow between various echelons to be a success. Efficient Consumer Response (ECR),[30] which is a variant of JIT at the retail level, relies a lot on interfirm supply chain coordination. Decreased inventory levels, order cycle time, and variance have been found to be positively associated with implementation of ECR (Stank et al. (1999)). Quick Response,[31] which is a variation of ECR for the retail industry, can be used for both internal and external supply chain efficiency (Birtwistle et al. (2003)). Vendor-Managed Inventory (VMI) policies also gain by increased coordination (Cheung and Lee (2002); Angulo et al. (2004)). Postponed manufacturing[32] uses flow of information and high level of coordination between large geographical areas to make the supply chains as efficient as possible.

Now, consider the example of a chip manufacturer, Intel, selling its finished goods to Sony, HP, and Apple. In the following example, it is possible that none of the manufacturers named above will use similar harmonized decision making tools as far as their ordering policies go with each other. Each of them might use different order policies[33] to come up with their forecasts and

[29] See Simchi-Levi et al. (2003); Lambert et al. (1998).

[30] See Simchi-Levi et al. (2003); Lambert et al. (1998).

[31] See Simchi-Levi et al. (2003); Lambert et al. (1998).

[32] Defer the conversion of a product from an intermediate stage the final stage to as close as possible to the point of sale as possible.

[33] Also called heuristics.

may also be using different information technology systems to make their decisions. Even then, the supply chains between Intel and Sony or between Intel and HP or between Intel and Apple may not be performing sub-optimally. Traditional supply chain textbooks (Simchi-Levi et al. (2003); Lee et al. (1997a); Handfield and Nichols (1999)) advocate using uniform information technology and harmonized heuristics in their forecasting techniques for the entire supply chains to be operating optimally. But as the example above shows, there could be situations when supply chains need not necessarily act in a holistic manner to optimize their entire supply chain. In fact, in an analytical paper, Khouja (2003) showed that harmonized coordination within multi-echelon supply chains actually costs more in terms of total cost for both single and multiple components, compared with non-harmonized[34] supply chains. The implicit assumption in the model was that information was flowing throughout the supply chain. Hence, even with information flowing,[35] the notion that one heuristic fits all for a complex supply chain tends to break down in certain situations. Some studies have found that coordination might result in lower cost but may not necessarily lead to higher quality (Starbird (2003)). A recent study has shown that not all coordination within supply chains results in positive gains in terms of profitability when customer service and market shares are considered (Boyaci and Gallego (2004)). Further studies have also shown that non-hierarchial firms within a supply chain generate optimum solutions, as compared with hierarchial supply chain, once the non-hierarchial firms start using harmonized heuristics (Dudek and Stadtler (2005)). For this dissertation, the view taken is that harmonized supply chains should perform better than non-harmonized supply chains.

In most cases, it is a fact that the entire supply chain needs to have coordinated and harmonized heuristic and information technology systems to be optimum. However, there are situations where the above statement may not hold true. This dissertation looks at these abnormal conditions under which non-harmonized supply chains perform optimally compared to harmonized supply chains and also investigates whether the length of the supply chain influences better per-

[34]Supply chains acting selfishly.

[35]In terms of the information technology put in place.

formance in terms of minimizing net stock.

3.2.5 Coordination and Transaction Cost Economics

If transaction costs decrease due to lowering of uncertainty in the external environment, the supply chain would tend towards more market-based transactions and, hence, greater coordination is needed amongst different echelons of the supply chain. This does not mean that coordination mechanisms between different supply chain members have to be harmonized. It is perfectly possible for different echelons to act in their selfish interests and still optimize the entire network. If transaction costs increase because of increase in asset specificity or increase in frequency of transactions, supply chains would tend to be more vertically integrated and the coordination mechanisms would tend to be synchronized. Unfortunately, it is very difficult to study the various elements of TCE independently to empirically in relation to the coordination mechanisms. Based on outcomes of supply chain performance,[36] researchers can conclude whether the harmonized or non-harmonized coordination mechanisms used are optimum or not.

Past literatures that use TCE and coordination often refer to the governance structure. The assumption in these literatures is that supply chains follow the same heuristics and coordination mechanisms. In the case of stable monopolistic supply chains (such as defense procurement), TCE could not explain why coordination among different echelons often resulted in a zero-sum game (Humphries and Wilding (2001)). Within the U.S. food industries, a "vertical coordination index"[37] predicted an increase in the rise of vertical integration as asset specificity rose (Frank and Henderson (1992). In the case of a transitioning economy, TCE helped explain how increasing asset specificity coupled with greater use of contracts led to greater vertical integration and coordination (Boger et al. (2001)).

[36]By using supply chain metrics like inventory turnover, total inventory

[37]The vertical coordination index consisted of two parts which included the input–output matrix to look at the interdependencies within a limited number of industries and a measure that looked at the degree of administrative control over the transactions.

This dissertation looks at the basic assumption that complete coordination may not be necessary if a firm could determine that the element of the transaction cost dominating the total transaction cost was lowering of uncertainty. This dissertation looks at supply chain performance by evaluating net stock. Supply chains that minimize their net stock are considered more efficient than other supply chains.

3.2.6 Market Microstructure

Governance Structure and Disintermediation / Intermediation

Firms would tend to favor market-based relationships compared to hierarchies when the flow of information increases over time (Malone et al. (1987)). According to Transaction Cost Economics, an increase in the flow of information should decrease uncertainty and bounded rationality of the person or firm(Coase (1937), Williamson (1975)). This would lead to a lowering of search costs and coordination costs, and, hence, would enable more market-based transactions. Empirical evidence suggests that the use of more information in the form of EDI and Internet should lower the transaction costs and increase market-based transactions. Increased use of information led to greater external procurement (Clemons et al. (1993)). Increased use of information technology substantially decreased hierarchy-based transactions (Hitt (1999)). The success of Amazon.com, Ebay.com, Ubid.com are testimony to the success of the information technology in disintermediation traditional retailers/ wholesalers who did not add value in the supply chain. Anecdotal evidence also pointed to the fact that on-line shoppers would face significant price reduction than if they had shopped at a traditional retailer. It costs 2-5 percent less to buy a CD online, 8-15 percent less to buy a life insurance on-line, and drawing up simple contracts could cost 75-80 percent less if done online (Atkinson (2001)). Dell Computers has become the leading computer manufacturer by adopting direct marketing and eliminating the middlemen. An empirical study has found that the Internet reduced term life insurance prices by about 8-15 percent (Brown and Goolsbee (2002)).

A decrease in transaction cost need not lead to market-based transactions. Analytical studies have shown that more information flow could lead to higher investments among different echelons of the supply chain and hence would increase the asset specificity that would force firms to go in for hierarchy-based transactions (Bakos and Brynjolfsson (1993)). According to Transaction Cost Economics, an increase in asset specificity would lead to increase in inter- and intra-firm investments. This would lead firms to get into long-term contracts to protect their investments. In the absence of long-term contracts firms would not increase their asset specificity even with an increase in information (Joskow (1987)).

Firms do not necessarily have to lie in the two extreme governance structures of either market-based transactions or hierarchial based transactions. Most firms lie in between these extreme governance structures. This structure is called the "Hybrid Structure"[38] and is characterized by a contract that is elastic in nature and in which the entities within the supply chain retain a degree of autonomy. Franchising, alliances, and strategic partnership are some hybrid governance structures.

Hybrid structures are as efficient as market-based and hierarchial structures. Disturbances[39] are primarily of three types: "inconsequential, consequential, and highly consequential" (Williamson (1996)). In inconsequential disturbances, the efficiency of hybrid structures are not disrupted greatly as the deviation from the contract is not great. In consequential disturbance, the deviation is substantial, but realignment is possible with some costs built into it. An example could be having a flexible contract that builds into the costs a range of prices based on the inflation rate. Arbitration is often resorted to if the contract is terminated. Under highly consequential disturbances, the contract under a hybrid structure completely breaks down and litigation is resorted to. There are no efficiency gains in these kind of disturbances.

[38] See Williamson (1996).

[39] See Williamson (1996) loss in efficiency due to deviation from the contracts.

The number of intermediaries present in a supply chain is based on the value-added service provided by them as well as the costs associated with having them in the supply chain. Electronic marketplaces tend to reduce buyer-search costs as in the airline ticketing market, thus disintermediating[40] conventional travel agents. Reducing the transaction cost for searching would tend to eliminate middlemen who do not provide enough value addition (Bakos (1997)). Disintermediation need not necessarily occur due to greater flow of information (Bailey and Bakos (1997); Bakos (1998, 2001); Jallat and Capek (2001)). Past literature points to four important roles of an intermediary. Intermediaries do not get disintermediated often because of some of the important roles they play within a supply chain to increase the efficiency of the customer in terms of price and services. These include aggregation or "Price Setting,"[41] trust or guaranteeing and monitoring the transaction, facilitation or providing liquidity and immediacy to the transaction, and matching or providing market-clearing mechanisms (Bailey and Bakos (1997); Spulber (1996); Jallat and Capek (2001); Bakos (1998)). Greater information flow has helped these intermediaries adopt information technology to help them being more efficient in their roles (Nissen (2001)). The effect of electronic commerce does not by itself lead to disintermediation but other factors like the type of contract, nature of commodity, and flexibility of the service provider decide whether or not the provider gets disintermediated (partially or wholly)(Delfmann et al. (2002)). According to Transaction Cost Economics, if the intermediary fails to lower the overall transaction cost or if the intermediary does not increase the asset specificity of the supply chain, then they are likely to get disintermediated.

According to Transaction Cost Economics, supply chains with market-based governance structure would tend to have a lower transaction costs than supply chains with a hybrid governance structure. In turn, hybrid supply chains would have lower transaction costs when compared to hierarchial supply chains. This dissertation looks into the phenomena of which governance structure dominates what kind of supply chains and whether they change over time.

[40]Reducing the number of intermediaries in a supply chain.

[41]To achieve economies of scale and scope.

3.3 Hypotheses

3.3.1 Effect of Transaction Costs on Supply Chain Length

Increasing flow of information over time through telephone and faxes in the 1980s, to EDI systems in the 1990s, to extensive use of the Internet in the 2000s, should lower the transaction and coordination costs. The flow of knowledge or information has increased due to a substantial decrease in the cost of the medium facilitating it (Temin (1999)). However, a stream of literature argues that even though coordination costs and transaction costs are reduced, they are not totally eliminated due to incomplete contracts.[42] Firms within a supply chain tend to increase their asset specificity between their suppliers or buyers (Bakos and Brynjolfsson (1993)). Asset specificity[43] is normally non-transferable and is very specific between the firm and its supplier or buyer. Hence, asset specificity would prevent firms from seeking market-based transactions in order for them to recover the investments made in the assets. Firms also try to increase their economies of scale in their buying decisions to minimize their overall costs.

Anecdotal evidence also suggests that not all firms have embraced market-based transactions. This could be because increase in the flow of information also allows for traditional middlemen to re-intermediate themselves in the supply chain through "aggregating information goods, providing trust relationships and ensuring the integrity of the markets, matching customers and suppliers, and providing marketing information to suppliers" (Bailey and Bakos (1997)). This would tend to either increase or let the number of echelons[44] in supply chains remain the same.

[42] Because of bounded rationality.

[43] Assets which are of primary value to one firm compared to another and creates unique value to the firm.

[44] The links between the supply chain members in a given supply chain are the number of echelons in that specific supply chain. The starting NAICS number of each member of the supply chain is in an ascending order. For example, in this dissertation, supply chains will start with firms with NAICS code "1" and end with firms with NAICS code "5" or "7." See Table 4.1 and Figure 4.4.

According to Transaction Cost Economics, supply chains could also be hybrids[45] due to the nature of their contracts and could avoid market-based transactions (Williamson (1996)). Since hybrids lie in a continuum between two extremes of market-based transactions and hierarchial-based transactions, they would tend to exhibit behavior of the governance structures they are close to. As an example, most McDonalds eateries are owned by franchises and would technically be "hybrids" but are closer to being hierarchial in all their buying and ordering behavior.

Increase in the flow of information over time should move firms to market-based transactions due to reduction in transaction and coordination costs (Malone et al. (1987)). According to Transaction Cost Economics, an increase in the flow of information should result in a decrease in bounded rationality among the agents,[46] which would then lead to decrease in uncertainty and, hence, an increase in the number of market-based transactions. The theory of disintermediation too heavily draws on Transaction Cost Economics to point out that reduction in coordination and transaction costs leads to increase in market-based transactions (Clemons et al. (1993); Bakos (1997); Hitt (1999)). Empirical evidence also supports this viewpoint and is based on homogeneous products like books, CDs, life insurance, airline tickets, and construction materials (Bakos (1997); Atkinson (2001); Brown and Goolsbee (2002)). In all the above cases, the electronic market places use the power of greater flow of information to reduce the buyer's cost to acquire information and, hence, drive down costs in both commodity and differentiated goods (Bakos (1997)).

The common thread in all these examples is that firms that do not add value are being disintermediated. Obviously, at the level of the supply chain, it is not possible for an entire industry[47] to be disintermediated, but is possible that the "value added"[48] by a particular industry should decrease if the firms in the industry get disintermediated over time. So, even though the

[45]Franchising, alliances, and strategic partnership are some of the hybrid governance structures.

[46]In the context of a supply chain, the agents would be the various echelons.

[47]Represented as an echelon within the supply chain.

[48]Difference between a firms sales and its intermediate purchases of materials and services from other firms (Lawson (1997)). This definition is expanded and described fully in the methodology section.

length of the supply chain might increase or remain constant, we should be able to see a decrease in the "average value added" of the entire supply chain. "Average Value Added" is the average of all the "value added"[49] components of the echelons making up the supply chain.

Theoretical arguments about whether increasing information technology increases or decreases transaction costs are ambiguous. However, empirical evidence (Clemons et al. (1993); Bakos (1997); Hitt (1999); Atkinson (2001); Brown and Goolsbee (2002)) overwhelmingly points out that transaction costs are decreasing over time. Hence, in this dissertation, the view taken is that transaction costs do decrease due to flow of information and, hence, that should lead supply chains to go toward more market-based transactions. The increase in market-based transaction would manifest itself as an increase in lengths of supply chains. Hence, the first hypothesis:

H1 : The average length of the supply chain increases over time.

The value captured by the Input–Output table is the value added by the seller before it is purchased by the buyer. The final cost of the product to the end-user is the sum of value added at all preceding buy and sell transactions. Most goods and services tend to become commodities over time. If the price of these goods and services are adjusted for inflation over time, then prices should fall. As time increases, the transaction costs to make the goods or service decreases due to better ways of making the product, increase in the reliability of the product, and efficiency and learning within the firm from making the same product over and over again. The price of the product, which is the total value added by all the echelons of a supply chain, should decrease. If this total value added is summed across all the supply chains in a economy and averaged out, then the total average value added should fall. This leads to the second hypotheses:

[49]The Input-Output Table as published by the Bureau of Economic Analysis defines "value added" as "the difference between a firms sales and its intermediate purchases of materials and services from other firms" (Lawson (1997).

H2 : The total average value added by all the supply chains decreases over time.

Supply chain lengths should increase in size[50] over time due to a greater flow of information, and decrease in the overall transaction costs. Since most prices tend to fall over time (after accounting for inflation), the value added by the entire supply chain within the economy should also drop. This would lead to each individual echelon within the supply chain, to contribute less value addition over time. This could be due to several reasons: falling prices, an increase in imports, and/or obsolescence of the product or service from the market. This dissertation defines supply chains as echelons starting from primary raw materials and ending up as goods or services to final end-users. Most amount of value addition takes place at the level of primary and secondary industries. Hence, the largest drop in value addition over time should also take place at these industries. For example, lumbering and coal mining are used in the construction industry. The goods produced by the furniture industry are sold as furniture to the broadcasting industry. The maximum value added are in extraction of coal and processing of lumber. The value added by the furniture industry is in using coal as electricity to create a table and chair out of the lumber. In case of a reduction in transaction cost in the furniture supply chain, the largest reductions would tend to be at the upstream echelons of the supply chain. Thus, the third hypothesis theorizes:

H3 : Echelons within the supply chain contribute less value addition over time.

As a corollary to hypothesis H3, if a supply chain consists of a large number of echelons, the value addition at each echelon would be less than a smaller echelon supply chain. Hence, hypothesis four states:

H4 : The greater the number of echelons in a supply chain, the lesser would be the value added at each echelon.

[50] In other words, they should be moving towards market-based transactions.

The length of a supply chain depends upon the nature of the industry. For example, information-based service industries[51] would be more likely to have market-based transactions when compared to industries[52] that have high transaction cost due to asset specificity, uncertainty, or high frequency of transactions. Industry level supply chains consist of several firm level supply chains. The firm level supply chains comprising an industry can include sunrise, mature, and sunset products and services. In case of sunrise products or services, the supply chain lengths and numbers would expand dramatically at the level of the industry. In case of mature or sunset products and services the, the supply chain lengths and numbers will remain the same or decrease. In this dissertation, the level of analysis is a supply chain at the level of the industry. Hence, it is difficult to segregate individual products and services as sunrise, mature or sunset to make any a priori assumption. The only assumption that can be made is that the nature of the end industry does have an effect on the average length of the supply chains which constitute it. This leads to the fifth hypothesis:

H5 : The average length of the supply chain is determined by the nature of industry.

Think of a manufactured product like a bottle of soda. The cost of extracting silica[53] to make the bottle is the highest part of the total cost of the soda. Converting silica into a glass bottle and adding syrup to water in a big industrial plant[54] adds the next highest cost to the bottle of soda. Transportation and storage of soda accounts for a much lower level of cost than manufacturing or activities at a primary stage but much higher level than cost of service[55] associated with the products. Even in the service industries, the cost of providing a service is much lower than the cost incurred in supporting the service activity.[56] In fact, due to the high cost of

[51] Such as airline ticketing, online shopping.

[52] Such as chemicals, restaurants, hardware manufacturers.

[53] A primary/secondary industry.

[54] A manufacturing process.

[55] Services include branding, advertisement, research, and development.

[56] For example, to support research and development of soda, the cost of products like water, furniture, manufac-

primary and secondary activities, most developed economies tend to outsource these activities to less developed and cheaper economies. In this dissertation, a supply chain has been defined as the raw material manufacturer being upstream, followed by a primary goods manufacturer, followed by secondary goods manufacturer, followed by manufacturing industries and then followed by the service industries. Hence, more value would be added upstream[57] compared to downstream industries.[58] Standard supply chain management textbooks talk about the cost of raw materials being very high to the overall cost of the goods. Figures for manufacturing a product range from 5 percent to 30 percent of the total sale price of the end product (Chopra and Meindl (2001); Handfield and Nichols (1999); Shapiro (2001). This leads to our sixth hypothesis:

H6 : The value added in an economy is higher in an upstream industry when compared with value added in a downstream industry.

3.3.2 Effect of Coordination Mechanisms on Length of the Supply Chain

When compared with coordinated supply chains, uncoordinated supply chains tend to sub-optimize their performance objectives.[59] Supply chains could be uncoordinated in terms of location of retailers, warehouses, plants, and vendors, improper inventory management systems, faulty forecasting techniques, and wrong pricing policies (Munson et al. (2003)). The coordination of knowledge in terms of operational linkages (logistics synchronization and information sharing) and organizational linkages (incentive alignment and collective learning) is essential for the success of the supply chain (Simatupang et al. (2002)).

As per the "Bullwhip effect" literature, there is a high prevalence of "Not Invented Here."[60]

turing plants, etc., is higher than the cost of manpower.

[57]As close as possible to the raw materials, in this case primary, secondary, and manufacturing industries.

[58]As close to the customer as possible, in this case the service sector.

[59]In terms of either profits, inventory turnover ratio, end of the year inventory, stockout costs, holding costs, etc.

[60]Stands for the attitude among people or firms that either intentionally or unintentionally avoid using prior knowledge because the research and knowledge was not developed by them (Sterman (1992); Simchi-Levi et al.

Hence, it can be argued that individual members of the echelon should forgo the maximization of their individual objectives[61] in favor of the maximization of the objectives of the entire supply chain. It has also been suggested that the "Bullwhip effect" can be traced back to the kind of strategy adopted by the echelons of the supply chain. An echelon implementing the speculation strategy[62] compared with a postponement based strategy[63] increases the amount of demand amplification (Svensson (2003)). If the "Bullwhip effect" is due to the strategy adopted by various echelons,[64] then coordination among different echelons in terms of using the same unified forecasting, information sharing, and inventory management strategies assumes a big significance. It has been found that investment in information technology positively impacts market performance in terms of revenues, income, return on assets, costs, service levels, and working capital due to an increase in coordination between echelons within a supply chain (Ross (2002); Zhao et al. (2002b)).

The implicit assumption in the prevalent literature is that various echelons of the supply chain should work in harmony and uniformity to create the least amount of variation in the information being transmitted along the supply chain. This is consistent with the industrial organization (IO) theory of "Double Marginalization." Double Marginalization theory states that two separate firms will not derive as much profit acting independently as they would if they had instead been vertically integrated.

Standard textbooks tell us that different echelons in a supply chain acting independently sub-optimize the overall performance of a supply chain compared with an integrated approach taken by the entire supply chain as though they were a vertically integrated firm. This is also consistent with the prisoners' dilemma solutions from game theory, because the inability to coordinate actions often leads to outcomes that do not maximize the overall utility. This leads to the

(2003)).

[61] In terms of either profits, inventory turnover ratio, end of the year inventory, stockout costs, holding costs, etc.

[62] Also known as push-based strategy.

[63] Also known as pull-based strategy.

[64] Inefficiencies of inventory, capital, transportation, capacity utilization, and sales generation.

seventh hypothesis:

H7: Firms that maximize their own performance within a supply chain will sub-optimize the overall supply chain performance.

Better information flow and better ordering policies help to improve the efficiency of the supply chains by mitigating the "Bullwhip effect." Various heuristics have been studied in the literature with regard to better coordination between firms. These include single facility heuristic, independent facility heuristic, sequential collapse heuristic, steepest decent heuristic, myopic heuristic, improved myopic heuristic, and Crowston, Wagner, Henshaw heuristic (Williams (1981); Biggs (1979); Clark (1972); Markland (1975); Markland and Newett (1976)). These heuristics are variants of the Economic Order Quantity (EOQ) model.

Among the most common heuristics used in industry and standard textbooks are actual demand of the customer, moving average, and moving averages with a trend correction ((Tersine (1998)). In the recent past, Zhao et al. (2002a) used the moving average and a variant of trend correction of demand as heuristics.

The ultimate objective of all the papers mentioned above is to reduce or eliminate excess inventory as much as possible. In all cases, different echelons of the supply chain used a harmonized heuristic as it was thought to have optimized decision making across the supply chain. Flowing from the discussion for hypothesis seven, one could argue that the use of harmonized heuristics among the various echelons of the supply chain would tend to reduce the chances of variability and distortion of demand. Hence, not much thought was given in earlier research as to whether different echelons in the supply chain could use different heuristics and still optimize their inventory across the entire supply chain.[65]

[65]For example, the discussion of a chip manufacturer, Intel, selling its finished goods to Sony, HP, and Apple and still being abe to optimize its supply chain without necessarily using the same heuristics of either Sony, HP, or

Echelons in a supply chain often face excess stock and stockouts in their day to day operations. The objective of most echelons is to reduce this variation. Hence, the performance criteria is net stock which is the summation of the absolute values of excess stock and stockouts. Net stock for the entire supply chain is arrived at by adding all the absolute values of stockouts and excess stock at each and every echelon of the supply chain. The closer the net stock is to zero for the entire supply chain, the more efficient a supply chain is. Hence minimization of net stock is the performance measure chosen for this dissertation. This leads to the eighth hypothesis:

H8 : Firms that harmonize their supply chain heuristic minimize their net stock.

Firms within a supply chain disintermediate because they do not add value and the supply chain performs more efficiently in their absence. The role of the disintermediated firm is normally taken by an electronic intermediary (Bakos (1997); Bailey and Bakos (1997)).

According to Transaction Cost Economics (Williamson (1985)), a smaller supply chain might do better than a long supply chain because of losses in asset utilization,[66] accounting problems,[67] incentive sharing problems,[68]and bureaucracy.[69] Since not all gains or losses can be factored into

Apple.

[66]The longer the supply chain the more the chances of not utilizing resources to their optimum. Standards, procedures, and specifications might be built in, but it would be easier to implement these standards in smaller supply chains.

[67]Firms that come together in a supply chain would need to appropriate the gains and losses in an equitable manner, but they normally end up sharing the gains based on the bargaining power of the dominant player (Bakos and Brynjolfsson (1993)).

[68]Since supply chains are by nature hierarchial, we would expect that high-powered incentives to the workers and managers would be substituted by low powered incentives in the form of salaries and time-bound promotions.

[69]"The propensity to manage" (Williamson (1985)) is all pervading in any formal organizational structure. In fact this "propensity" increases as the number of firms / layers in an organization go up. Bureaucracy also is very "forgiving" toward mistakes compared to the market. Hence, we would see long supply chains with more firms involved have greater bureacracy than shorter supply chains, and the "propensity to manage" the supply chain by

a contract due to bounded rationality, the chances of accurate accounting in longer supply chains for unexpected appropriations of gains and losses among different members of the supply chain will be more complex and unequitable compared to shorter supply chains. Incentive sharing in owner-managed firms is different from incentives in professionally managed firms. For the owners, a share of the profits is the main incentive while for the other employees their incentives come in the form of wages or salaries. In any given firm, we would find more employees than owners. Hence, in a supply chain we would find this reflected also. The further away the supply chain is from market-based transactions, the lower their incentives. Shorter supply chains would be in a better position than longer supply chains to give more incentives to their workers and managers to be more efficient. In the previous section, it was argued that uniform coordination mechanisms should increase the efficiency of the supply chain. Combining uniform coordinating mechanisms with disintermediation should make a supply chain more efficient than a non-disintermediated supply chain with uniform coordination mechanism. Therefore the ninth hypothesis is:

H9 : Disintermediation in supply chain increases supply chain performance.

The next two chapters develop the methodology to test the hypothesis developed in this chapter. Chapter four derives the methodology to extract supply chains from Input–Output tables to test hypotheses one through six. Chapter five helps in deriving the methodology for the simulation to analyze hypotheses seven through nine.

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a dominant supplier or manufacturer will be greater in a long supply chain compared with a short supply chain.

Chapter 4

Research Methodology - Length of Supply Chain and the Input–Output Table

4.1 Macroeconomics

Accounting at the level of the macro economy is done by the Department of Commerce. It involves the *product* side of the accounts and the *income* side of the accounts. The product side of the accounts looks at the goods and services produced in an economy, while the income side of the accounts look at factor incomes earned by workers for producing the goods. Gross Domestic Product or GDP is the total market value of all final goods and services produced in a country in a given year, which is equal to total consumer, investment, and government spending, in addition to the value of exports, while subtracting the value of imports.

In terms of pure accounting, product side accounting = GDP = income side accounting. The product side of accounting, which reflects the flow of goods and services, can be represented by

$$GDP = C + I + G + X$$

where

1. C = Consumer expenditure
2. I = Business expenditure
3. G = Government expenditure
4. X = Exports

Therefore, any good or service produced in the economy ends up being consumed by any one of the final consumers: personal, business, government, or exports (Branson (1989)).

The first empirical connection between "Gross National Product" (GNP)[1] and interindustry

[1] GDP = GNP - (income paid to domestic factors of production by the world) - (income paid to foreign factors

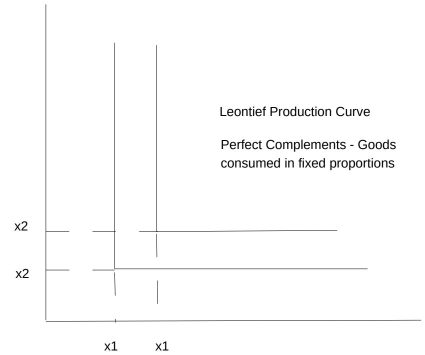


Figure 4.1: Leontief Production Curves

analysis was established by the statistical work done by Bureau of Labor Statistics in 1947. Also, empirical studies by Evans and Hoffenberg and Liebling confirm the close connections between GNP and interindustry data (of Economic Research (1955)). They based their arguments on the fact that the total GNP of a country was merely aggregated data of industries within an economy.[2]

The Input-Output table uses this argument to present data at the level of the industry and aggregate it to the GDP of the nation. This dissertation uses the industries and the data given in the Input-Output table to generate supply chains at the level of analysis of an industry.

4.2 Leontief Production Curves

A production set is the combination of all inputs that comprise a technologically feasible way to produce an output and the function describing the boundaries of all possible outputs given these inputs is called the production function (Varian (1999)). These production functions can be represented as isoquants, which are basically various combinations of inputs to produce a given amount of output.

A special case of the isoquant is the L-shaped curve as given in Figure 4.1. Here, both X_1 and X_2 are consumed together in fixed proportions and are called perfect complements. This

of production by the domestic economy).

[2]Household was also treated as an industry.

L-shaped curve is also called “Leontief Production Curve.”

The Input-Output Table uses the “Lieontief Production Curves” as their basis of computing the production sets. The production curve of the industry, in turn, is assumed to be additive of all the individual production curves of the firms representing the industry. Hence, the supply chains created at the level of the industries using the Input-Output table, would be aggregation of supply chains of all the firms within the industry.

4.3 Input-Output Tables

4.3.1 Origin and Uses of Input-Output Table

According to Lawson (1997),“The Input-Output accounts show the production of commodities (goods and services) by each industry, the use of commodities by each industry, the commodity composition of gross domestic product (GDP), and the industry distribution of the value added.”

This analytical framework was originally developed by Wassily Leontief in the 1930s, for which he was awarded the Nobel Prize in Economic Science in 1973. The concept was, however, originated by a French economist, François Quesnay in 1758 in his publication titled “Tableau Economique” in which he traces the path of money in a local economy. Walras (1874) utilized a set of production coefficients that associated the inputs to a particular product to the total output of the (production) of that product (Miller and Blair (1985)). Leontief (1936) presented the theoretical framework and later followed up with a book (Leontief (1941); Sohn (1986)), in which the Input–Output structure of the U.S. economy was first written. The Bureau of Labor Statistics, in 1947, made the interindustry connection with the federal expenditure while Evans and Hoffenburg made the empirical connection between GNP and industry (of Economic Research (1955)). The Bureau of Economic Analysis currently publishes the benchmark Input–Output tables every five years.

Input-Output Tables have traditionally been used to study macroeconomic problems like policy simulation, effect of pollution, distribution of income, and simulation of data (Sohn (1986)). Norway uses the Input-Output Table to look at the employment level in their economy.[3] The University of Maryland developed a simulation model called INFORUM which aims to make long-term forecast for the American economy by using 185 sectors of the economy.[4] Changes in the coefficients of the sectors of the U.S., Japanese and the U.K. economies have been studied to predict the future of these sectors in the overall economy and to frame appropriate policies at the macroeconomic level.[5]

A few studies have used the basic framework of the Input-Output Table to create new Input-Output Tables based on criteria other than purchase or sale of goods or services in an economy. The United Nations System of National Accounts[6] adapts the Input-Output Table to report comparable national accounts by different countries. Demographic matrixes to explain education problems in a *social accounting* context was formalized using the Input-Output Table as the basis.[7]

Conventional theory on International Trade suggests that countries with large comparative advantages end up trading with each other. However, the success of the European Union where countries with similar factors of production came together to trade (Leontief paradox) was explained using the Input-Output Tables (Hoen (2002)).

Several articles on the measurement and implications of technological change on the macroeconomy have been captured using the Input-Output Table.[8] This work has been extended to

[3]See Bjerkholt in Sohn (1986).

[4]See Buckler et. al. in Sohn (1986).

[5]See Vaccara, Heller and Lynch in Sohn (1986).

[6]See Aidenoff in Sohn (1986).

[7]See Stone in Sohn (1986).

[8]See Duchin, Blair et. al. and Kanemitsu in Miller et al. (1989).

also study regional economies and interregional differences within a bigger economy.[9] Structural changes and the sources of Industrial growth in countries have been studied at the level of individual sectors of the economy using the Input-Output Table (Akita and Hermawan (2000); Ghosh and Roy (1998); Alauddin and Tisdell (1988))).

Input-Output Tables have been adapted to microeconomics in the areas of marketing to identify relevant market segments for a firm (Rothe (1972)) and also to benchmark companies against their competitors in the area of industrial environmental performance (Matthews and Lave (2003)).

Earlier literature, however, does not look at the economy from the perspective of supply chains. This dissertation attempts to use the Input-Output Table to construct entire supply chains at the level of the industry and analyze the changes within these supply chains over time in the U.S. economy.

4.3.2 Computation of Input-Output Table

The computation of the Input-Output table as given by Miller and Blair (1985) is as follows. The Bureau of Economic Analysis (BEA) uses the same method of computation for its data methodology.

The Input–Output table consists of a set of n linear equations with n unknowns and hence can be solved through matrix manipulation.The solution to the Input–Output equation system is an inverse matrix.

Suppose the total flow of monetary value of the goods from sector i to sector j is given by z_{ij}. Let the total economy be divided into n sectors and let X_i be the total output of sector i.

[9] See Torii et al., Beyers and Nijkamp and Reggiani in Miller et al. (1989).

Further, let Y_i be the total demand for all of sector i's product. Then

$$X_i = z_{i1} + z_{i2} + \ldots + zij + \ldots + Yi \tag{4.1}$$

Thus (4.1) can be written as the following equations for each of the n sectors.

$$\begin{aligned}
X_1 &= z_{11} + z_{12} + \ldots + z_{1j} + \ldots + Z_{1n} + Y_1 \\
X_2 &= z_{21} + z_{22} + \ldots + z_{2j} + \ldots + Z_{2n} + Y_2 \\
&\vdots \\
X_i &= z_{i1} + z_{i2} + \ldots + z_{ij} + \ldots + Z_{in} + Y_i \\
&\vdots \\
X_n &= z_{n1} + z_{n2} + \ldots + z_{nj} + \ldots + Z_{nn} + Y_n
\end{aligned} \tag{4.2}$$

Here the jth column of the z's represents the monetary value of the total sales to sector j from the various producing sectors.

$$\begin{bmatrix} z_{1j} \\ z_{2j} \\ \vdots \\ z_{ij} \\ \vdots \\ z_{nj} \end{bmatrix}$$

The rows are hence represented by the sellers, while the columns are represented by the purchasers.

The main assumption here that the interindustry flows from i to j for a given period depends entirely and exclusively on the total output of the sector j for that same time period (Miller and Blair (1985)). Hence,

$$a_{ij} = \frac{z_{ij}}{X_j} \tag{4.3}$$

where a_{ij} is also known as the input–output co-efficient. In simple terms, it means the dollar worth of input from sector i per dollar's worth of output from sector j. Economies of scale are thus ignored in the Input-Output Table as they are assumed to be operating under the Leontief production function, which assumes constant returns to scale.

Since the technical coefficients are fixed for a Leontief model, (4.3) is rewritten as

$$X_j = \frac{z_{1j}}{a_{1j}} = \frac{z_{2j}}{a_{2j}} = \ldots = \frac{z_{nj}}{a_{nj}} \tag{4.4}$$

The only problem is if $a_{ij} = 0$, since that would mean $\frac{z_{ij}}{a_{ij}}$ would be infinity. Hence the production function used in the Input–Output Table takes the form of

$$X_j = min\left(\frac{z_{1j}}{a_{1j}}, \frac{z_{2j}}{a_{2j}}, \ldots, \frac{z_{nj}}{a_{nj}}\right) \tag{4.5}$$

Now, substituting equation (4.5) in equation(4.2) yields

$$\begin{aligned}
X_1 &= a_{11}X_1 + \ldots + a_{1i}X_i + \ldots + a_{1n}Xn + Y_1 \\
X_2 &= a_{21}X_1 + \ldots + a_{2i}X_i + \ldots + a_{2n}Xn + Y_2 \\
&\vdots \\
X_i &= a_{i1}X_1 + \ldots + a_{ii}X_i + \ldots + a_{in}Xn + Y_i \\
&\vdots \\
X_n &= a_{n1}X_1 + \ldots + a_{ni}X_i + \ldots + a_{nn}Xn + Y_n
\end{aligned} \tag{4.6}$$

Here the interdependence between interindustry flows and total output for each sector can be clearly seen. Bringing all the X_1s together in the first equation and so on we get

$$
\begin{aligned}
Y_1 &= (1-a_{11})X_1 - \ldots - a_{1i}X_i - \ldots - a_{1n}Xn \\
Y_2 &= -a_{21}X_1 - \ldots - a_{2i}X_i - \ldots - a_{2n}Xn \\
&\vdots \\
Y_i &= -a_{i1}X_1 - \ldots - (1-a_{ii})X_i - \ldots - a_{in}Xn \\
&\vdots \\
Y_n &= -a_{n1}X_1 - \ldots - a_{ni}X_i - \ldots - (1-a_{nn})Xn
\end{aligned}
\tag{4.7}
$$

In terms of matrices, we could write the equation (4.7) as

$$
Y = (I-A)X \tag{4.8}
$$

to know whether a unique solution for X exists, $(I-A)^{-1}$ should exist.

Hence,

$$
X = (I-A)^{-1}Y \tag{4.9}
$$

where $(I-A)^{-1}$ is called the Leontief inverse.

If the elements of $(I-A)^{-1}$ are denoted by α_{ij} (Miller and Blair (1985)) equation (4.9) becomes

$$
\begin{aligned}
X_1 &= \alpha_{11}Y_1 + \ldots + \alpha_{1j}Y_j + \ldots + \alpha_{1n}Yn \\
&\vdots \\
X_i &= \alpha_{i1}Y_1 + \ldots + \alpha_{ij}Y_j + \ldots + \alpha_{in}Yn \\
&\vdots \\
X_1 &= \alpha_{n1}Y_1 + \ldots + \alpha_{nj}Y_j + \ldots + \alpha_{nn}Yn
\end{aligned}
\tag{4.10}
$$

Input-Output Table of Inter-Industry Flow of Goods

			Purchasing Sector												Total Commodity Output
			Industries								Users				
			1	2	3	4	5	6	7	8	a	b	c	d	
Selling Sector	Commodities	1	z11				z15								
		2													
		3		z32											
		4								z48					
		5			z53				z57						
		6													
		7				z74				z78					
		8					z85								
Total Industry Output											a - Personal b - Federal and State Governments c - Imports and Exports d - GDP				

aij = Value added by the ith industry and then sold to the jth industry

Source : Adapted from the U.S. Department of Commerce, Bureau of Economic Analysis

Figure 4.2: Example of an Input–Output Table

Hence each industry's gross output is dependent on the final demand for the product.

Figure 4.2 is a representation of the Input–Output table. The rows consist of the selling sector, while the columns consist of the purchasing sector. Lawson (1997) gives comprehensive detail on the way the U.S. Input–Output Tables are created. The Input–Output tables consist of the "Make" and "Use" table where the "Make" table shows the value in producers' prices of each commodity produced by each industry while the "Use" table shows the value in producers' prices of each commodity used by each industry or by each final user. This dissertation uses the "Use" table.

4.3.3 Reading an Input–Output Table

Figure 4.2 is an example of the "Use" Input–Output table generated by the Bureau of Economic Analysis under the U.S. Department of Commerce. The columns are the purchasing industries while the rows are the producing industries.

The 1997 benchmark Input–Output table is logically partitioned into eight broad categories based on the North American Industry Classification System (NAICS). NAICS replaced the Standard Industrial Classification System (SIC), which was in use until the 1992 benchmark Input–Output table. "NAICS is the first-ever North American industry classification system. The system was developed by the Economic Classification Policy Committee (ECPC), on behalf of the Office of Management and Budget (OMB), in cooperation with Statistics Canada and Mexico's Instituto Nacional de Estadistica Geografia e Informatica (INEGI) to provide comparable statistics across the three countries" (Bureau (1987)). The three countries involved are Canada, U.S., and Mexico. The NAICS code is also comparable to the International Standard Industrial Classification System (ISIC, Revision 3), maintained by the United Nations.

The NAICS code was based on the concept that industries or firms producing similar goods or services were grouped together. The SIC code was not based on this concept, and hence there was much confusion about comparing time series data due to reconfiguration or regrouping of industries. The SIC code was a four-digit system compared to the six-digit NAICS system. This enabled NAICS-based tables to show a greater number of industries that affect the economy. NAICS also recognized the growing influence of service-based industries within the U.S. economy, and is flexible enough to include new sectors as and when they emerge. "NAICS allows each country to recognize activities that are important in the respective countries, but may not be large enough or important enough to recognize in all three countries" (Bureau (1987)).

The NAICS codes are arranged in a logical order based on the concept of similar goods and services. Table 4.1 illustrates the relevant supply chain members producing similar goods and services at the six-digit NAICS code level. As can be seen from the table, all industries with a six-digit NAICS code starting with "1" are basic primary industries (natural resource producers) like agriculture, hunting, fishing, forestry, crop production, and logging. All industries with a six-digit NAICS code starting with "2" fall into the category of secondary industries (mining and

Supply Chain Members	NAICS Code	Number of Industries
Primary Industries (Natural Resource Producers)	1xxxxx	18
Secondary Industries (Mining and Construction)	2xxxxx	27
Manufacturing Industries	3xxxxx	344
Warehousing and Trans.	4xxxxx	12
Service sector (Info, Fin, Prof. and Buss. service)	5xxxxx	48
Education and health service	6xxxxx	10
Service sector (Leisure and Hosp.)	7xxxxx	11

Table 4.1: Supply Chain Members and Relevant Six Digit NAICS Codes

construction) and include specific industries like oil and gas extraction, coal mining, metal and non-metal mining, quarrying, power generation, gas distribution, water, sewage and other systems, residential and non-residential construction, and maintenance of construction. NAICS codes starting with "3" include all kinds of manufacturing activities like food, metals, consumer durables, industrial intermediates, textiles, furniture, and wood products. Industries like warehousing, retail and wholesale operations, and transportation modes like air, road, water, pipeline, couriers, and sightseeing fall under the NAICS code starting with "5." Information, finance, professional and business services like newspapers, books, software, motion picture, data processing, insurance, securities, architecture, design service, legal services, scientific research, advertisement, and other business and professional services fall under NAICS code "5." All kinds of elementary, high school, college and university level education, hospitals, and social care start with "6" as their NAICS codes. Service industries like performing arts, amusement, leisure, sports, gambling, accommodation, and food services belong to NAICS codes starting with "7."

The benchmark Input–Output tables are generated once every five years by the Bureau of Economic Analysis. Since the tables prior to 1997 were on the basis of SIC codes, it is necessary to make the tables across time consistent between the SIC based benchmark Input–Output table and the NAICS based benchmark Input–Output table. The U.S. Census Bureau has published tables in Appendix A of the "Survey of Current Business, December 2002" and "Benchmark Input-Output Accounts of the United States, 1997," which compares the classification system of the old SIC codes and the new NAICS code and reconciles them.

As explained in the previous section, the intersection between the row and column in the Input–Output table is the cell that contains the "value added" by the producing industries. Value added has been defined as the difference between a firm's sales and its intermediate purchases of materials and services from other firms (Lawson (1997)). Any dollar sale from any of the producing industries to any of the consuming industries is recorded in these cells. A cell with zero value denotes no transaction between the consuming and producing industries.

4.3.4 Generating Supply Chains from the Input-Output Table

Supply chains are networks of suppliers, manufacturers, distributors, retailers, and customers (Akkermans et al. (2003); Lambert et al. (1998); Simchi-Levi et al. (2003); Beamon (1998)). Table 4.1 categorizes various supply chains members based on NAICS codes that are, in turn, based on the similarity of goods or services that are produced. The Input–Output table is based on these NAICS codes and are organized as per Figure 4.2. The Input–Output table is organized in such a way in which raw materials occupy the top of table, followed by secondary industries, manufacturing industries, retail and transportation, and finally followed by the service industry. This is very similar to the definition of a supply chain. This fact is used to construct supply chains at the level of the industry.

To construct a valid supply chain, the end customer needs to be defined. This dissertation defines the end customer as any of the service sector industries starting with a NAICS code of "5" and "7." Industries starting with NAICS code "6" are not taken as end customers because of issues with data aggregation, which shall be explained later. The end customer could have been chosen to be any of the NAICS codes, but this dissertation concentrates on the service sector.

4.3.5 Operationalizing the Input–Output Table to generate Supply Chains

The benchmark Input-Output table is compiled by the Bureau of Economic Analysis on a five-year basis. Hence, data for the period 1978–1982 would be available in the benchmark 1982 Input-Output table. Similarly, data for the periods 1983–1987, 1988–1992, and 1993-1997 would be available in the benchmark 1987, 1992, and 1997 Input–Output tables respectively. The Input–Output table for the years 1998–2002 will be available only in the year 2007 according to the details on the BEA's website. The data on each of the years is available on their website URL "http://www.bea.gov/bea/dn2/home/benchmark.htm."

The NAICS code of the benchmark 1997 Input–Output table was used as the basis for comparing data for the years 1982, 1987, 1992, and 1997. Since the classification of the Input–Output tables for the years 1982, 1987, and 1992 were on the basis of SIC codes, the Census Bureau has published tables in the "Survey of Current Business, December 2002" and "Benchmark Input-Output Accounts of the United States, 1997," to reconcile the differences between SIC codes and NAICS codes. All the SIC codes for the years 1982, 1987, and 1992 were converted to 1997 NAICS codes before supply chains were generated.

Also, all the dollar figures used in the analysis were converted to 1997 real prices using the GDP inflator / deflator calculator. From the year 1982 till 1997 the inflation index was 1.5346, which means that a \$100 value in 1982, at constant prices adjusted for inflation, would cost \$153.46 in 1997. Similarly, comparing the years 1987 and 1992 with the base year 1997, the inflation index stands at 1.3075 and 1.1061 respectively. All dollar figures reported in the dissertation are at 1997 constant prices, unless otherwise noted.

4.3.6 Assumptions Made in Generating the Supply Chains

The definition of a supply chain as used by this dissertation is that goods or products flow from a raw material supplier to a manufacturer, then onto a wholesaler and / or retailers, and then finally to the consumer. The absolute final users in the U.S. macro economy are individuals, federal and state governments, and exports. However, in the Input–Output table, all goods and services flow into either of these three categories and the dollar figure reported in these categories are summations of all the products or services bought by them. There is no known methodology to de-aggregate the total sum into its individual industry level components other than to have access to firm-level data, which is proprietary information with the Bureau of Economic Analysis. This dissertation uses service industries which have the NAICS codes beginning with "5" and "7" as end users. Industries that have NAICS codes beginning with "6" like educational institutions and hospitals are not used as end industries as, prior to 1997, these industries were not distinct entities but were part of a bigger group called non-residential buildings. This prevented any kind of comparison between these industries prior to 1997. End users can also be defined as industries with different NAICS codes, but they could be studied in the future. This dissertation demonstrates the methodology of generating supply chains with the Input–Output table, and the scope of using industries other than service industries lies outside the dissertation.

The 1997 Input–Output table consists of 470 industries spanning all the NAICS codes "1" through "7." Table 4.1 gives the the number of industries present in each of the NAICS codes. Of the 470 industries, eighteen industries belong to NAICS code "1," twenty-seven industries belong to NAICS code "2," three hundred and forty-four industries belong to NAICS code "3," twelve industries belong to NAICS code "4," forty-eight industries belong to NAICS code "5," ten industries belong to NAICS code "6," and eleven industries belong to NAICS code "7." Since the 1982, 1987, and 1992 Input–Output tables have been made compatible with the 1997 Input–Output table, all the initial Input–Output tables are a 470 by 470 matrix. Because of the huge number of permutations and combinations possible on such a large matrix, and due to constraints in computing power and data storage, this dissertation makes a few assumptions while generating the supply chains.

The first assumption is that the supply chain always begins in the first partition whose NAICS code begins with “1.” This assumption helps in tracing all the finished products or services of an end user to its primary raw material. Also, it conforms to the definition of supply chain used by this dissertation, which starts from the raw materials.

The second assumption is that a partition or a supply chain member is defined as each partition beginning with a different NAICS code. This ensures that supply chain members of a particular group who produce similar goods or services as per the NAICS code belong to the same partition. Hence, echelons in the supply chain would simply be the number of linkages between the raw material producer and the final consumer.

The third assumption is that the supply chain is unidirectional. This means that the flow of materials is from the raw material producer to the end customer. It is possible, and the Input–Output table shows, that back linkages exist between the downstream supply chain member and the upstream supply chain member. However, this dissertation concentrates on only that part of the Input–Output table that is to the right of the diagonal. This is one of the limitations of this study that would be relaxed in further research. The reason for this limitation is that there are many industries that keep referencing each other, and there would be no way of terminating those supply chains. Also, computationally keeping track of back linkages was challenging and was found to be beyond the scope of this dissertation.

4.3.7 Complexity of the Input–Output Tables

The number of industries within each partition or echelon has been discussed table 4.1. For example, the total number of combinations possible if each and every industry at NACIS code “2xxxxx”

Echelons	2	3	4	5	6	7
1	486	6192	216	864	180	198
2		9288	324	1296	270	297
3			4128	16512	3440	3784
4				576	120	132
5					480	528
6						110

Table 4.2: Feasible Combinations in Input–Output Table for All Years

Echelons	2	3	4	5	6	7
1	22	297	15	34	28	23
2		1170	46	98	33	36
3			841	1426	678	502
4				236	80	72
5					189	168
6						0

Table 4.3: Actual Combinations in 1982 Benchmark Input–Output Table

Echelons	2	3	4	5	6	7
1	11	273	14	30	27	21
2		1154	42	93	32	33
3			760	1513	714	513
4				239	81	72
5					191	168
6						0

Table 4.4: Actual Combinations in 1987 Benchmark Input–Output Table

Echelons	2	3	4	5	6	7
1	46	426	11	42	25	25
2		1334	49	124	46	39
3			662	1430	670	516
4				284	95	75
5					259	215
6						0

Table 4.5: Actual Combinations in 1992 Benchmark Input–Output Table

Echelons	2	3	4	5	6	7
1	22	211	24	28	37	50
2		1897	66	204	42	49
3			1204	4608	1401	1424
4				449	96	100
5					340	368
6						26

Table 4.6: Actual Combinations in 1997 Benchmark Input–Output Table

consumed goods and services from each and every industry in "1xxxxx" is $27x18 = 486$. This is reflected in the intersection of cells of producing industry "1" and consuming industry "2"[10] in table 4.2. Similarly, the total possible combinations of all the intersections of producing and consuming industries that are toward the right of the diagonal[11] are given in table 4.2. For this dissertation, the focus is on the cells which are to the right of the diagonal, and the reason for using these specific cells has been addressed in the earlier section.

Even at a casual glance, it is apparent that to construct supply chains, the number of permutations and combinations needed is approximately of the order of magnitude of $10E17$. Hence, a significant amount of computational power and memory storage area are required to process the generation of supply chains. This dissertation uses Matlab and "C" programming language to manipulate matrices of these sizes to generate the supply chains. The hardware consisted of using a 2000 Windows server with a 4GB RAM and a 250GB hard drive space to statistically analyze the data using STATA SE. [12] The initial generation of supply chains from the 1982, 1987, and 1992 benchmark Input–Output tables used LINUX as its operating system on an Intel Xeon dual processor chip whose processor speed is 2 Giga Hertz with a 256 kilobyte cache and a 1 gigabyte RAM. The 1997 benchmark Input–Output table used a cluster of machines[13] to generate supply chains, due to the huge size of the data set and the long time needed to generate each supply chain.

Table 4.3, 4.4, 4.5, and 4.6 gives the actual number of feasible cells. A feasible cell would have a non zero element in the intersection of a producer and user industry. For example, the total number of possible combinations from producing industries "1" to consuming industries "2" is $27x18 = 486$. However, since in reality not all outputs of all industries become inputs in the consuming industries, the actual combinations drastically drop. To calculate the actual number

[10] All rows are producing industries and all columns are consuming industries.

[11] To avoid cross references and infinite length supply chains.

[12] STATA SE's statistical analysis is limited by the configuration and memory of the hardware used unlike SAS or SPSS and hence was the optimum statistical package used for this dissertation.

[13] The LINUX based cluster consisted of 351 machines.

Input-Output Benchmark Years	Number of Supply Chains	Total Value Added (1997 prices ($ billions))	GDP of U.S. (1997 prices ($ billions))	Total Value Added as % of GDP
1982	61,392	612.17	3,203.19	19.11
1987	44,259	491.49	4,635.99	10.60
1992	60,545	450.17	6,169.46	7.29
1997	79,767	418.74	8,732.35	4.79

Table 4.7: Total Value Added of the Supply Chains as a Percentage of U.S. GDP

of feasible cells for a given producer and user intersection, the following methodology is adopted. For example, to calculate the intersection of "1" and "2", the total number of times a specific industry within NACIS code "1xxxxx" refers[14] to any of the industries within "2xxxxx" is calculated. This number is then added for all industries starting with NACIS code "1xxxxx" and referring to any industry ending with "2xxxxx". The actual combination of the intersection of "1" and "2" drops drastically from 486 to 22. The feasible cell is a subset of table 4.2. Each feasible cell is an echelon, which is part of either a valid or invalid supply chain, depending on whether the supply chain terminates at NAICS code "5" or "7." for the 1982, 1987, 1992, and 1997 benchmark Input–Output table. Table 4.4 has fewer non-zero cells compared to table 4.3. Also, the total number of non-zero elements increase from the 1987 benchmark Input–Output table till the 1997 benchmark Input–Output table.[15] The analysis and results of these non-zero elements, which form an echelon within a supply chain, will be discussed in the results section of this dissertation.

Table 4.7 refers to the total value added of supply chains as a percentage of the U.S. GDP[16] used in the dissertation analysis. This dissertation uses only the cells that are to the right of the diagonals of the Input–Output table. All GDP and "Total Value Added" are at 1997 prices. The number of supply chains increase over time even though the analysis uses the same NAICS codes consistently throughout the four Benchmark Input–Output tables. In 1982, the total value added by supply chains used in the analysis was 19.11 percent of the GDP of U.S. In 1987, this percentage dropped to 10.60, followed by 7.29 percent of U.S. GDP in 1992 and 4.79 percent of U.S. GDP in

[14]The presence of non zero element in the Input–Output table.

[15]Table 4.4, 4.5, and 4.6.

[16]See http://www.infoplease.com/year.

1997. These numbers may indicate that this analysis is only capturing a small percentage of the overall economy. However, it is important to note that the majority of the GDP is captured by the diagonal cells in the Input–Output tables. The diagonal cells cannot help us in identifying valid supply chains because they provide an infinitely recursive loop of material flow. Furthermore, the decrease in percentage of GDP captured over time can be explained mostly from the requirement to examine a stable set of NAICS codes. If the analysis were expanded to examine the entirety of Input–Output table to the right of the diagonals, the approximate percentage of GDP captured in other benchmark years would be same as 1982.

4.3.8 Differences Between NAICS Code-Based Tables and SIC Code-Based Tables

The 1997 NAICS code based Input–Output table differed significantly from the 1982, 1987, and 1992 SIC code based Input–Output table. The NAICS code was based on grouping industries based on the similarity of products manufactured or processed. Some of the SIC codes were grouped differently in every benchmark table.

Certain industries that played prominent roles in the U.S. economy were given a separate code under NAICS, whereas these industries were grouped together under the SIC codes.

The 1982 value added figures were expressed in thousands of dollars compared to millions of dollars for value added figures in the 1987, 1992, and 1997 tables.

The data was stored in different formats in the Bureau of Economic analysis' website for different years. For the years 1982 and 1987, the website had a partial matrix, during which an entire matrix was generated. Since the final matrix was a 470 by 470 matrix, MATLAB had to be used to generate the matrix.

4.3.9 The Supply Chain

The Input–Output table is used to create complete supply chains. [17] The raw material is procured from basic industries such as agriculture, hunting, fishing, forestry, crop production, and logging. These industries have NAICS codes starting with "1." The end consumers belong to NAICS code "5" and "7," which are the service industries.

The raw data for the five year periods 1978–1982, 1983–1987, 1988–1992, and 1993–1997 are consolidated into "benchmark" Input–Output tables of 1982, 1987, 1992, and 1997 respectively, by the Bureau of Economic Analysis under the Department of Commerce. This data is available in the website of the Bureau of Economic Analysis.[18] The data can be downloaded onto a storage medium for further analysis.

The raw data of the SIC coded benchmark Input–Output tables 1982, 1987, and 1992 are made consistent with the 1997 NAICS coded benchmark Input–Output table. The basis of comparison across time is the NAICS 1997 codes, as there is consistency with the data being compared and also there is a logical connection of industries within the same NAICS code. The basis for making the SIC codes and NAICS codes consistent with each other are the tables published by U.S. Census Bureau in Appendix A of the "Survey of Current Business, December 2002" and "Benchmark Input-Output Accounts of the United States, 1997."

After making the codes consistent across tables, the next step is to trace the path of the supply chain within each table. To construct a valid supply chain at the level of the industry, the starting point is always the raw materials source, which is represented by all the industries with a NAICS code starting with "1." The supply chain is complete when the end user is reached. The detailed procedure is given below.

[17] A complete supply chain tracks the movement of products right from the stage of raw material procurement till its consumption by the end consumer.

[18] See www.bea.gov.

The entire Input–Output table is in the form of a 470 by 470 matrix. The basic supply chain generating code is written in Matlab. The reason for choosing Matlab is that it is a very versatile application for matrix manipulation. The rows of the matrix are the producing industries while the columns represent the user industries.

The Matlab code starts with looking at the very first industry starting with NAICS code "1."[19] The Matlab code then looks at all the non-zero elements in the intersection (cell) of the producer row and the user columns. Once the first non-zero cell[20] is detected, the six-digit user industry NAICS code is recorded. The program also stores the value of the cell. This user industry then becomes the producing industry for the next set of downstream user industry. The row for this user industry[21] is located and then the code locates other user industries whose starting NAICS code has a number greater than the producing industry's NAICS code.[22] This procedure is repeated till the end user industry[23] is reached. At this point, the program records the path taken and also the "value added" between each of the producing and user industries.[24] In case there exists a cell that has a zero element, then the supply chain is considered to be incomplete and the Matlab code goes back to the first partition[25] and starts the procedure all over again. Incomplete supply chains are not recorded. The Matlab program then goes through all the raw material suppliers starting with NAICS code "1" and terminating at any of the end users terminating at either "5" or "7." A flow chart is attached (Figure 4.3) to further illustrate the generation of a supply chain.

[19]In the first row.
[20]A non-zero cell indicates that the user industry is buying from the producer industry.
[21]This now becomes the producing industry.
[22]This is to prevent back linkages and same industry references which in turn would sometimes lead to an infinitely long supply chain.
[23]Industries starting with NAICS code "5" or "7."
[24]As defined by the researcher.
[25]Industries starting with NAICS code "1."

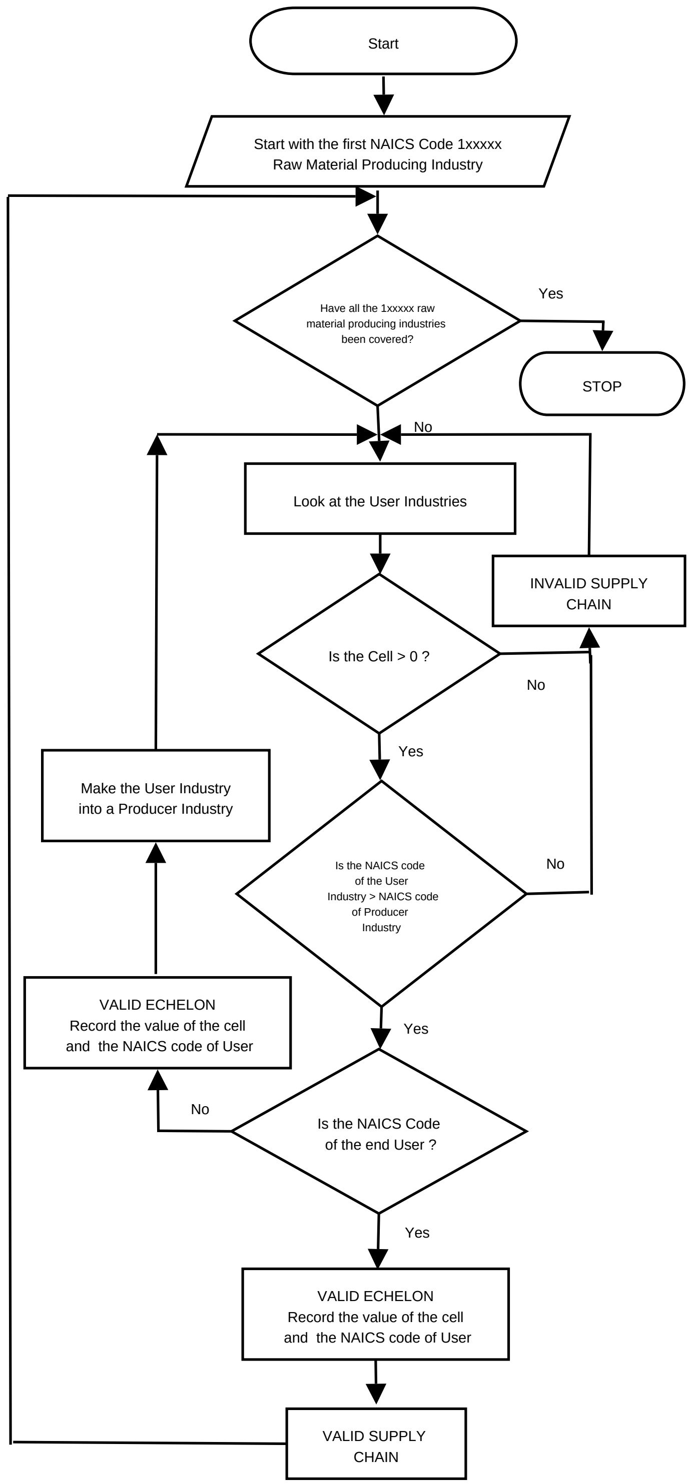


Figure 4.3: Flowchart to Generate a Valid Supply Chain

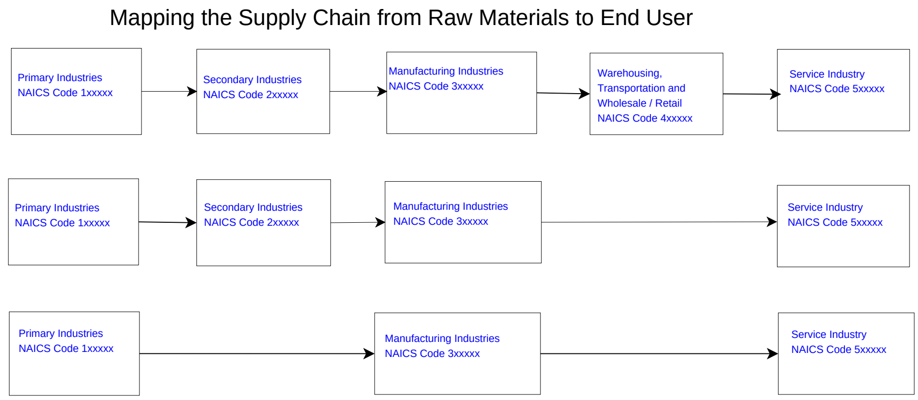


Figure 4.4: Defining Echelons in a Supply Chain

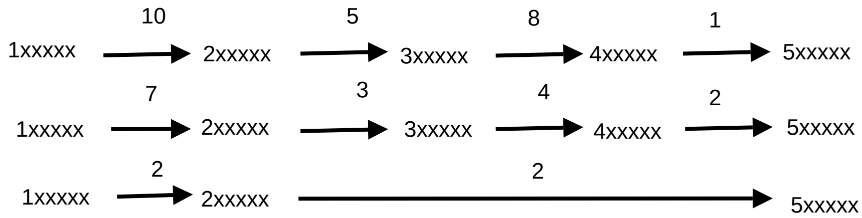
The links between the supply chain partners in a given supply chain are the number of echelons in that specific supply chain. For example, in Figure 4.4, the first supply chain consists of five supply chain members from different NAICS codes, and the number of echelons is four. Similarly, the second supply chain is a three-echelon supply chain and the third supply chain is a two-echelon supply chain.

4.3.10 Total Average Value Added and Length of the Supply Chain

The length of the supply chain is the number of echelons in the supply chain. For example, in Figure 4.4, the length of first supply chain is five, the length of the second supply chain is three, and the length of the last supply chain is two. The problem with this definition of supply chain is that it assigns equal weight to all the supply chains independent of the value contributed by each supply chain to the specific end user.

The average length of the supply chain should take into account the different value added[26] by each of the different supply chains that make up the industry or the economy. This ensures that each supply chain gets a proportionate weight in the overall length of the supply chain, either at the level of the economy or at the level of the industry. Consider the following hypothetical

[26] "Difference between a firms' sales and its intermediate purchases of materials and services from other firms" (Lawson (1997)).



All value added figures are in dollars

Total value added of all the supply chains $= 44$

Avg. length of the supply chains without value addition
$= (4+4+2)/3 = 3.3333$

Avg. length of the supply chains with value addition
$= (24/44)x4 + (16/44)x4 + (4/44)x2 = 3.8181$

Figure 4.5: Computation of Average Length of Supply Chain

example. In Figure 4.5, the assumption is that there are three supply chains with lengths of four, four, and two, which make up the economy. Each of these supply chains have echelons that add a different amount of "value addedness" at each stage. If the amount of value added at each echelon was not a criteria in the length of the supply chain, the average length of the supply chain for the entire economy ends up to be 3.3333. This clearly distorts the picture, since the first supply chain contributes more to the overall economy compared with the last chain. The first supply chain should have more weight compared with the last supply chain. To correct this distortion, the amount of value added by each echelon is taken as a weight for that specific supply chain. The average length of the supply chain after including the value added by each of the supply chains is now 3.8181, which is the true reflection of the economy.

Each of the individual supply chains have their lengths corresponding to the amount of value added by each one of them. The lengths of the supply chains before considering the value added by each of them are 4, 4, and 2, respectively. Only when the lengths of supply chains are aggregated at the level of the industry or economy does the notion of weighting the value added by each of the supply chains come into question.

	2xxxxx	3xxxxx	4xxxxx	5xxxxx
1xxxxx	20	3		1
2xxxxx		5	3	
3xxxxx			6	
4xxxxx				3

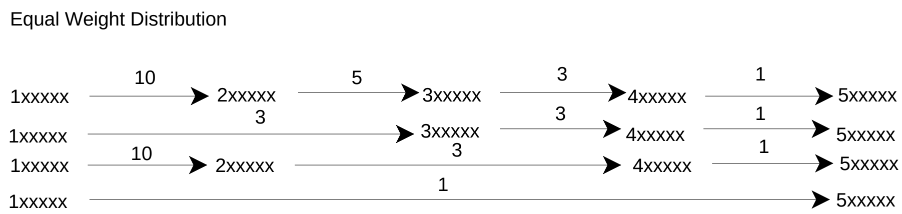


Figure 4.6: Calculation of Value Added at Each Echelon of a Supply Chain

This dissertation uses the value added by each of the echelons in the individual supply chains to weight the average length of the supply chains at the aggregate level.

The aggregated values between different members of the supply chain, as given in the Input–Output table, need to be disaggregated between different echelon members to prevent multiple counting of the value added in each unique supply chain. Figure 4.6 gives an illustration on how the value added figures are distributed in each unique supply chain.

For example, in the first supply chain, the producer industry 1xxxxx adds value worth \$20 before selling it to 2xxxxx. Industry 2xxxxx in turn adds \$5 before selling it to 3xxxxx which in turn adds \$3 in value and sells it to 4xxxxx. 4xxxxx adds \$1 in value and becomes the producer to 5xxxxx. The total number of unique supply chains that can be generated using this Input–Output table are four.[27] Since there are two supply chains sharing \$20 between 1xxxxx and 2xxxxx, \$10 is allocated to each of the echelons of these unique supply chains. Similarly, three supply chains share \$3 between 4xxxxx and 5xxxxx, and hence \$1 is allocated to each of those echelons. This

[27]Assuming the starting raw material producer to be 1xxxxx and the end user to be 5xxxxx.

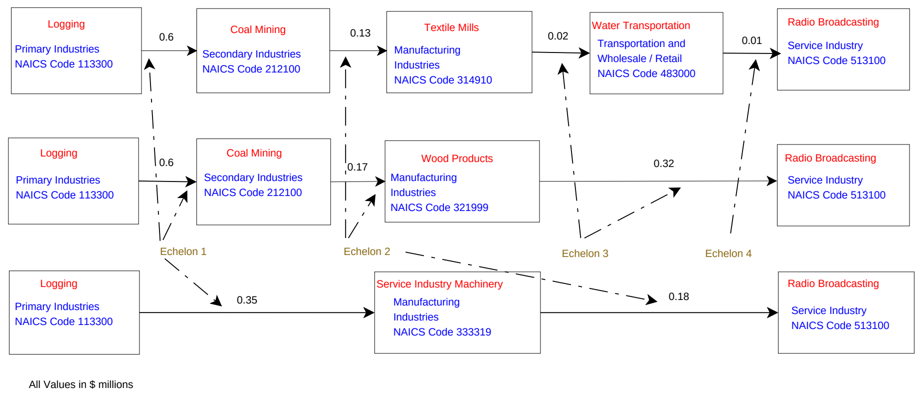


Figure 4.7: Supply Chains Lengths Weighted by Value Added at Each Echelon

dissertation breaks down the aggregate value added in the supply chains generated by dividing the aggregate value added by each pair of echelon and dividing it by the number of pairs of echelons.

4.4 The Final Supply Chain

A good indication of the final appearance of the supply chain is given in Figure 4.7.[28] The supply chain in this example is terminating at the service industry "Radio Broadcasting" with a NAICS code "513100." There are many ways in which the end user,[29] could have raw materials processed and converted into usable products by other supply chain members. In this example taken from the benchmark 1997 Input–Output table, the primary raw material lumber,[30] reaches the end user radio broadcasting in three different ways. In the first supply chain, coal has been used along with the logs in the textile mills to reach the end consumer via water transportation. This is an example of a four-echelon supply chain. In the second supply chain, lumber and coal have been used in making furniture or hardwood, which have been used by radio broadcasting. This is an example of a three-echelon supply chain. The third supply chain consists of lumber being used by a service machinery builder, which in turn supplies the machinery to the end user, i.e., radio broadcasting. This is an example of a two-echelon supply chain. Also note that due to the way the supply chain

[28]Figure 4.4 is the raw supply chain.

[29]In this case radio broadcasting.

[30]NAICS Industry Code 113300 (logging).

has been constructed, back linkages and same industry reference have not been allowed and thus are limiting factors in generating more complex supply chains.

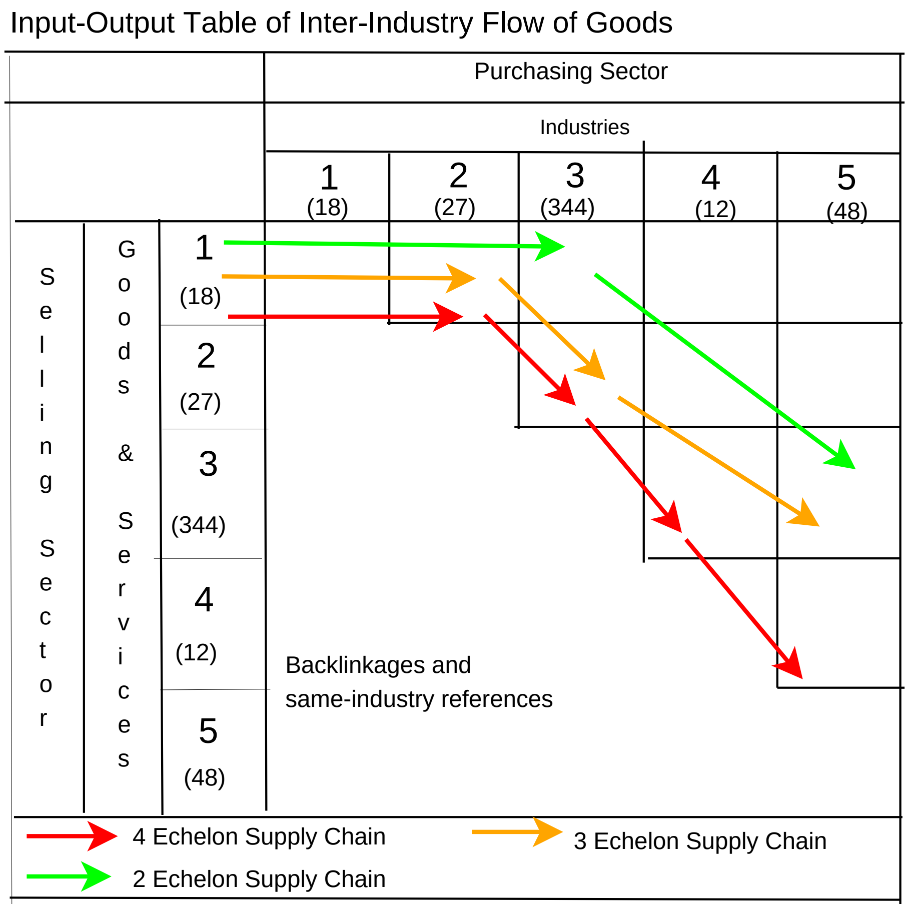
The values written at the link between two supply chain members denote the value added to the product by the previous supply chain member. For example, in the second supply chain, logging adds \$0.6 million value to lumber, which is then sent to the coal mining industry for further refining. Coal mining in its turn adds another \$0.17 million to the value of the lumber before sending the output to the wood products industry. This industry adds \$0.32 million to its input and sells the output to radio broadcasting. The total value added by this entire supply chain is \$1.09 million, while the average value added by this three-echelon supply chain is \$0.363 million.

Figure 4.8 is an example of how the Input–Output table would look given the assumptions made in generating the supply chains. The entire left quadrant of the Input–Output table and the diagonals would not be considered in generating supply chains due to the problems already listed.

The length of the supply chains compared across time would have to include only those industries that existed consistently for the year 1982 benchmark Input–Output tables through the years 1997 benchmark Input–Output table. This is done to ensure that new industries being added at different time periods do not distort the results of the evolution of the supply chains of existing industries. The industries that existed at the beginning of the 1982 benchmark Input–Output table have been used as the reference for all other years.

The data collected while generating unique supply chains for the 1982, 1987, 1992, and 1997 benchmark Input–Output table are the year of the benchmark Input–Output table, the number of echelons in each unique supply chain, each echelon member that makes up the supply chain, the value added by each of the echelons,[31] the total value added by the entire supply chain, and the

[31] After disaggregating the value added to each supply chain member.



Adapted from : Inout-Output Table : U.S. Department of Commerce,
Bureau of Economic Analysis

Figure 4.8: Mapping Supply Chains from Input–Output Table

average value added by each of the supply chain.[32] This data is then used in the analysis on the evolution of supply chain lengths and to answer the question whether supply chains tend towards more market-based transactions.

Transaction Cost Economics provides a basis to study the length of the supply chain. Even though the elements of TCE are not directly observable, and in most cases difficult to measure, past literature relies on reconciling the theory of TCE and the outcomes of a firm (Hobbs (1996)). In the case of Canadian forest product industries, TCE predicted a hierarchial structure, which was confirmed through empirical investigation (Globerman and Schwindt (1986)). Levy (1985) use intensity of research and development expenditure as a proxy to asset specificity in the U.S. food industry to measure transaction cost. Lack of data to evaluate complete supply chains and criticism of case-based studies and limited industry specific data were not representative of the wider economic environment even when used with TCE (Hobbs (1996); Frank and Henderson (1992)). This dissertation develops industry wide supply chains and uses TCE to make predictions about the governance structure and the U.S. economy in general. These supply chains can be used by future researchers to generalize their findings.

[32] At 1997 prices.

Chapter 5

Research Methodology - Length of Supply Chain and Coordination Mechanisms

5.1 Simulation and Supply Chains

This dissertation uses simulation, in the absence of empirical data, to model the effect of different coordination mechanisms on the length of the supply chain.[1] Simulation has the advantage of building an experimental model of a system and then evaluating the alternatives, which are specific to the model in a series of test runs (Powers (1991)). Simulation is used in cases where the system is too complicated to be broken up into an analytical framework or where gathering of primary or secondary sources of data is nearly impossible. Simulation also helps in understanding the system as a whole and can be manipulated to test the system under different sets of inputs.

Several analytical papers have looked at ordering policies and supply chains. Almost all of the papers have assumed the ordering policies to be the same for all echelons of the supply chain. Boyaci and Gallego (2004); Khouja (2003); Starbird (2003) have found that, compared with harmonized supply chains (in terms of ordering policies), non-harmonized supply chains may not be inefficient, under certain circumstances. The contribution of this dissertation is to use simulation to determine the circumstances under which non-harmonized supply chains may be as efficient as non-harmonized supply chains.

Current literature in the field of inventory management focuses on research in supply chains, which are normally not longer than two echelons. The rationale for this may not be surprising. Lee et al. (1999) looked at EDI adoption on thirty-one retail chains to gauge the effect on the entire supply chain. Data collection on the entire supply chain was difficult to collect and hence the results of the retailers were used to draw conclusions on the performance of the entire supply chain. Zhao et al. (2002a); Lee et al. (1997b); Ozer (2003); Iyer and Jain (2003); Chen (1999); Lee (1987); Graves and Tomlin (2003) are some of the authors who took this approach. Most of these

[1] Coordination mechanisms and heuristics will be used interchangeably.

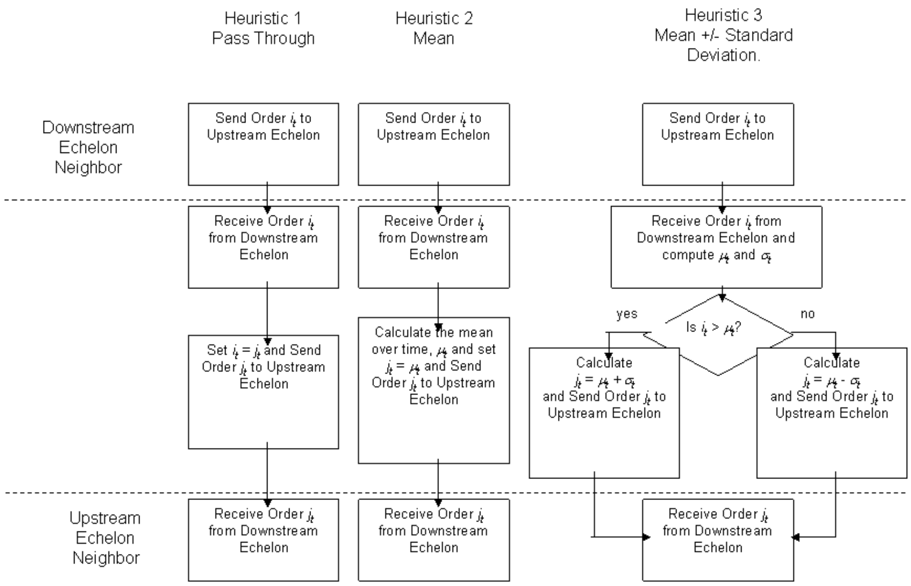


Figure 5.1: Heuristics Used in the Simulation

papers were analytical in nature with numerical examples used to back up the analytical framework.

Some papers, which looked at multi-echelon supply chains, pertained to the "Bullwhip effect" (Taylor (1999); Lee et al. (1997a); Towill and McCullen (1999)) and inventory management (Williams (1981); Biggs (1979); Clark (1972); Markland (1975); Markland and Newett (1976); Chen (1999)). All of the papers mentioned above were analytical and assumed a harmonized coordination systems (ordering policies or heuristics) among different echelons of the supply chain.

5.2 Heuristics / Coordination Mechanisms Used in the Simulation

From past literature, three heuristics have been developed to simulate ordering policies between various echelons of the firm; i.e., from the customer to the raw material supplier. Beamon (1998) summarizes the various models and methods used and the most favorable outcomes determined, to reduce the Bullwhip effect. Transmitting the actual demand along the entire supply chain (Taylor (1999); Forrester (1958); Lee et al. (1997a); Beamon (1998); Kalchschmidt et al. (2003)) was found to be one of the most popular heuristics used to control the Bullwhip effect. Another

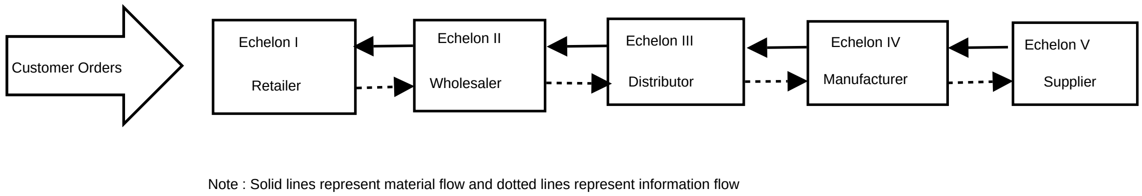


Figure 5.2: Five Echelon Supply Chain

heuristic used in the literature was to transmit the mean demand along the entire supply chain (Zhao et al. (2002a); Kalchschmidt et al. (2003)). The mean demand is a moving average of previous demand forecasts. Participants in the "Beer Game," for example, use this methodology to find a pattern over a period of time and to increase their demand-forecasting accuracy. Another popular heuristic commonly used is to calculate demand based on mean and then correct for the upward or downward trend in demand by either adding or subtracting the standard deviation from the mean (Zhao et al. (2002a); Ozer (2003); Kalchschmidt et al. (2003)). This has been developed as an extension to the mean. The standard deviation helps to account for upward and downward trends. A summary of the three heuristics used by the echelons can be seen in figure 5.1.

5.3 Use of Long Supply Chains in the Simulation

This dissertation uses a five-echelon supply chain to simulate information and material flow. The supply chain consists of a raw material supplier, a manufacturer, a wholesaler, a retailer, and a customer (Figure 5.2). This configuration has been adapted from the Beer Game (Sterman (1984); Chen and Samroengraja (2000); Sterman (1992)).

in the methodological section, the contribution of this dissertation over past literature is the examination of long supply chains instead of short supply chains.[2] Analytical papers have used a dyadic relationship between two echelons in the supply chain[3] to analyze supply chain coordination

[2]Past literature mostly used dyadic relationships in their analysis.

[3]Usually a buyer-seller, manufacturer-distributor, or wholesaler-retailer.

and performance (Munson et al. (2003); Ko et al. (2004); Boyaci and Gallego (2004); Dudek and Stadtler (2005); Schneeweiss and Zimmer (2004); Gan et al. (2004); Shang and Song (2003); Cachon (2004)). In all of the above-mentioned studies, the results obtained on the effect of coordination on a dyadic relationship were extrapolated onto the entire supply chain. There have been several empirical papers on supply chain coordination and performance (Svensson (2003); Ross (2002); Choi and Hartley (1996); Boger et al. (2001); Humphries and Wilding (2001); Williams et al. (2002); Ettlie and Sethuraman (2002)). These papers are mostly survey-based and use a dyadic relationship as their unit of analysis. Some papers have used simulation to look at the effect of coordination on performance (Zhao et al. (2002b)), but have looked at a dyadic relationship. Case-based studies have looked at entire supply chains but their results are not easily generalizable (Taylor (1999)). Kemppainen and Vepsalainen (2003) used a three-echelon supply chain in their empirical investigation on coordination and IT systems, but their respondents were limited to the focus industry within the three-echelon supply chain. Khouja (2003) used multiple dyadic relationships to recreate an entire supply chain in their analytical work. Taylor (1999) used a case study methodology of the supply chain within a steel mill to show and measure the existence of the "Bullwhip effect." In this dissertation, the structure of the supply chain and the ordering policy is adapted from the Beer Game.

5.4 The Simulation

This dissertation uses the structure of the supply chain data used in the Beer Game (Sterman (1984); Chen and Samroengraja (2000); Sterman (1992)), as a basis for running the simulation.

5.4.1 Flowchart of the Simulation

Taylor (1999) examined the supply chain within a steel mill[4] to analyze and measure the Bullwhip effect. The study concluded that demand amplification exists in supply chains and that the amplification in demand increases in the upstream echelons (supplier / manufacturer) of the supply

[4]See figure 5.2.

chains compared to the downstream echelons (retailer) of the supply chain. These results are typical of most supply chains and are taught in supply chain management textbooks (Simchi-Levi et al. (2003); Handfield and Nichols (1999)). This dissertation uses five-echelons in its supply chain, with the supplier being at one extreme followed by the manufacturer, distributor, wholesaler, and retailer. The customer generates the demand, which flows up the supply chain from the retailer to the supplier and is indicated by dotted lines in figure 5.2. Material flow is indicated by solid lines and flows from the supplier all the way down to the customer.

The simulation runs on the basis of the Beer Game.[5] Figure 5.3 gives a graphical representation of the simulation. The customer orders materials every week from the retailer. The retailer in turn orders materials from the wholesaler. This upward movement of ordering materials continues until the manufacturer orders materials from the supplier. As in Taylor (1999), there is a built-in lead time of one week between each echelon of the supply chain in both ordering of a product and receiving the product. Hence, the lead time between the customer's order for goods and the customer's receipt of the goods is nine weeks.

At the beginning of each week, all the echelons forecast the demand for the next week based on the heuristics given in figure 5.1. The results of demand forecasts based on different heuristics are tracked individually. In the next activity, the demand from the previous echelon is met. In case the echelon has stock, demand is met from this stock. In case an echelon runs out of stock, demand is back-ordered, and a count is kept of the stockouts. Two separate counters keep count of the total orders and the total orders supplied. Net stock, which is the addition of stockouts and excess stock, is calculated for the entire supply chain for the week for all possible combinations using different kinds of heuristics.

[5] See Sterman (1984); Chen and Samroengraja (2000); Sterman (1992).

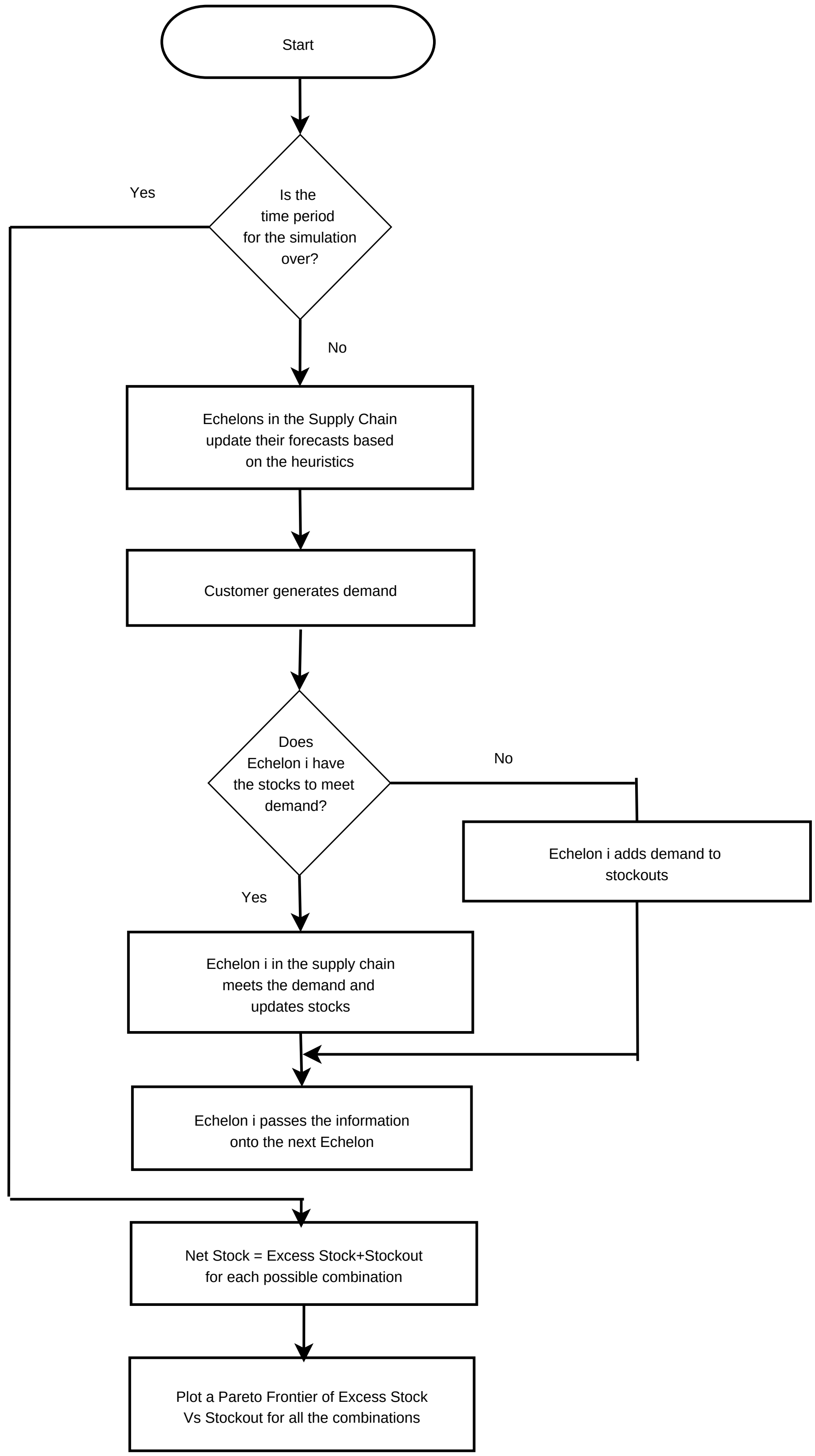


Figure 5.3: Flowchart of the Simulation

5.4.2 Demand Distributions and Coordination Mechanisms

The objective of this section of the dissertation is to look at the effects of the coordination mechanisms on the length of the supply chain as well as on the performance of the supply chain. The simulation starts when the customer first places the order with the retailer. In this simulation, the customer demand is the driving force behind the entire simulation and, hence, to make the results robust enough, different demand distributions.

The different distribution functions used in this simulation are a normal distribution with a 20 percent and 50 percent standard deviation, a poisson distribution, and a uniform distribution. These distributions were chosen for the simulation because these are the popular distributions used both in standard textbooks on inventory management (Tersine (1998)) and in past literature relying upon simulation (Zhao et al. (2002a); Ozer (2003); Kalchschmidt et al. (2003); Beamon (1998)).

As explained in the previous section, the coordination mechanisms or heuristics used are the actual demands generated by the customer, the mean of the past demands generated by the customers, and the mean of the past demands corrected for the trend. Looking at the different distribution functions and the various coordination mechanisms and also drawing upon the theory behind coordinated supply chains, it would seem that the use of actual demand by all five echelons should outperform any other combination of heuristics as they would tend to harmonize the coordination mechanisms for the entire supply chain.

5.4.3 Generation of Customer Demand

Customer demands are generated based on the different demand distributions[6] mentioned in the previous section. Common random numbers are used when generating these numbers in Matlab.[7] Customer demands for each of the demand distributions are generated for 104 weeks or two years.

[6] Normal distribution with standard deviations of 20 percent and 50 percent, poisson distribution and uniform distribution.

[7] Popular mathematical tool used for analysis.

The reason for using such a large number of weeks in the data set is to allow the simulation to achieve a steady state before any meaningful analysis can be done.

A normal distribution with a high standard deviation can produce negative demands during random number generation. For this dissertation, the random numbers generated by Matlab were all positive. In case a negative demand was generated, this dissertation would have treated the observation as zero demand.

In the initial stage, a mean of 10 is used as customer demand distribution for 104 weeks. This is consistent with Zhao et al. (2002a,b). As part of the sensitivity analysis mean customer demand of 50 and 100 are used for 104 weeks and the results between mean demand of 10, 50, and 100 are checked for robustness.

5.4.4 Sample Size of the Simulation

The five-echelon supply chain uses three different heuristics while analyzing the conditions in which non-harmonized heuristics perform as well as harmonized heuristics. Further, these heuristics are tested for a period of 104 weeks, which is equivalent of two years. Also, each of the four demand distributions for a particular mean[8] get tested for 104 weeks. The unit of observation is a specific heuristic adopted by a supply chain for 104 weeks. Hence, the total number of observations generated for each mean is 4x3x3x3x3x3 = 972.

Not all results generated by the simulation will be used in the analysis. This is because the simulation takes certain number of cycles to build up to a steady state. The observations generated before the simulation reaches a steady state cannot be used in the analysis. For this simulation, approximately 20 weeks of data could not be used in the analysis. Figure 5.4 gives the simulation result of the total demand met for all the 104 weeks for a particular demand distribution.[9] The

[8] The different means used in the simulation are 10, 50, and 100 to test the robustness of the results.

[9] $\mu = 10 and \sigma = 2$.

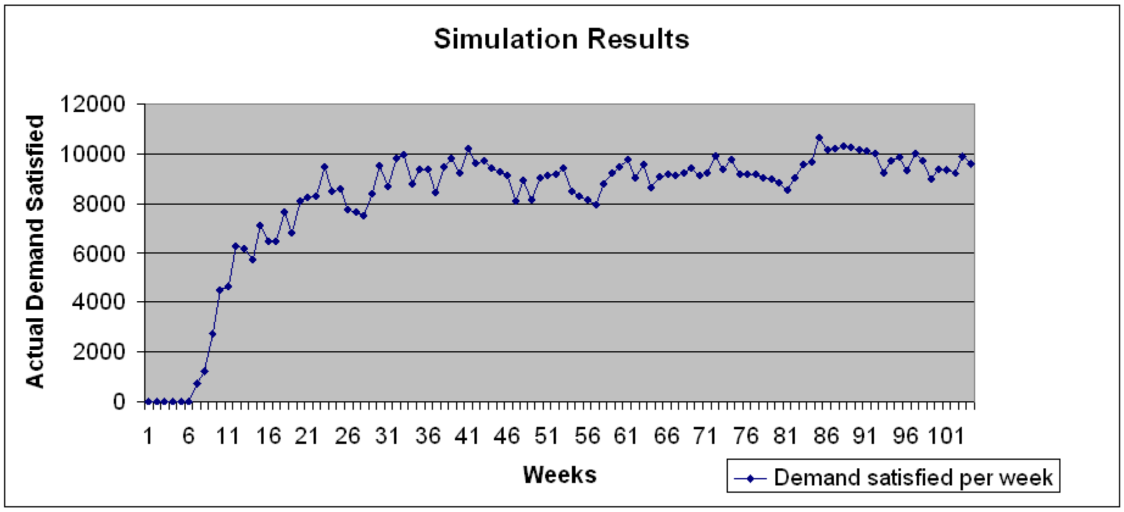


Figure 5.4: Simulation Results with Demand Normally Distributed with $\mu = 10, \sigma = 2$

X-axis consists of the total number of weeks while the Y-axis records the total demand met every week. After 20 weeks of running the data with every possible combination of strategy adopted by the supply chains, the total demand met settles into a steady state. This is true of all other demand distributions too. Hence, this dissertation does not use the first twenty weeks of data in the analysis. The total number of observations remain the same at 972, but the number of weeks used to analyze each strategy gets reduced from 104 weeks to 84 weeks.

5.4.5 Calculation of Net Stock

The customer generated demand is transmitted up the supply chain, and each of the echelons are free to use any of the heuristics given in figure 5.1. The simulation considers all possible permutations and combinations[10] and provides the number of stockouts and excess stocks for each echelon as the output. For example, the actual customer demand can be used as a heuristic between two echelons, while two other echelons could use the average of previous orders as their heuristics for coordinating between themselves. Net stock for each supply chain, for every possible combination of heuristics, are computed by adding the absolute value of stockouts and excess stocks generated by individual echelons. Since the entire decision tree and payoff in terms of net stock can be rep-

[10]Total number of usable observations generated is 1012.

resented as a matrix, MATLAB is used as the preferred tool of programming. The large volume of transactions necessitated the use of STATA as a tool to statistically analyze the data.

As explained earlier, net stock (at the level of a supply chain) is the summation of the absolute values of all excess stock and stockouts (at the level of individual ecelons). Hence, any week whose net stock deviates from zero would in effect have demand amplification in the system. A supply chain using a specific heuristic or a combination of heuristics outperforms other supply chains when the net stock generated by the supply chain is the minimum (as close to zero as possible).

5.4.6 Net Stock as Performance Measure

The performance measure used to analyze the effectiveness of coordination mechanisms is the net stock[11] at hand after each of the echelons has placed an order. Zhao et al. (2002a); Ko et al. (2004); Munson et al. (2003); Taylor (1999); Svensson (2003); Dudek and Stadtler (2005) are some papers that use net stock as a performance variable in the absence of relevant costs. For this dissertation, it is impossible to assign any stockouts costs or holding costs to stock, as these costs vary sharply between different industries. However, mathematically, if costs are assigned to the stocks, the final results may change since stockouts have a greater weight than excess stock. Here, the prime objective is to find out whether coordinated supply chains outperform uncoordinated supply chains using net stock as a measure of performance. Hence, based on past literature and in the absence of relevant costs, this dissertation uses net stock as a performance measure.

In order to find the minimum net stock among all the heuristics used by the supply chains, a scatter plot is used. Net stock is represented on the X-axis while heuristics are represented on the Y-axis. The heuristic which has the least amount of net stock would be the first data point on the scatter plot. A histogram is also plotted to know the total number of heuristics which have

[11]Total net stock at hand is the summation of all the surplus stock and stockouts generated by any of the echelons (surplus stock + excess stock).

the minimum net stock.

The assumptions made in the analysis are that lead-times are uniform across all the echelons of the supply chain,[12] cost is not a criteria in terms of stock-outs and excess inventory, and all the players can independently follow any heuristic they choose. Uniform lead-times are chosen across all the echelons to reduce the complexity of the problem.

5.4.7 Determining Harmonized Heuristics

A supply chain is deemed to be using harmonized heuristics if it uses the same set of heuristics across all its echelons within the supply chain. All members of a supply chain basing their ordering policies on the mean of the previous demands is an example of harmonized heuristic. Even if one of the supply chain members uses a heuristic not used by other members of the supply chain, the supply chain is deemed to be using non-harmonized heuristic.

In the entire set of combinations of heuristics, there are only three situations in which supply chains use harmonized heuristics. First, when all members use actual demand as their ordering policy (denoted by 11111); second, when all members use means as ordering policy (denoted by 22222), and third, when all members use means adjusted for the trend as their ordering policy (denoted by 33333). Hence, for each week and for each demand distribution, there can be only three heuristics that are harmonized out of a possible 243 combinations. As explained earlier, the expectation as per standard textbooks and literature is that these three harmonized heuristics would dominate all other combinations and have the minimum net stock.

As per current literature and hypothesis seven, supply chains tend to sub-optimize when the individual members of the supply chain act selfishly and do not have harmonized heuristics among themselves. This hypothesis is tested by using a "t-test" on the net stock of supply chains using harmonized heuristics and supply chains using a non-harmonized heuristics. The expectation is

[12] In this case one week between each echelon.

to reject the null hypothesis and find significant differences in the net stock of harmonized and non-harmonized supply chains. The harmonized supply chains should have a significantly lesser net stock than the non-harmonized chains.

Hypothesis eight states that supply chains which use harmonized heuristics should have a minimum net stock. The expectation is to find only harmonized supply chains to be efficient in terms of minimum net stock. If in case there are non-harmonized echelons with lesser net stock, then the net stock of the harmonized supply chains should not be significantly lower than the net stock of supply chains with non-harmonized supply chains but which have minimized net stock. This hypothesis is tested by using a "t-statistic" on the net stock of harmonized supply chains and net stock of supply chains with minimum net stock.

5.5 Disintermediating Supply Chains

A solution that is often cited in the literature to reduce Bullwhip Effect is to disintermediate the supply chain of members that contribute negligible value addition (Simchi-Levi et al. (2003); Lee et al. (1997a,b); Heller (2000); Bakos (1997); Spulber (1996); O'Hara (1997); Brown and Goolsbee (2002); Delfmann et al. (2002); Handfield and Nichols (1999); Chopra and Meindl (2001)). Disintermediation of supply chains is done through the removal of one or more echelons within the supply chain. To see the effect of disintermediation on the coordination mechanisms and net stock, the wholesaler and both the wholesaler and retailer are disintermediated in stages. By disintermediating the supply chain, this dissertation hopes to find better performance in terms of smaller amount of net stock.

In this simulation, disintermediating one echelon of the supply chain is equivalent to eliminating either the retailer or the wholesaler from the supply chain. In this scenario, the total number of observation becomes 324 (4x3x3x3x3). As in the case of a five-echelon supply chain, the number of weeks used in the analysis for each demand distribution is 84 weeks.[13] The total number of coordinated heuristics remain the same at three. The reduction in Bullwhip is felt because of the overall reduction in lead time due to the removal of an echelon. The assumption made here is that the echelon disintermediated does not add any value to the overall supply chain.

Disintermediation of two echelons in the supply chains is equivalent to eliminating both the wholesaler and the retailer from the supply chain. In this scenario the total number of observations becomes 108 (4x3x3x3). The total number of coordinated heuristics still remain the same at three. The number of weeks analyzed remains at 84. The assumption in using this methodology in disintermediation is that no value is being added by the intermediaries and that the lead time between echelons remain the same. This is done to simplify the problem in hand. For future research, these assumptions can be relaxed.

The objective in the ninth hypothesis, is to show that a reduction in the length of the supply chain leads to an increase in supply chain performance. The net stock in the case of disintermediation should be lower than when there is no disintermediation. This hypothesis can be tested by looking at the "t-statistic" of net stock amongst a five-echelon supply chain, a four-echelon supply chain, and a three-echelon supply chain, after accounting for the Bernforroni's factor.

[13] In order to get the simulation in a steady state; 104 weeks - 20 weeks.

Chapter 6

Results and Discussion - Length of Supply Chain and the Input–Output Table

This chapter presents the results of generating the supply chains based on the methodology developed in the preceding chapter. This chapter traces the evolution of supply chains from the four benchmark Input–Output tables of 1982, 1987, 1992, and 1997. This covers a twenty-year period from 1977 to 1997. This first section consists of results pertaining to the effect of transaction costs on the length of the supply chain, and the second section consists of discussion of the results.

6.1 Results

6.1.1 Descriptive Statistics on the Length of Supply Chain

Supply Chains Ending with NAICS code 5xxxxx

The end users with NAICS code starting with "5" consists of the following service industries: information, finance, professional and business services like newspapers, books, software, motion pictures, data processing, insurance, securities, architecture, design service, legal services, scientific research, advertisements, and other business and professional services. The number of industries represented by these groups of end users is forty-eight. However, to maintain consistency between industries from the 1982 until the 1997 benchmark Input–Output tables, the number of industries used in the analysis are twenty-five. Twenty-three industries either did not exist in all the years being compared, or were not classified separately, and hence are being excluded from the analysis.

The total number of valid supply chains generated[1] for the benchmark years 1982, 1987, 1992, and 1997 are 61392, 44259, 60545, and 79767 respectively. Figure 6.1 gives the graphical representation of all the valid supply chains terminating with NAICS code "5xxxxx." The graph clearly shows that there is a decline in the number of valid supply chains from 1982 through 1987,

[1] Taking the 1982 benchmark Input–Output table as the base year and after excluding all the new NAICS industries.

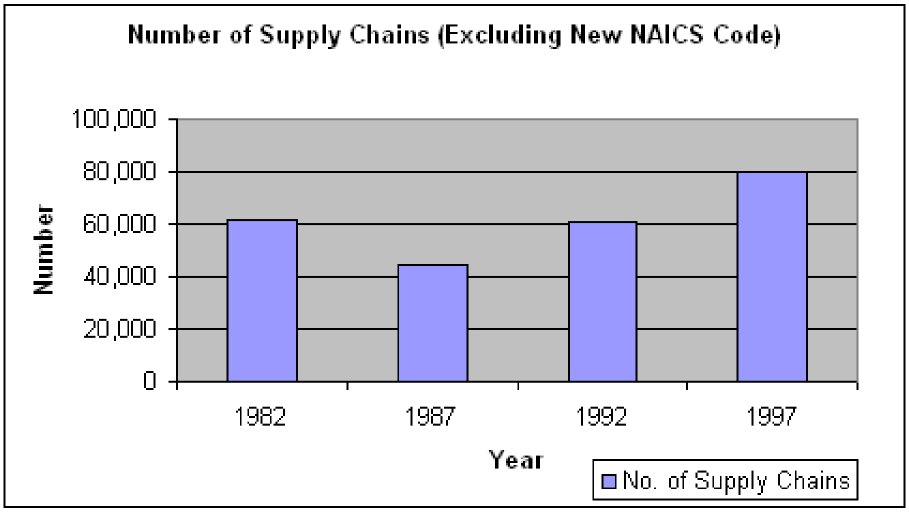


Figure 6.1: Number of Valid Supply Chains Excluding New NAICS Codes Terminating at NAICS Code 5xxxxx

and then there is an increase in the number of valid supply chains from 1987 through 1997.

Supply Chains Ending with NAICS code 7xxxxx

The end users with NAICS code starting with "7" consists of the following service industries: performing arts, amusement, leisure, sports, gambling, accommodation, and food services. The number of industries represented by these groups of end users is eleven. However, to maintain consistency between industries from the 1982 till the 1997 benchmark Input–Output tables, there are eight industries used in the analysis. Three industries either did not exist in all the years being compared, or were not classified separately and hence are being excluded from the analysis.

The total number of valid supply chains generated for the benchmark years 1982, 1987, 1992, and 1997 are 400533, 288498, 377375, and 563348 respectively. Figure 6.2 gives the graphical representation of all the valid supply chains terminating with NAICS code "7xxxxx." As in the previous section, the graph is "U"-shaped, which is skewed toward the right. There is a decline in the number of valid supply chains from 1982 through 1987, but then there is an increase in the

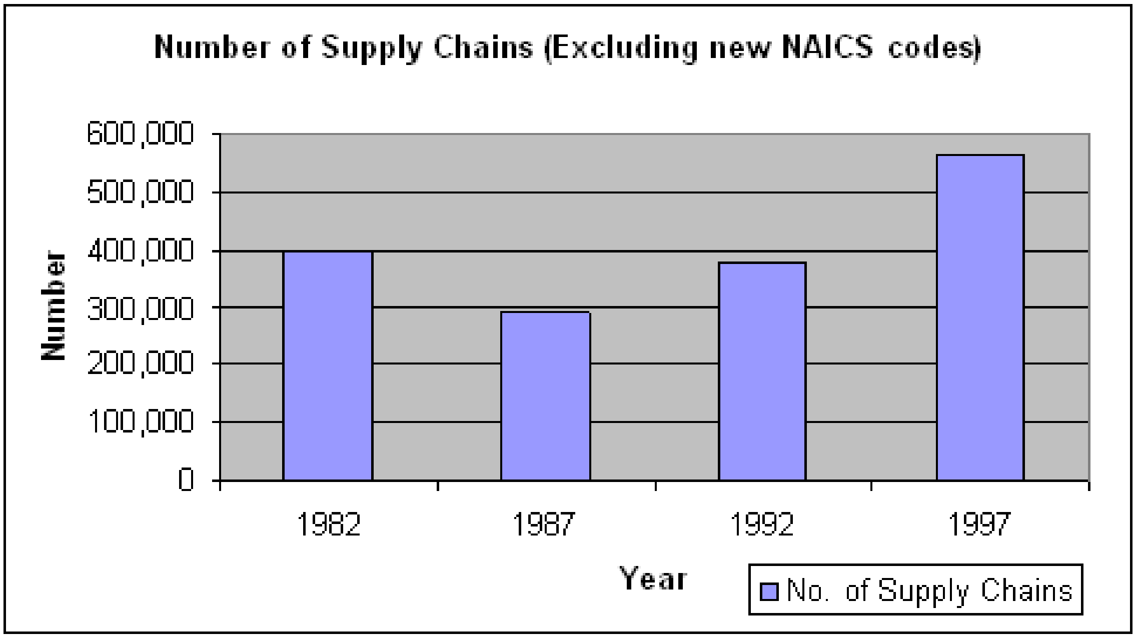


Figure 6.2: Number of Valid Supply Chains Excluding New NAICS Codes Terminating at NAICS Code 7xxxxx

Benchmark Years	1982	1987	1992	1997
No. of Valid Supply Chains	61,392	44,259	60,545	79,767
Avg. Length of Supply Chains	3.4318	3.2972	3.3118	3.4618
Standard Deviation	0.0004652	0.0003929	0.0002884	0.0003014

Table 6.1: Descriptive Statistics on Valid Supply Chains Ending with NAICS Code 5xxxxx

number of valid supply chains from 1987 through 1997.

6.1.2 Average Length of Supply Chain

According to *Hypothesis 1*, supply chains should increase in length as transaction costs decrease over time. Table 6.1 and 6.2 gives the results of the number of valid supply chains generated in all the Benchmark years. The total number of supply chains generated is that of a popula-

Benchmark Years	1982	1987	1992	1997
No. of Valid Supply Chains	400,533	288,498	377,375	563,348
Avg. Length of Supply Chains	4.1655	4.0101	4.0001	4.1406
Standard Deviation	0.0000875	0.0000905	0.0000707	0.0000559

Table 6.2: Descriptive Statistics on Valid Supply Chains Ending with NAICS Code 7xxxxx

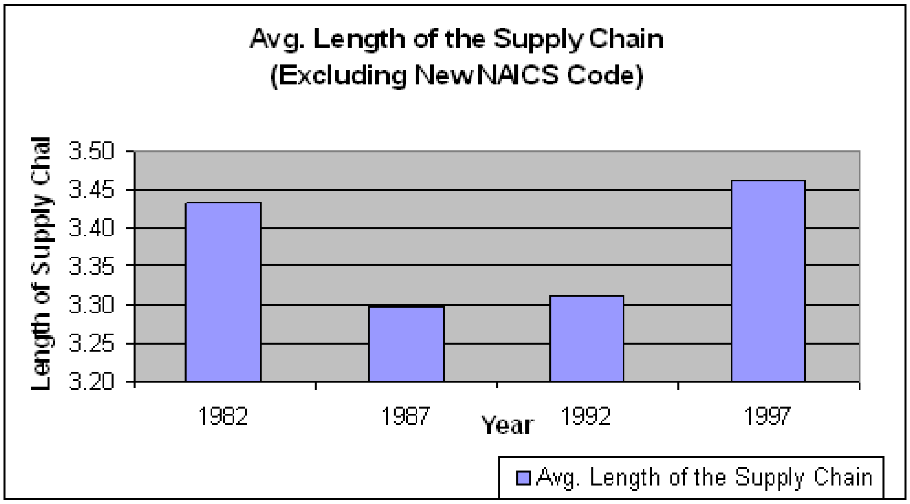


Figure 6.3: Average Length of Supply Chains Terminating at NAICS Code 5xxxxx

tion.[2] The maximum length of the supply chain[3] possible for all supply chains ending with NAICS code "5xxxxx" is **four**, while the maximum length of the supply chains ending with NAICS code "7xxxxx" is **five**. The lengths of the supply chains ending with NAICS code "5xxxxx" are 3.4318 (1982), 3.2972 (1987), 3.3118 (1992), and 3.4618 (1997). The lengths of the supply chains ending with NAICS code "7xxxxx" are 4.1655 (1982), 4.0101 (1987), 4.0001 (1992), and 4.1406 (1997).

Figures 6.3 and 6.4 give a graphical presentation of the results of the average length of the supply chain for all supply chains ending with NAICS codes "5xxxxx" and "7xxxxx" respectively. A "U"-shaped figure that is skewed toward the right is clearly visible. For supply chain lengths ending with "5xxxxx," the average lengths of the supply chain decrease from 1982 to 1987 but

[2]Given the assumptions and limitations described in the methodology.

[3]Also number of echelons.

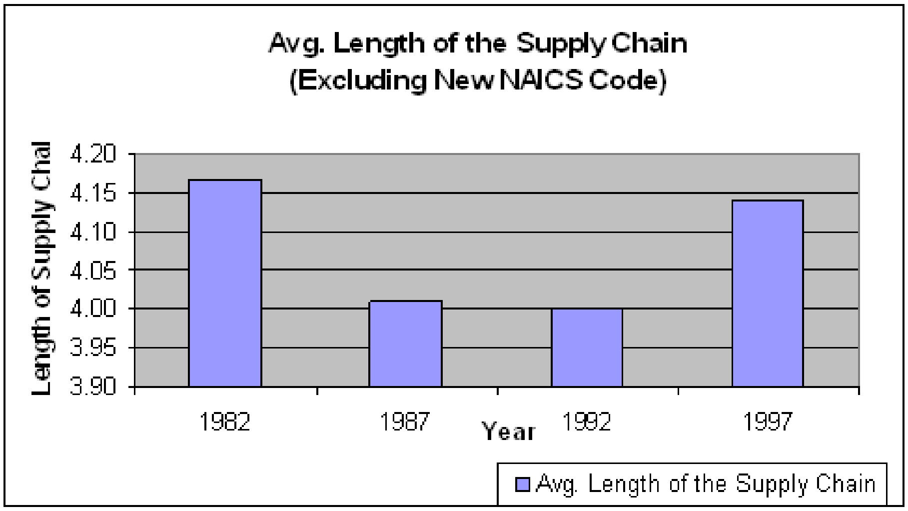


Figure 6.4: Average Length of Supply Chains Terminating at NAICS Code 7xxxxx

increase consistently from 1987 till 1997. For supply chain lengths ending with "7xxxxx," the average lengths of the supply chain decrease from 1982 to 1987 but increase from 1987 till 1997.

A pairwise "t-test" with Bonforroni's adjustment was done to determine whether or not the average lengths of the supply chain are significantly different from each other. Tables 6.6 and 6.7 give the results. All pairwise observations are statistically significant at 99 percent level. For supply chain lengths ending with "5xxxxx," *Hypothesis 1* for the years 1987 until 1997 is **supported**. For supply chain lengths ending with "7xxxxx," *Hypotheses 1* for the years 1992 until 1997 is **supported**.

The length of the supply chain could be kept from increasing in the period from 1982 to 1987 because the period from 1982 to 1987 saw a lot of mergers and acquisition, and it was a time when the U.S. economy was coming out of a recession.

Benchmark I-O Tables	Number of Supply Chains	Avg. Length of Supply Chains	Std. Error	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
1982	61,392	**3.4318**	1.88e-06	0.000465	3.431796	3.431804		
1987	44,259	**3.2972**	1.86e-06	0.000392	3.297196	3.297204		
Combined	105,651	3.375414	0.0002043	0.0664109	3.375013	3.375814	5.0e+04	0.0000
1982	61,392	**3.4318**	1.88e-06	0.000465	3.431796	3.431804		
1992	60,545	**3.3118**	1.17e-06	0.000288	3.311798	3.311802		
Combined	121,937	3.372217	0.0001718	0.06	3.37188	3.372554	5.4e+04	0.0000
1982	61,392	**3.4318**	1.88e-06	0.000465	3.431796	3.431804		
1997	79,767	**3.4618**	1.07e-06	0.000301	3.461798	3.461802		
Combined	141,159	3.448753	0.0000396	0.0148773	3.448675	3.44883	-1.5e+04	0.0000
1987	44,259	**3.2972**	1.86e-06	0.000392	3.297196	3.297204		
1992	60,545	**3.3118**	1.17e-06	0.000288	3.311798	3.311802		
Combined	104,804	3.305634	0.0000223	0.0072192	3.305591	3.305678	-7.0e+03	0.0000
1987	44,259	**3.2972**	1.86e-06	0.000392	3.297196	3.297204		
1997	79,767	**3.4618**	1.07e-06	0.000301	3.461798	3.461802		
Combined	124,026	3.403062	0.0002239	0.0788561	3.402623	3.403501	-8.3e+04	0.0000
1992	60,545	**3.3118**	1.17e-06	0.000288	3.311798	3.311802		
1997	79,767	**3.4618**	1.07e-06	0.000301	3.461798	3.461802		
Combined	140,312	3.397075	0.0001983	0.0742937	3.396686	3.397463	-9.4e+04	0.0000

Table 6.3: Pairwise t-Statistic to Compare Average Length of Supply Chain Ending with NAICS Code 5xxxxx.

Benchmark I-O Tables	Number of Supply Chains	Avg. Length of Supply Chains	Std. Error	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
1982	400,533	**4.1655**	1.38e-07	0.0000875	4.1655	4.1655		
1987	288,498	**4.0101**	1.68e-07	0.0000905	4.0101	4.0101		
Combined	689,031	4.100434	0.0000924	0.0766661	4.100253	4.100615	7.2e+05	0.0000
1982	400,533	**4.1655**	1.38e-07	0.0000875	4.1655	4.1655		
1992	377,375	**4.0001**	1.15e-07	0.0000707	4.0001	4.0001		
Combined	777,908	4.085262	0.0000937	0.0826634	4.085078	4.085446	9.1e+05	0.0000
1982	400,533	**4.1655**	1.38e-07	0.0000875	4.1655	4.1655		
1997	563,348	**4.1406**	7.45e-08	0.0000559	4.1406	4.1406		
Combined	963,881	4.150947	0.0000125	0.0122713	4.150922	4.150971	1.7e+05	0.0000
1987	288,498	**4.0101**	1.68e-07	0.0000905	4.0101	4.0101		
1992	377,375	**4.0001**	1.15e-07	0.0000707	4.0001	4.0001		
Combined	665,873	4.004433	6.07e-06	0.0049559	4.004421	4.004445	5.1e+04	0.0000
1987	288,498	**4.0101**	1.68e-07	0.0000905	4.0101	4.0101		
1997	563,348	**4.1406**	7.45e-08	0.0000559	4.1406	4.1406		
Combined	851,846	4.096403	0.0000669	0.0617603	4.096272	4.096534	-8.2e+05	0.0000
1992	377,375	**4.0001**	1.15e-07	0.0000707	4.0001	4.0001		
1997	563,348	**4.1406**	7.45e-08	0.0000559	4.1406	4.1406		
Combined	940,723	4.084238	0.000071	0.0688636	4.084099	4.084377	-1.1e+06	0.0000

Table 6.4: Pairwise t-Statistic to Compare Average Length of Supply Chain Ending with NAICS Code 7xxxxx.

Benchmark Years	1982	1987	1992	1997
Total Average Value Added by 5xxxxx	9.9715	11.1049	7.4353	5.2496
Total Average Value Added by 7xxxxx	1.8608	2.2185	1.6413	1.0220

Table 6.5: Total Average Value Added by all the Supply Chains Ending with NAICS Code 5xxxxx and 7xxxxx

All values in $ millions

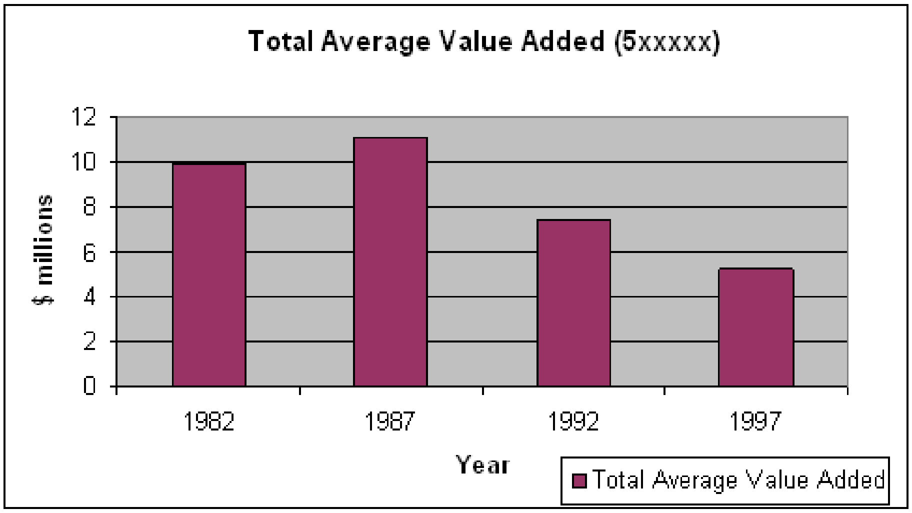


Figure 6.5: Total Average Value Added of all Supply Chains Ending with NAICS Code 5xxxxx

6.1.3 Total Average Value Added by all the Supply Chains

Hypothesis 2 states that the total average value added by all the supply chains decreases over time. This is because the price of similar products and services keeps falling over time, and since the average length of the supply chain increases, then the total average value added[4] across all the supply chain would decrease over time.

As can be seen from Table 6.5 and Figures 6.5 and 6.6, the total average value added by all the supply chains across time shows a declining trend with some exceptions. The total average

[4]The calculation of total average value added has been discussed in the methodology section. Total average value added reflects the value added contributed by each of the echelons.

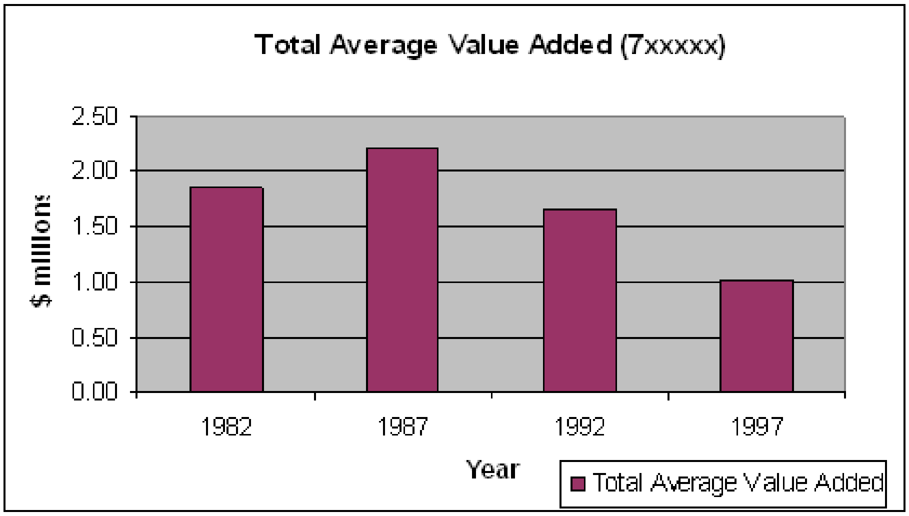


Figure 6.6: Total Average Value Added of all Supply Chains Ending with NAICS Code 7xxxxx

value added for all the supply chains ending with NAICS code “5xxxxx” and “7xxxxx” show a declining trend from 1982 to 1987 and from 1992 to 1997. For the years 1987 to 1992, the total value added shows an increase.

To find out whether there is a statistical difference between the total average value added between the years, a pairwise “t-test” with Bonforroni’s adjustment is calculated, the results of which are shown in Tables 6.3 and 6.4. For supply chains ending with NAICS code“5xxxxx,” all the pairwise years are statistically significant except the years 1982 and 1987.

Supply chains ending with NAICS code “7xxxxx” have the total average value significant at the 99 percent level, for all the years. Hence *Hypothesis 2* is **supported** for the years 1982 to 1992 and 1997, 1987 to 1992 and 1997, and 1992 to 1997 for all supply chains ending with NAICS codes “5xxxxx” and “7xxxxx.” All other figures are significant even though they are not supported by the hypothesis.

One of the reasons that the years 1987 have a higher total average value is that the number

Benchmark I-O Tables	Number of Supply Chains	Tot. Value Added by all Supply Chains	Std. Error	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
1982	61,392	9.9715	0.3357	83.18	9.3135	10.6294		
1987	44,259	11.1049	0.2941	61.88	10.5283	11.6814		
Combined	105,651	10.4463	0.2327	74.9987	9.9940	10.8985	-2.4236	0.0154
1982	61,392	**9.9715**	0.3357	83.18	9.3135	10.6294		
1992	60,545	**7.4353**	0.1875	46.14	7.0677	7.8028		
Combined	121,937	8.7122	0.1930	67.39	8.3334	9.0904	6.5714	0.0000
1982	61,392	**9.9715**	0.3357	83.18	9.3135	10.6294		
1997	79,767	**5.2496**	0.1706	48.19	4.9151	5.5840		
Combined	141,159	7.3032	0.1750	65.77	6.9600	7.6463	13.3788	0.0000
1987	44,259	**11.1049**	0.2941	61.88	10.5283	11.6814		
1992	60,545	**7.4353**	0.1875	46.14	7.0677	7.8028		
Combined	104,804	8.9849	0.1649	53.38	8.6617	9.3082	10.9972	0.0000
1987	44,259	**11.1049**	0.2941	61.88	10.5283	11.6814		
1997	79,767	**5.2496**	0.1706	48.19	4.9151	5.5840		
Combined	124,026	7.3390	0.1520	53.55	7.0410	7.6371	18.4724	0.0000
1992	60,545	**7.4353**	0.1875	46.14	7.0677	7.8028		
1997	79,767	**5.2496**	0.1706	48.19	4.9151	5.5840		
Combined	140,312	6.1927	0.1263	47.32	5.9450	6.4403	8.57	0.0000

Table 6.6: Pairwise t-Statistic to Compare Total Average Value Added Across Supply Chain Ending with NAICS Code 5xxxxx.

Benchmark I-O Tables	Number of Supply Chains	Tot. Value Added by all Supply Chains	Std. Error	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
1982	400,533	**1.8608**	0.0314	19.92	1.7991	1.9224		
1987	288,498	**2.2185**	0.0404	21.71	2.1392	2.2977		
Combined	689,031	2.0105	0.0249	20.68	1.9617	2.0594	-7.0805	0.0000
1982	400,533	**1.8608**	0.0314	19.92	1.7991	1.9224		
1992	377,375	**1.6413**	0.0275	16.94	1.5872	1.6953		
Combined	777,908	1.7543	0.0210	18.53	1.7131	1.7951	5.2204	0.0000
1982	400,533	**1.8608**	0.0314	19.92	1.7991	1.9224		
1997	563,348	**1.022**	0.0155	11.65	0.9915	1.0524		
Combined	963,881	1.3705	0.0159	15.63	1.3393	1.4017	25.96	0.0000
1987	288,498	**2.2185**	0.0404	21.71	2.1392	2.2977		
1992	377,375	**1.6413**	0.0275	16.94	1.5872	1.6953		
Combined	665,873	1.8913	0.0234	19.15	1.8453	1.9373	12.1857	0.0000
1987	288,498	**2.2185**	0.0404	21.71	2.1392	2.2977		
1997	563,348	**1.022**	0.0155	11.65	0.9915	1.0524		
Combined	851,846	1.4272	0.0171	15.80	1.3936	1.4607	33.0948	0.0000
1992	377,375	**1.6413**	0.0275	16.94	1.5872	1.6953		
1997	563,348	**1.022**	0.0155	11.65	0.9915	1.0524		
Combined	940,723	1.2704	0.0144	14.01	1.2421	1.2987	21.0079	0.0000

Table 6.7: Pairwise t-Statistic to Compare Total Average Value Added Across Supply Chain Ending with NAICS Code 7xxxxx.

	5xxxxx							
	1982		1987		1992		1997	
	Length	Total Avg. Value Added	Length	Total Avg. Value Added	Length	Total Avg. Value Added	Length	Total Avg. Value Added
Length	1		1		1		1	
Total Avg. Value Added	-0.06160	1	-0.0979	1	-0.08810	1	-0.0656	1
	7xxxxx							
	1982		1987		1992		1997	
	Length	Total Avg. Value Added	Length	Total Avg. Value Added	Length	Total Avg. Value Added	Length	Total Avg. Value Added
Length	1		1		1		1	
Total Avg. Value Added	-0.0645	1	-0.0750	1	-0.0791	1	-0.0690	1

Table 6.8: Correlation Between Length of the Supply Chain and Total Average Value

of supply chains is lower[5] in 1987 compared with 1982.

6.1.4 Correlation between Length of the Supply Chain and Total Average Value Added

To avoid multicollinearity[6] in future analysis, Table 6.8 looks at the correlation between the length of the supply chain and the total average value added. There is virtually no correlation between length of the supply chain and the total average value added. However, for all the years the direction of the relationship is an inverse relationship.

6.1.5 Total Average Value Added and Echelons of the Supply Chain

In the theory section, it was explained that due to an increased flow of information, overall transaction cost decreases and hence each echelon of the supply chain contributes less value addition over time. Table 6.9 and 6.10 gives the total average value added by supply chains of different lengths. It is clearly visible empirically that the average value contributed by each echelon in the supply chains falls drastically. Figures 6.7 and 6.8 gives the graphical illustration of the fall of average value added in each of the echelons.

[5]See Figures 6.3 and 6.4.

[6]When two or more independent observations are highly correlated.

	1982		1987	
Echelons in the Supply Chain	Number of Supply Chains	Total Average Value Added	Number of Supply Chains	Total Average Value Added
1	27	71.56351	26	108.0548
2	1,705	17.1258	1,570	27.94704
3	21,155	13.39824	17,970	13.89458
4	38,505	7.728902	24,693	7.901825
	1992		1997	
Echelons in the Supply Chain	Number of Supply Chains	Total Average Value Added	Number of Supply Chains	Total Average Value Added
1	33	113.6602	14	250.3643
2	1,822	21.23479	1,564	20.20428
3	21,864	10.12574	17,654	8.622418
4	36,826	5.060079	60,535	3.822971

Table 6.9: Total Average Value Added by Different Echelon Supply Chains Ending with 5xxxxx

	1982		1987	
Echelons in the Supply Chain	Number of Supply Chains	Total Average Value Added	Number of Supply Chains	Total Average Value Added
1	22	301.0118	20	283.0803
2	1,001	48.29188	918	60.34807
3	17,369	4.334711	15,550	5.587856
4	144,501	2.151284	119,981	2.329889
5	237,640	1.280153	152,029	1.398043
	1992		1997	
Echelons in the Supply Chain	Number of Supply Chains	Total Average Value Added	Number of Supply Chains	Total Average Value Added
1	20	255.2326	38	207.2368
2	1,109	49.79973	1,107	30.14734
3	17,481	5.508378	18,036	4.649655
4	140,661	1.790395	147,453	1.318605
5	218,104	0.9671956	396,714	0.6458562

Table 6.10: Total Average Value Added by Different Echelon Supply Chains Ending with 7xxxxx

No. of observations = $245,963$			R-squared = 0.0113		
Root MSE = 134.416			Adj. R-squared = 0.0112		
Dependent Variable = Total Average Value Added					
Independent Variables	Partial SS	df	MS	F	Prob > F
Model Fit	50,567,504.2	6	8,427,917.37	466.47	0.0000
Year	3,501,1124.8	3	11,670,374.9	645.93	0.0000
Length	14,646,941.7	3	4,882,313.91	270.22	0.0000
Residual	4.4438e+09245956		18,067.61		

Table 6.11: Anova Result for Total Average Value Added Controlling for Length of the Supply Chain and Year for 5xxxxx

No. of observations = $1,629,754$			R-squared = 0.0303		
Root MSE = 44.7453			Adj. R-squared = 0.0303		
Dependent Variable = Total Average Value Added					
Independent Variables	Partial SS	df	MS	F	Prob > F
Model Fit	101,983,943	7	14,569,134.8	7,276.77	0.0000
Year	5,920,445.28	3	1,973,481.76	985.68	0.0000
Length	95,978,121.2	4	23,994,530.3	11,984.4	0.0000
Residual	3.2630e+091629746		2,002.14269		

Table 6.12: Anova Result for Total Average Value Added Controlling for Length of the Supply Chain and Year for 7xxxxx

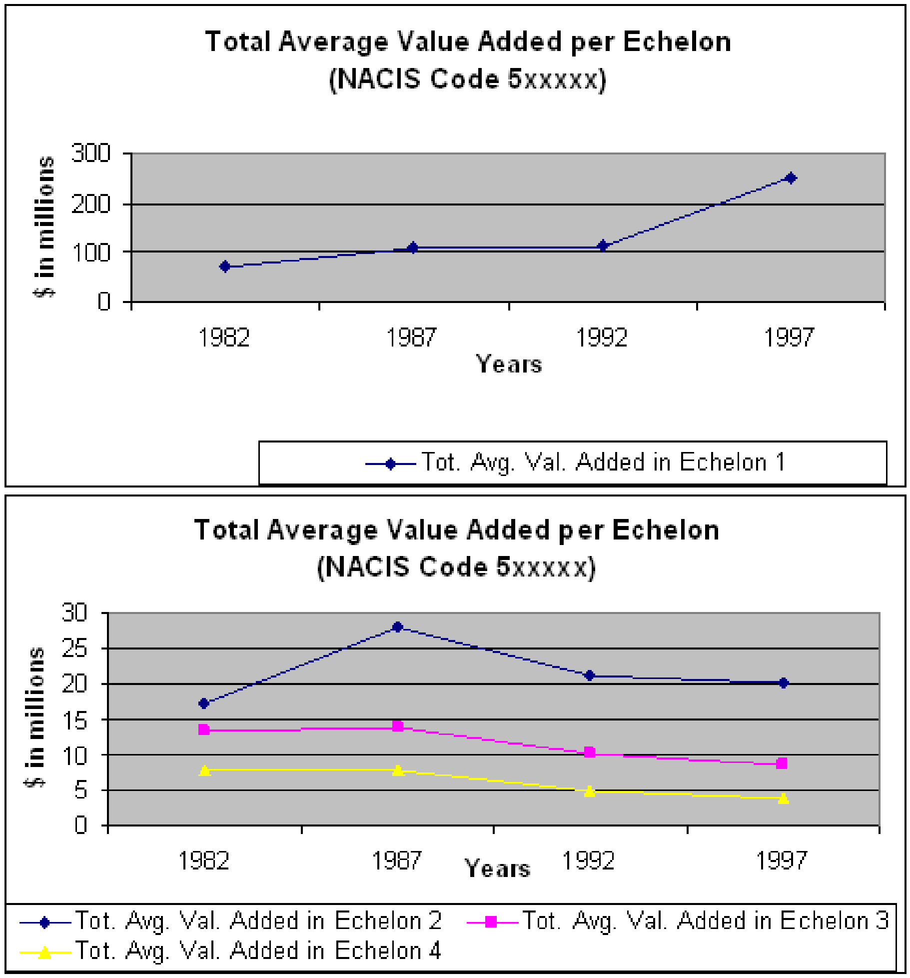


Figure 6.7: Total Average Value Added by Echelons over Time for all Supply Chains Ending with 5xxxxx

The choice of the statistical tool used to test this result is Anova, where the variance of total average value added is looked at, after controlling for the length of the supply chain and the benchmark year. Tables 6.11 and 6.12 give the results for the Anova. Even though the "R-squared" is low, the model is significant at the 99 percent level.

For all supply chains terminating at NACIS code "5xxxxx",[7] the total average value added by echelon one over time increases and is significant. The total average value added by echelon two increases from 1982 to 1987 ,and then decreases from 1987 to 1997. Similarly, echelons three

[7]See Figure 6.7.

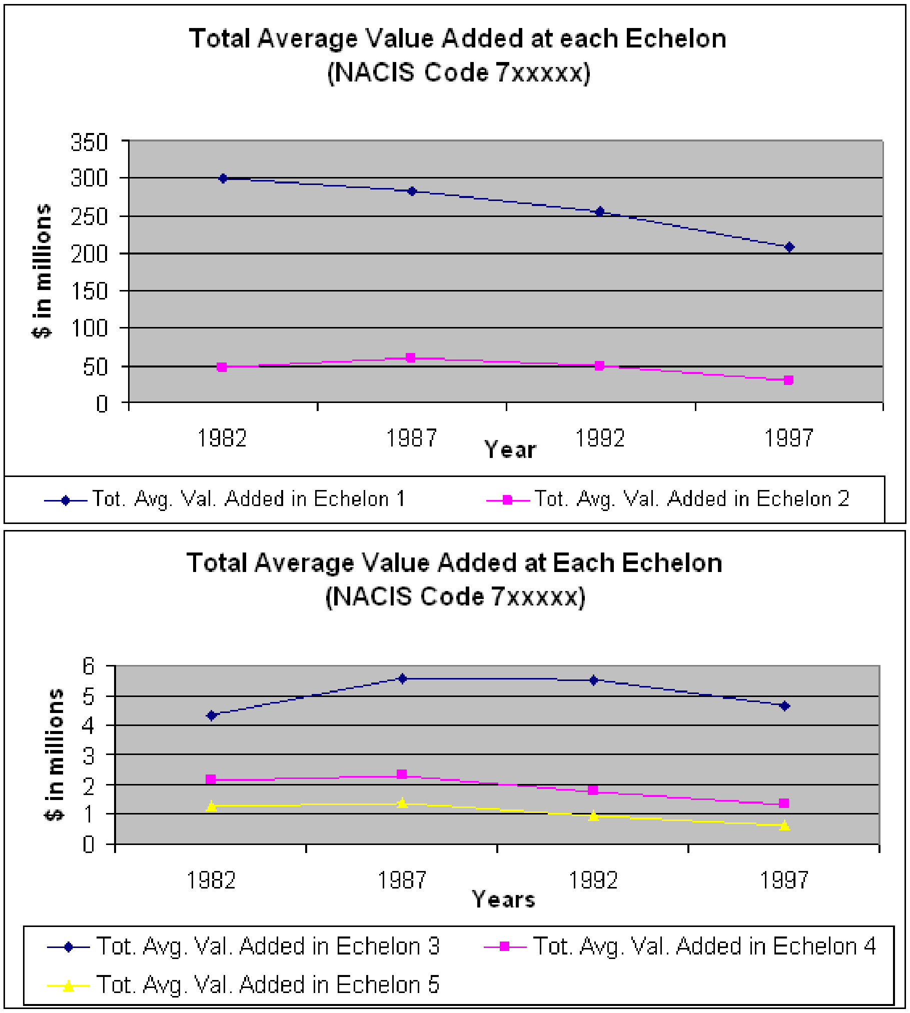


Figure 6.8: Total Average Value Added by Echelons over Time for all Supply Chains Ending with 7xxxxx

and four show a slight increase in total value added from 1982 to 1987, and then show a consistent decrease from 1987 to 1997.

For all supply chains terminating at NACIS code "7xxxxx",[8] echelon one shows a consistent decline in their total average value added across time. Echelons two, three, four, and five show a slight increase in their total average value added in the years 1982 to 1987. From 1987 onwards to 1997, all the echelons show a decrease in their total average value added.

[8]See Figure 6.8.

Hence *Hypothesis 3* is **supported** for all echelons for the years 1987 through 1997. There is a significant decrease in total average value added within echelons across time from 1982 onwards till 1997.

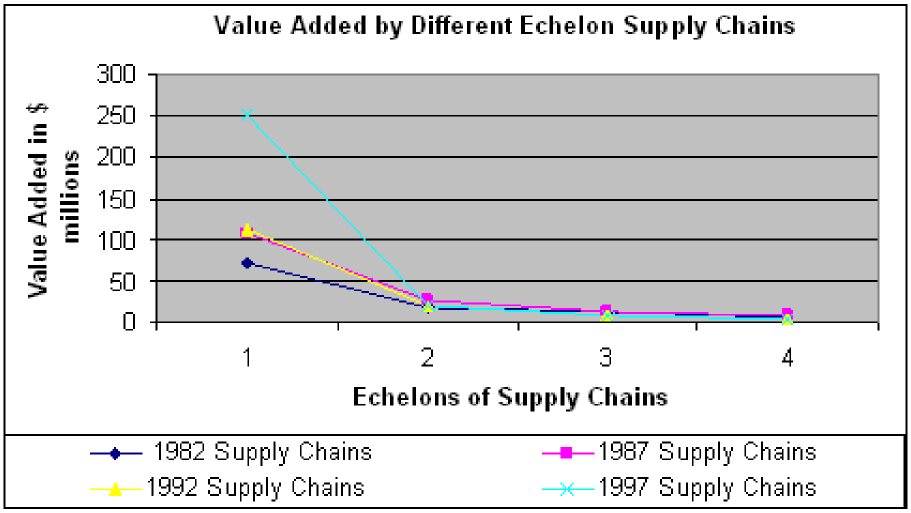


Figure 6.9: Total Average Value Added by Echelons over Time for all Supply Chains Ending with 5xxxxx

For similar reasons, it has been argued that a longer supply chain would contribute less and less to the total average value of the supply chain as the prices of products tend to fall over time and each addition of echelons in the supply chain would lead to lower and lower value addition of the final product. Tables 6.9 and 6.10 empirically demonstrate this fact while Figures 6.9 and 6.10 graphically illustrate the fact.

A pairwise "t-test" with Bonforroni's adjustment is conducted on each of the echelons for a given year to find out whether or not the fall in total average value is statistically significant. There is no significant difference in the total average value added for echelons two and echelon three for the year 1982 for supply chains ending with "5xxxxx." However, all other values are significant at the 99 percent level for supply chains ending with NACIS code "5xxxxx" and "7xxxxx." Hence,

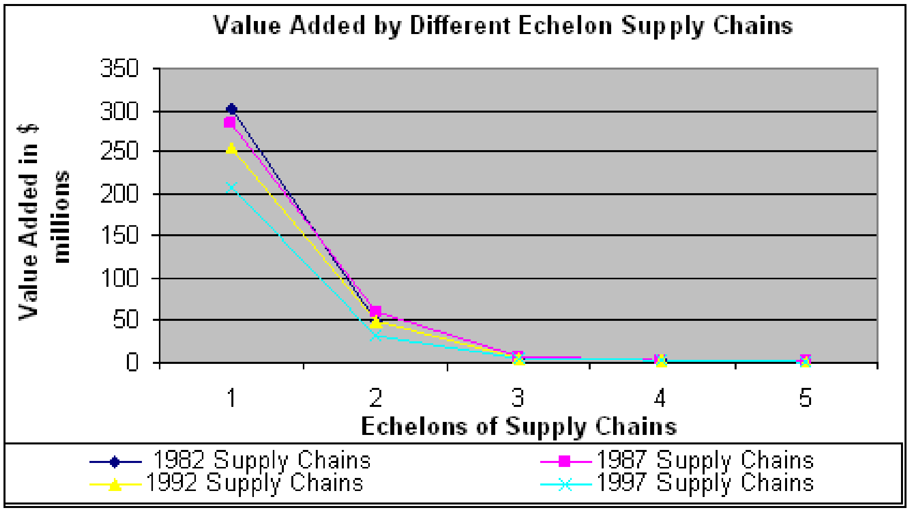


Figure 6.10: Total Average Value Added by Echelons over Time for all Supply Chains Ending with 7xxxxx

other than for echelons two and echelon three for the year 1982 for supply chains ending with "5xxxxx," there is **support** for *Hypothesis 4*, that the greater the number of echelons in a supply chain, the lesser would be the total average value added at each echelon.

6.1.6 Length of the Supply Chain and Nature of Industry

In the previous chapter, it was discussed that the length of a supply chain depends upon the nature of the industry. At the aggregate level of the U.S. economy, Tables 6.13 and 6.14 give the result of looking at the variance of supply chain length while controlling for the benchmark year and the end user industry. The results are significant at the 99 percent level and **support** *Hypothesis 5* that the average length of the supply chain is determined by the nature of the industry.

6.1.7 Total Value Added by Echelons of the Supply Chain

Hypothesis 6 suggests that the value added upstream is higher than the value added downstream. In this dissertation, the upstream echelons would consist of the primary, secondary, and manufacturing industries, while downstream would consist of service industries. In the theory section,

No. of observations = 245, 963 Root MSE = .00363 Dependent Variable = Length of the Supply Chain			R-squared = 0.0014 Adj. R-squared = 0.0013		
Independent Variables	Partial SS	df	MS	F	Prob > F
Model Fit	.000046944	27	1.7387e-06	13.21	0.0000
Year	.000027477	3	9.1589e-06	69.57	0.0000
5xxxxx	.000019333	24	8.0555e-07	6.12	0.0000
Residual	.032378618245935	1.3166e-07			

Table 6.13: Anova Result for Length of the Supply Chain Controlling for Industry (5xxxxx) and Year

No. of observations = 245, 963 Root MSE = .00363 Dependent Variable = Length of the Supply Chain			R-squared = 0.0014 Adj. R-squared = 0.0013		
Independent Variables	Partial SS	df	MS	F	Prob > F
Model Fit	.000027037	10	2.7037e-06	486.52	0.0000
Year	8.4010e-06	3	2.8003e-06	503.91	0.0000
7xxxxx	.00001864	7	2.6628e-06	479.16	0.0000
Residual	.0090569481629743	5.5573e-09			

Table 6.14: Anova Result for Length of the Supply Chain Controlling for Industry (7xxxxx) and Year

	1982			1987		
Echelon	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added
1	46,552	15.67	18.28	8,840	9.35	21.99
2	40,240	52.91	53.38	24,583	5.71	37.35
3	60,259	15.88	23.98	38,788	2.99	30.80
4	56,519	3.07	4.35	38,407	0.96	9.85
	1992			1997		
Echelon	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added
1	27,418	3.73	25.16	11,796	5.81	16.36
2	38,394	3.67	34.63	47,857	3.23	36.88
3	59,001	2.11	30.57	71,181	2.10	35.67
4	53,805	0.73	9.64	63,983	0.73	11.09

Table 6.15: Contribution of Individual Echelons to the Total Average Value Added for Supply Chains Ending with 5xxxxx

	1982			1987		
Echelon	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added
1	261,989	3.11	16.76	36,219	2.52	18.64
2	212,439	10.25	44.86	127,493	1.15	29.95
3	337,930	4.07	28.29	178,967	0.93	33.88
4	339,716	0.78	5.46	201,840	0.24	9.87
5	301,594	0.74	4.62	189,819	0.20	7.66
	1992			1997		
Echelon	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added	No. of Supply Chains	Tot. Avg. Value Added	% of Tot. Avg. Value Added
1	76,145	1.49	20.22	79,202	1.09	14.95
2	194,054	0.77	26.79	275,903	0.59	28.44
3	284,850	0.67	34.09	390,422	0.54	36.79
4	282,692	0.19	9.57	363,230	0.18	11.33
5	265,519	0.20	9.32	362,605	0.13	8.49

Table 6.16: Contribution of Individual Echelons to the Total Average Value Added for Supply Chains Ending with 7xxxxx

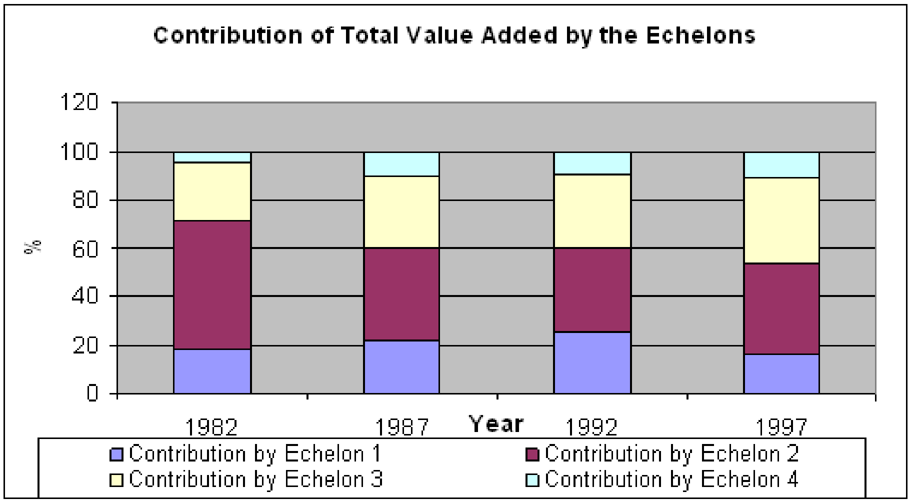


Figure 6.11: Total Average Value Added by Individual Echelons for Supply Chains Ending with 5xxxxx

the dissertation discusses how most of the costs are concentrated in the echelons closer to the raw materials. Tables 6.15 and 6.16 give the results to determine contribution added by each echelon of the supply chain. The primary, secondary, and manufacturing echelons of a four-echelon supply chain contribute between 88 percent - 96 percent of the total value added of the entire supply chain, while the service sector adds between 4 percent - 12 percent of the total value of the entire supply chain. For a five-echelon supply chain, the value added by the upstream industries is around 80 percent while the value contributed to the overall supply chain by the downstream industries is around 20 percent. Figures 6.11 and 6.12 give a graphical representation of the contribution of each echelon to the total value added of the entire supply chain. Hence this dissertation finds **support** for *Hypothesis 6*.

6.1.8 Average Length of the Supply Chain and Individual Industries

In the context of the overall economy, the lengths of the supply chains decrease from 1982 to 1987 and then start increasing from 1987 to 1997 for supply chains ending with "5xxxxx." For supply chains ending with "7xxxxx," their length decreases from 1982 to 1987, remains the same till 1992, and then starts increasing till 1997. This section looks at the specific industries that cause this

	1982		1987	
Service Industry Represented	Number of Supply Chains	Supply Chain Length	Number of Supply Chains	Supply Chain Length
Newspaper publishers	2,555	3.1819	1,852	3.0389
Periodical publishers	2,459	3.3861	1,785	3.2560
Book publishers	2,450	3.4584	1,777	3.3557
Database publishers	2,451	3.4994	1,780	3.3784
Motion picture / Video	2,581	3.2734	1,865	3.1067
Radio and television	2,420	3.5146	1,758	3.4095
Data processing services	2,493	3.4064	1,815	3.2410
Securities, investments	2,452	3.5186	1,779	3.4690
Insurance carriers	2,459	3.4589	1,780	3.3999
Insurance, brokerages	2,443	3.5246	1,771	3.4396
Monetary authorities	2,503	3.3813	1,814	3.2417
Real estate	2,541	3.2481	1,844	3.0465
Automotive rental,leasing	2,494	3.4509	1,806	3.1964
Machinery rental,leasing	2,534	3.5246	1,847	3.4096
Legal services	2,451	3.4899	1,780	3.3755
Accounting, bookkeeping	2,454	3.5068	1,780	3.4001
Arch. and Eng.	2,444	3.5130	1,773	3.4249
Advertising	2,483	3.4888	1,801	3.4219
Photographic	2,496	3.4713	1,807	3.3427
Employment services	2,491	3.4604	1,807	3.2981
Business support	2,492	3.4722	1,811	3.2813
Travel, reservation	1,839	3.4925	1,344	3.4078
Invest., security	2,457	3.5351	1,493	3.4960
Buildings	2,497	3.4952	1,808	3.3767
Waste, remediation	2,453	3.4170	1,782	3.2938
	1992		1997	
Newspaper publishers	2,556	3.2512	3,229	3.4098
Periodical publishers	2,055	3.2589	3,182	3.4468
Book publishers	2,054	3.2758	3,177	3.4374
Database publishers	2,054	3.3866	3,177	3.5259
Motion picture / Video	2,217	3.3440	3,084	3.5248
Radio and television	2,038	3.4671	2,976	3.5611
Data processing services	2,594	3.3084	3,019	3.5785
Securities, investments	2,051	3.4663	3,247	3.464795
Insurance carriers	2,464	3.3677	3,168	3.5988
Insurance, brokerages	2,553	3.4142	3,163	3.6275
Monetary authorities	2,635	3.286	3,280	3.5837
Real estate	2,672	2.8473	3,352	2.9493
Automotive rental,leasing	2,577	3.3640	3,234	3.5581
Machinery rental,leasing	2,628	3.4221	3,081	3.5831
Legal services	2,574	3.3901	3,269	3.5941
Accounting, bookkeeping	2,491	3.3720	3,226	3.5623
Arch. and Eng.	2,533	3.4066	3,256	3.5484
Advertising	2,516	3.3399	3,338	3.5107
Photographic	2,555	3.3778	2,962	3.5960
Employment services	2,164	3.3736	3,180	3.6147
Business support	2,653	3.2458	3,266	3.5595
Travel, reservation	2,471	3.4536	3,214	3.5350
Invest., security	2,314	3.3230	3,267	3.5923
Buildings	2,617	3.3862	3,243	3.2122
Waste, remediation	2,509	3.3175	3,177	3.4427

Table 6.17: Average Supply Chain Lengths for Individual Industries Ending with NACIS Code 5xxxxx

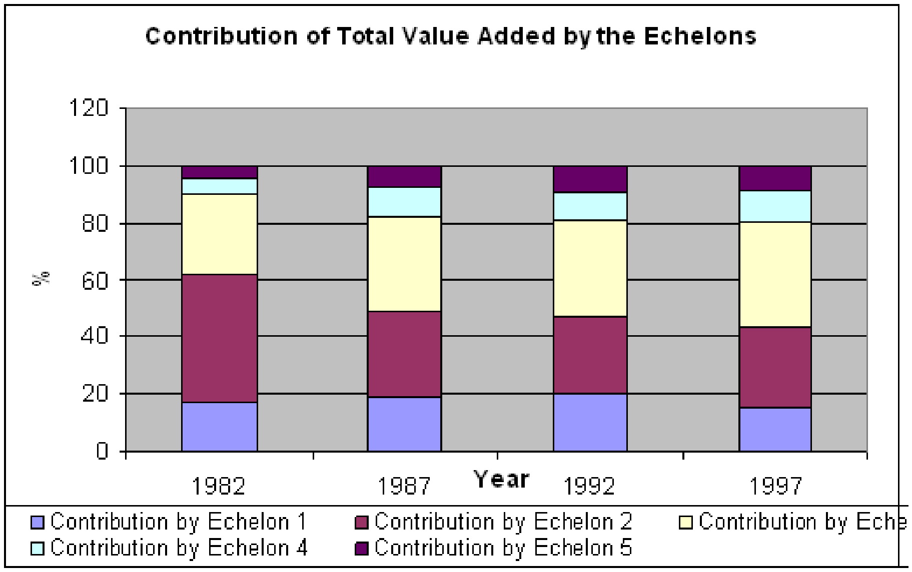


Figure 6.12: Total Average Value Added by Individual Echelons for Supply Chains Ending with 7xxxxx

change to happen.

Table 6.17 refers to the lengths of supply chains for all industries ending with "5xxxxx." Between the years 1982 and 1987 none of the industries went against the overall U.S. economy trend of decrease in their overall lengths of their supply chains. Between the years 1987 to 1992, some industries did go against the trend of increase in the lengths of supply chains for the U.S. economy by decreasing their overall lengths. These industries belong to book publishers, securities, commodity contracts and investments, insurance carriers, insurance agencies, brokerages, real estate agencies, accounting and bookkeeping services, architectural and engineering services, advertising and related services, business support services, and investigation and security services. From 1992 to 1997, the industries that decreased their average supply chain lengths were securities, commodity contracts, investments services, and services to buildings and dwellings.

Table 6.18 refers to the lengths of supply chains for all industries ending with "7xxxxx." All the industries from 1982 to 1987 go in the direction of the overall U.S. economy by decreasing their

	1982		1987	
Service Industry Represented	Number of Supply Chains	Supply Chain Length	Number of Supply Chains	Supply Chain Length
Performing arts	50,246	4.3199	36,184	4.1868
Spectator sports	45,217	4.3886	32,539	4.2589
Promoters, agents	45,231	4.3882	32,542	4.2585
Fitness, rec. centers	50,271	4.3777	38,043	4.2478
Bowling centers	47,695	4.3923	34,334	4.2716
Amusement, gambling	54,770	4.3628	39,492	4.2285
Hotels and motels	54,771	4.2846	37,659	4.1330
Food, drink places	52,332	3.5433	37,705	3.4257
	1992		1997	
Service Industry Represented	Observations	Supply Chain Length	Observations	Supply Chain Length
Performing arts	49,426	4.2769	70,612	4.4097
Spectator sports	41,367	4.2651	67,368	4.3997
Promoters, agents	43,720	4.2889	66,823	4.4172
Fitness, rec. centers	51,228	4.2577	74,380	4.3858
Bowling centers	36,477	4.2684	60,811	4.3841
Amusement, gambling	51,771	4.1955	74,464	4.2991
Hotels and motels	51,557	4.1928	74,453	4.2281
Food, drink places	51,829	3.4339	74,438	3.620609

Table 6.18: Average Supply Chain Lengths for Individual Industries Ending with NACIS Code 7xxxxx

supply chain lengths. Between 1987 and 1992, all the supply chains increase their lengths slightly except for bowling centers, which show a decreasing trend. From 1992 to 1997, all industries show an increase in their lengths. Food and drink services had the shortest lengths among all other industries whose NAICS code ends with "7xxxxx."

6.1.9 Dynamic Nature of Supply Chains

Supply chains are dynamic in nature. According to Table 6.19,[9] only 1,644 out of 61,188 supply chains in 1982, 44,300 supply chains in 1987, 60,329 supply chains in 1992, and 78,849 supply chains in 1997 had the same configuration throughout the four Benchmark tables. Approximately 18,936 echelons between 1982 to 1987 were disintermediated from the U.S. economy compared to the period 1982 to 1987. This figure rises to 18,727 and 39,244 echelons disintermediated from the U.S. economy for the periods 1987 to 1992, and 1992 to 1997. The number of newly formed or reintermediated echelons in the supply chains rise from 1,697 in the U.S. economy, within the

[9]For all supply chains ending with NAICS code "5xxxxx."

Particulars	1982	1987	1992	1997
Number of supply chains	61,188	44,300	60,329	78,849
Total avg. value added of all the supply chains	9.9144	11.0060	7.3609	5.2725
Number of supply chains disintermediated	n//a	18936	18727	39244
Total avg. value added of the supply chains disintermediated	n//a	2.2539	5.9651	5.0396
Number of newly formed supply chains	n//a	1,697	34,910	57,745
Total avg. value of newly formed supply chains	n//a	2.186	6.8214	3.4637
Number of constant supply chains	1,644	1,644	1,644	1,644
Total avg. value of constant supply chains	23.5065	23.2746	20.3056	7.6252

Table 6.19: Dynamic nature of all Supply Chains ending at NAICS Code 5xxxxx

All values are in million dollars and at 1997 prices.

period 1982 to 1987, to 34,910 and 57,745 supply chains in the U.S. economy, for the period 1987 to 1992, and 1992 to 1997. A detailed discussion in the next section will follow.

6.2 Discussion

Hypothesis 1 states that the length of the supply chain should increase over time. This is because the overall transaction costs are decreasing over time. The results however find that the length of the supply chains actually decrease from 1982 to 1987 and then start increasing from 1987 onwards (Figures 6.3 and 6.4). The decrease in supply chain length (1982-1987) is influenced by a corresponding decrease in the total number of supply chains during this period (Figures 6.1 and 6.2). One of the likely reasons is the macro environment prevalent in the U.S. economy during the 1980s. The economy was just recovering from a major recession[10] and a wave of mergers and acquisitions (PiperJaffray (2003); Andrade et al. (2001)). Both recession, and mergers and acquisitions lead to either closure of industries and / or vertical integration. Service industries were the hardest hit; specifically airlines, broadcasting, entertainment, natural gas, trucking, banks and thrifts, utilities,and telecommunications (Andrade et al. (2001)). The end-user industries in this dissertation consists of service industries and hence the results are not surprising. This accounts for the decrease in total number of supply chains as well as the decrease in the total average length

[10]See http://en.wikipedia.org/wiki/.

of the supply chains.

In the early 1990s, there was an increase in the adoption of technology in business. This led to adoption of information based systems like the EDI. LaLonde and Emmelhainz (1985) predicted the more usage of information based systems in the 1990s and the ability of such systems to reduce costs. A survey of industries found an increase in the number of firm suppliers after the adoption of EDI (Zack (1994)). Hence, since 1990s, there has been a steady increase in the adoption of information based technologies like the Internet, VSAT, etc., which have reduced transaction costs and have thus enabled supply chains to grow longer and bigger. Also, the U.S. economy went through a prolonged "boom" during this period especially in the service sector. Therefore, the total number of supply chains and the average length of the supply chains have increased after 1987.

Hypothesis 2 stated that the average value of the products would decrease with time. Figures 6.5 and 6.6 confirm this result. This is not surprising since it is an accepted fact that the cost of goods produced decreases with time. Hence, since new NACIS codes are not considered in this analysis, these results hold.

Lowering of transaction costs leads to increases in supply chain lengths coupled with decreases in prices of goods and services produced. Hence, as more echelons are added to an existing supply chain, the value added by each of these echelons will decrease over time. This result is confirmed by Figures 6.9 and 6.10.

It is not possible to determine whether supply chain lengths of an industry would increase, decrease or remain constant depending on the end-user industry. As discussed in the theory section, each industry would have a bundle of sunrise, mature and sunset products and services. Therefore, no a priori prediction can be made. The only prediction that can be made is that the end-user industry would have a significant impact on the supply chain length. Tables 6.13 and

6.14 confirm this result.

Standard inventory management textbooks emphasize material cost drives the total cost of the product. Past case studies, analytical literature, and anecdotal evidence provide basis for these results. Most of the cost is in the raw material of the goods. This dissertation empirically proves that the average value added is higher in upstream industries than in downstream industries (Figures 6.11 and 6.12).

Supply chains are dynamic in nature. New supply chains constantly get created, old supply chains get disintermediated, existing supply chains evolve into new supply chains by changing the nature of their products or services. Table 6.19 gives a glimpse into the dynamic nature of supply chains. The number of supply chains which have stayed the same over a 20 year period is a minuscule 1644, which represents 2 percent of the total number of supply chains. The average total value of these supply chains have been decreasing over the years, which indicate that the products or services offered by these supply chains are in mature or sunset industries. The number of supply chains which get disintermediated from the U.S. economy every five years ranges from 18 percent in 1987 to around 49 percent in 1997. The number of new supply chains formed have increased from 3 percent in 1987 to around 73 percent in 1997. The number of new supply chains, for existing products and services, created in the economy could be used as an indicator of the competitiveness of the economy and the industry. Future research could look at the dynamism within an industry to predict its decline or assent.

Chapter 7

Results and Discussion - Length of Supply Chain and Coordination Mechanisms

This chapter presents the results of looking at the impact of coordination mechanisms and reduction in length of the supply chains on the overall performance of the supply chains. A five-echelon supply chain is evaluated for a period of 104 weeks and then the results are compared with a four and a three echelon supply chain. This first section consists of results while the second section discusses the results.

7.1 Results

7.1.1 Individual Supply Chain Member Optimization vs. Supply Chain Optimization

In this dissertation, one of the questions being answered is whether the maximization of an individual supply chain member's performance leads to a situation where the supply chain as a whole performs sub-optimally. Firms acting in selfish interests[1] should make the overall supply chain inefficient due to the reasons mentioned in the theory section.

Table 7.1 gives the number of supply chains that have their net stock minimized for all demand distributions whose mean is 10.[2] The expectation is that all harmonized supply chains would dominate the supply chains with the least minimum net stock. But, out of twelve possible harmonized supply chains, only four harmonized supply chains have the least net stock. Among the four harmonized supply chains, three of them use the heuristic of trend correction while one supply chain uses the moving average demand as a heuristic. Surprisingly, the actual demand transmitted along the supply chain does not figure in the table, and the reasons will be discussed in the next section. Even for all the non-harmonized supply chains, it is only the last echelon

[1]Firms acting selfishly by our definition are firms that tend to have non-harmonized heuristics.

[2]The confidence interval of the net stock estimate is approximately ±7 percent of the mean net stock. This confidence interval was estimated by examining four percent of the total number of runs. This confidence interval may be significant when interpreting the results for Hypotheses 7 and 8.

Demand Distribution	Heuristics Used	Net Stock	Harmonized Supply Chains	Net Stock Minimized
Normal (10, 2)	22221	2234.76	No	Yes
	22222	2234.76	Yes	Yes
	22223	2234.76	No	Yes
Normal (10,5)	33331	1841.64	No	Yes
	33332	1841.64	No	Yes
	33333	1841.64	Yes	Yes
Poisson (10)	33331	1969.75	No	Yes
	33332	1969.75	No	Yes
	33333	1969.75	Yes	Yes
Uniform (10,2)	33331	2064.86	No	Yes
	33332	2064.86	No	Yes
	33333	2064.86	Yes	Yes

Table 7.1: Heuristics That Have Minimum Net Stock for Demand Distribution of 10

1-Actual Demand Heuristic 2-Moving Average Heuristic 3-Moving Average with Trend Heuristic

Demand Distribution	Heuristics Used	Net Stock	Harmonized Supply Chains	Net Stock Minimized
Normal (10, 2)	11111	2593.41	Yes	No
	22222	2234.76	Yes	Yes
	33333	2270.32	Yes	No
Normal (10,5)	11111	2476.74	Yes	No
	22222	1909.69	Yes	No
	33333	1841.64	Yes	Yes
Poisson (10)	11111	2457.00	Yes	No
	22222	2119.78	Yes	No
	33333	1969.75	Yes	Yes
Uniform (10,2)	11111	2485.18	Yes	No
	22222	2151.58	Yes	No
	33333	2064.86	Yes	Yes

Table 7.2: Heuristics That are Harmonized for Demand Distribution of 10

1-Actual Demand Heuristic 2-Moving Average Heuristic 3-Moving Average with Trend Heuristic which uses another heuristic.[3] This interesting result will be discussed in the next section. The normal distribution with a high standard deviation tended to have the least amount of net stock. Table 7.2 gives the details of all harmonized supply chains.

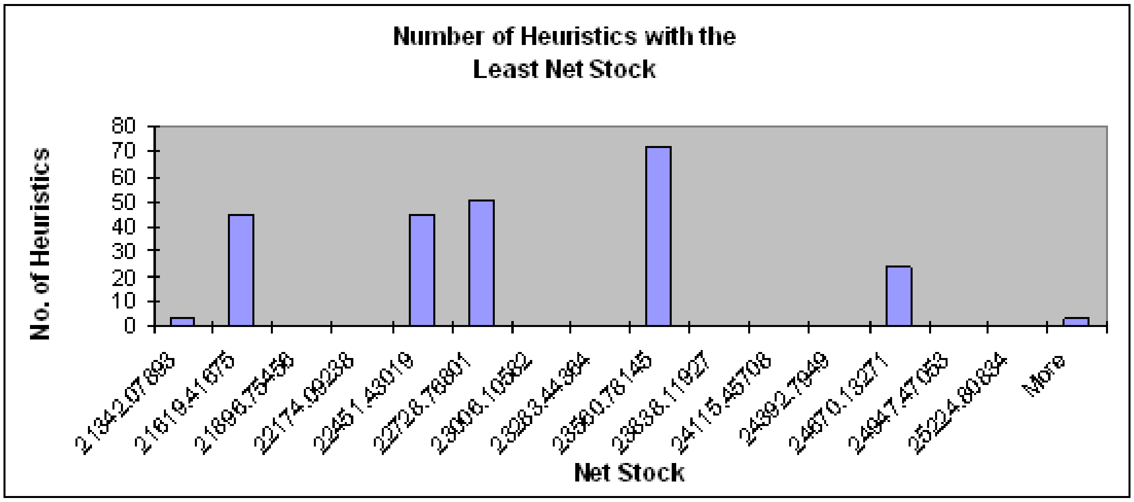


Figure 7.1: Number of Heuristics with the Least Net Stock for $\mu = 10$ and $\sigma = 2$

A scatter plot is created plotted by plotting net stock on the X-axis and the heuristics used on the Y-axis. The heuristic which has the least amount of net stock would be the first data point on the scatter plot. A histogram is also plotted to know the total number of heuristics which have the minimum net stock. Figure 7.2 gives an example of all the net stock generated by all possible combinations of heuristics used by a five echelon supply chain. This figure gives an indication on the relative performance of various strategies based on the net stock.

A histogram of net stock is presented in Figure 7.1. This gives a count on the number of supply chaions which have the least net stock and, hence, the best performing supply chain in terms of net stock. In this example of mean normal demand of 10 and standard deviation of 2, the total number of supply chains which have the least net stock are three. Off the three heuristics which have the least net stock, only one of the heuristics is harmonized.[4]

[3]For example, the first four supply chains use the second heuristic while the last supply chain uses first heuristic.
[4]Refer to Table 7.1.

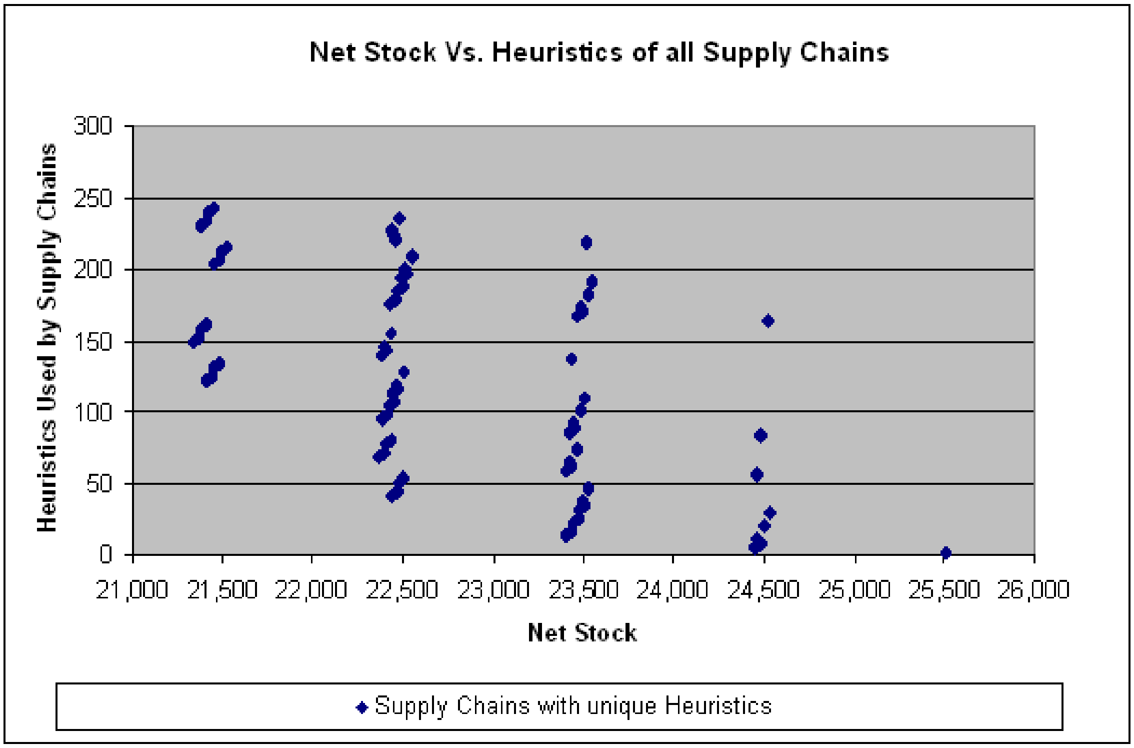


Figure 7.2: Net Stock vs. Heuristics for all Supply Chains for $\mu = 10$ and $\sigma = 2$

7.1.2 Least Net Stock Supply Chains and Other Supply Chains

Table 7.3 gives the results of the difference between least net cost supply chains (efficient) and other supply chains (inefficient). There is significant difference between the means of net stock of the efficient and inefficient supply chains. The least net stock supply chains have a significantly smaller net stock than other supply chains for all mean demands of 10, 50, and 100. The least net cost supply chains include both harmonized and non-harmonized supply chains. To test hypotheses seven, the results of the "t-test" between harmonized and non-harmonized supply chains are analyzed.

7.1.3 Non-Harmonized Supply Chains and Harmonized Supply Chains

Hypothesis 7 states that harmonized supply chains should have an optimum solution when compared to non-harmonized supply chains. This should mean that the net stock of harmonized sup-

Demand	Supply Chains	Obs	Mean	Std. Err.	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
10	Least Net Stock	12	2027.75	43.22	149.75	1932.60	2122.897		
	Supply Chains								
	Other Supply Chains	960	2216.87	4.80	148.87	2207.44	2226.29		
	Combined	972	2214.535	4.89	150.26	2205.07	2223.993	4.3731	0.0000
50	Least Net Stock	12	10714.51	136.45	472.67	10414.19	11014.84		
	Supply Chains								
	Other Supply Chains	960	11309.62	20.67	640.47	11269.05	11350.18		
	Combined	972	11302.27	20.58	641.86	11261.87	11342.67	3.2071	0.0014
100	Least Net Stock	12	21755.7	164.67	570.45	21393.25	22118.15		
	Supply Chains								
	Other Supply Chains	960	23028.84	28.81	892.85	22972.29	23085.39		
	Combined	972	23013.12	28.88	900.45	22956.44	23069.80	4.9255	0.0000

Table 7.3: Pairwise t-Statistic to Compare Least Net Cost Supply Chains and Other Supply Chains

Demand	Supply Chains	Obs	Mean	Std. Err.	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
10	Non-Harmonized	960	2214.54	4.78	148.11	2205.15	2223.92		
	Harmonized	12	2214.56	71.51	247.73	2057.16	2371.96		
	Combined	972	2214.56	4.79	149.53	2205.12	2223.95	-0.0005	0.9996
50	Non-Harmonized	960	11302.26	20.58	637.92	11261.86	11342.67		
	Harmonized	12	11302.74	272.28	943.21	10703.45	11902.03		
	Combined	972	11302.27	20.58	641.86	11261.87	11342.67	-0.0026	0.9979
100	Non-Harmonized	960	23013.11	28.62	887.02	22956.93	23069.29		
	Harmonized	12	23014.38	498.1494	1725.64	21917.96	24110.80		
	Combined	972	23013.12	28.88	900.45	22956.45	23069.80	-.0049	0.9961

Table 7.4: Pairwise t-Statistic to Compare Harmonized and Non-Harmonized Supply Chains

Demand	Supply Chains	Obs	Mean	Std. Err.	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
10	Least Net Cost Supply Chains	12	2027.75	43.22	149.75	1932.60	2122.89		
	Harmonized Supply Chains	12	2214.56	71.51	247.73	2057.15	2371.96		
	Combined	24	2121.15	45.26	221.76	2027.51	2214.8	-2.2355	0.0359
50	Least Net Cost Supply Chains	12	10714.51	136.44	472.67	10414.19	11014.83		
	Harmonized Supply Chains	12	11302.74	272.28	943.21	10703.45	11902.03		
	Combined	24	11008.63	161.06	789.04	10675.44	11341.81	-1.9314	0.0664
100	Least Net Cost Supply Chains	12	21755.70	164.67	570.45	21393.25	22118.15		
	Harmonized Supply Chains	12	23014.38	498.1494	1725.64	21917.96	24110.80		
	Combined	24	22385.04	288.17	1411.77	21788.90	22981.18	-2.399	0.0253

Table 7.5: Pairwise t-Statistic to Compare Least Net Cost Supply Chains and Harmonized Supply Chains

ply chains should be significantly different and lower than the net stock of non-harmonized supply chains. Table 7.4 gives the results of the difference between harmonized and non-harmonized supply chains. According to the "t-test," there is no difference between the means of supply chains that implement a harmonized coordination mechanism and supply chains with uncoordinated supply chains. Therefore, the null hypothesis cannot be rejected and *Hypothesis 7* is not supported. When taking into consideration the overlap between the confidence intervals of harmonized supply chains and non-harmonized supply chains, this result does not change.

7.1.4 Least Net Cost Supply Chains vs. Harmonized Supply Chains

Hypothesis 8 states that harmonized supply chains should have the least net stock. However, in the previous section, it was found that the supply chains with the least net stock were not necessarily harmonized supply chains. In order for *Hypothesis 8* to be valid, the net stock of harmonized supply chains should not be significantly different than net stock of supply chains with the minimum net cost. Table 7.5 gives the results of the difference between least net stock supply chains and harmonized supply chains. According to the "t-test," there is a significant difference between the means of supply chains that implement a harmonized heuristic and supply chains

Demand	Supply Chains	Obs	Mean	Std. Err.	Std. Dev.	Upper CI	Lower CI	t value	p > |t|
10	Five Echelon	972	2214.54	4.79	149.53	2205.13	2223.95		
	Four Echelon	324	1873.27	7.39	133.1	1858.72	1887.81		
	Combined	1296	2129.22	5.76	207.45	2117.91	2140.528	36.53	0.0000
	Five Echelon	972	2214.54	4.79	149.53	2205.13	2223.95		
	Three Echelon	108	766.48	5.48	57.03	755.60	777.35		
	Combined	1080	2069.73	13.92	457.53	2042.41	2097.05	99.80	0.0000
	Four Echelon	324	1873.27	7.39	133.1	1858.72	1887.81		
	Three Echelon	108	766.48	5.48	57.03	755.60	777.35		
	Combined	432	1596.57	23.78	494.26	1549.83	1643.31	83.83	0.0000
50	Five Echelon	972	11302.27	20.58	641.86	11261.87	11342.67		
	Four Echelon	324	8582.25	22.70	408.68	8537.58	8626.91		
	Combined	1296	10622.27	36.62	1318.65	10550.41	10694.12	71.58	0.0000
	Five Echelon	972	11302.27	20.58	641.86	11261.87	11342.67		
	Three Echelon	108	3911.36	17.68	183.76	3876.30	3946.41		
	Combined	1080	10563.18	70.019	2301.07	10425.79	10700.57	119.07	0.0000
	Four Echelon	324	8582.25	22.70	408.68	8537.58	8626.91		
	Three Echelon	108	3911.36	17.68	183.76	3876.30	3946.41		
	Combined	432	7414.52	98.99	2057.61	7219.95	7609.10	114.89	0.0000
100	Five Echelon	972	23013	28.88	900.41	22956.32	23069.68		
	Four Echelon	324	17653	40.50	729.11	17573.31	17732.69		
	Combined	1296	21673	68.78	2476.17	21538.06	21807.94	97.06	0.0000
	Five Echelon	972	23013	28.88	900.41	22956.32	23069.68		
	Three Echelon	108	7967.17	41.23	428.51	7885.43	8048.91		
	Combined	1080	21508.42	139.90	4597.89	21233.89	21782.94	171.45	0.0000
	Four Echelon	324	17653	40.50	729.11	17573.31	17732.69		
	Three Echelon	108	7967.17	41.23	428.51	7885.43	8048.91		
	Combined	432	15231.54	204.54	4251.48	14829.50	15633.58	130.67	0.0000

Table 7.6: Pairwise t-Statistic to Compare Complete Supply Chains and Disintermediated Supply Chains

that have the least net stock.[5] Therefore, the null hypothesis is rejected and *Hypothesis 8* is not supported. When taking into consideration the overlap between the confidence intervals of least net stock supply chains and harmonized supply chains, this result does not change.

7.1.5 Disintermediation and Coordination Mechanisms

According to *Hypothesis 9*, disintermediated supply chains should be more efficient than normal supply chain. The reason for this is that demand amplification is more pronounced in longer supply chains than shorter supply chains. To test this hypothesis, three pair wise "t-tests" were done on the net stock of a five-echelon supply chain, a four-echelon supply chain, and a three-echelon supply

[5]Note : The difference is significant at $\alpha < 0.05$ for mean demands of 10 and 100 and significant at $\alpha < 0.1$ for mean demand of 50.

chain. Table 7.6 gives the result. There is a significant decrease in the amount of net stock between a five-echelon supply chain, a four-echelon supply chain, and a three-echelon supply chain. Hence, hypotheses five is fully supported.

7.2 Discussion

The procedure used to simulate supply chain forecasting behavior has been used in the bullwhip literature. This procedure is based on the popular "Beer Game". In the "Beer Game", the supply chain members have visibility only of their immediate neighbors. Also, there is a lead time built into the system which further reduces the ability of the of the supply chain member to have a holistic view of the supply chain (Lee et al. (1997b)). This game mimics the problems faced by decision makers when forecasting. One of the methods which firms use to overcome forecasting errors is by holding inventory. The assumption is that it is cheaper to hold inventory rather than to lose a customer. Players in the "Beer Game", also use heuristics which increase the probability of holding excess inventory rather than stocking out. The simulation used in this dissertation also ends up with excess stock rather than with stockouts.[6] Hence all efficient firms with least net stock would consists of firms, which, on an aggregate would all have excess stocks rather than stockouts.

The expectation in *Hypothesis 7* is that the harmonized supply chains would outperform the non-harmonized supply chains. However, the results (Table 7.4) shows that the null hypothesis[7] cannot be rejected. A common pattern among the supply chains that have the least net stock is that except for the upstream supply chain member(the raw material supplier), all other echelons use the same heuristic. The raw material supplier holds most of the inventory. This is consistent with the "Beer Game" where most of the inventory is held by upstream echelons compared to downstream echelons. Even though the null hypothesis was not rejected, the results strongly favor supply chains which are "more" harmonized than "less" harmonized in terms of performance.

[6]Since it is based on the "Beer Game".

[7]Null hypothesis is that there is no significant differences between the mean net stocks of harmonized supply chains and non-harmonized supply chains.

A heuristic which is often said to be a cure for "Bullwhip effect" is for supply chains to use the actual demand of the customer as a trigger for their own forecasts. In this simulation, the heuristic, "actual demand", performs very poorly. There are two main reasons for it. First, there is a considerable lead time between the information flow and material flow. Second, supply chain members have no visibility outside of their neighborhoods. Hence, the heuristic "actual demand" will be efficient in cases where there is visibility across the supply chain of the actual customer demand.

Supply chains with the least net stock significantly outperform all other supply chains (Table 7.3). This result is consistent with the literature discussed earlier. Even though these "more" harmonized supply chains are not fully harmonized, in terms of performance[8] these supply chains outperform every other supply chain strategies.

The results show that harmonized supply chains are not necessarily the supply chains with the least net stock. Table 7.5 confirms that there is a significant difference between the means of supply chains with the least net stock and harmonized supply chains. But, according to Table 7.4, most of the supply chains with the least net stock are "more" harmonized than all other supply chains. Hence, if "more" harmonized firms are considered to be harmonized, then *Hypothesis 8* is supported.

A decrease in net stock is significant between a five echelon supply chain, a four echelon supply chain, and a three echelon supply chain. This is consistent with the theory discussed earlier. However, the assumption in this simulation is that all echelons are equal in terms of holding inventory and the lead time between echelons is constant after removal of a echelon. Future research could look at scenarios where capacity constraints exists in the echelons with reduction

[8] Measured as net stock.

in echelon size.

Chapter 8

Conclusions, Limitations and Future Research

8.1 Supply Chain Lengths and Input–Output Tables

8.1.1 Contributions

The Input–Output table has been used by macroeconomists to identify problems of income distribution, technological obsolescence, policy simulation, prediction of the economy and its various sectors, and comparative position of the economies. In the business literature, the Input–Output table has been used to benchmark competitors and to identify new market segments. The contribution of this dissertation is to use the Input–Output table to map out supply chains at the level of the industry. This enables an empirical study of complete supply chains which was not possible earlier.

The theoretical background for the dissertation is the Transaction Cost Economics (TCE). The advantage of using TCE to study supply chains is in its simplicity and assumptions which have helped in defining the key hypotheses. The key elements of TCE are uncertain environment, frequency of transactions and investment in asset specificity. All the three elements help in defining the notion of transaction costs. There are two major streams of thought linking transaction costs and supply chain lengths. The first approach assumes an increase in transaction costs due to an increase in asset specificity and hence hypothesizes a decrease in supply chain length. The second approach assumes a decrease in transaction costs and hence hypothesizes that supply chains should increase in lengths. This dissertation takes the view that transaction costs decrease as there is a greater flow of information over time. This is consistent with the "electronic market hypothesis." Supply chains will face lower transaction costs and will try to move towards more market based transactions. This would manifest itself as an increase in the length of supply chains. The Input–Output table helps in answering this key hypothesis. This empirical study proves that transaction costs have been decreasing from 1987 to 1997.

A new approach has been developed to study complete supply chains. Previous literature used case studies and analytical models to answer supply chain related questions. In case of case based methodologies, the results were not to generalizable. In case of analytical studies, the models were dyadic in nature and often lost the complexity of a complete supply chain. This new approach captures the complexity of the entire supply chain as well as generalizes the results across the entire economy. Future researchers can use this approach to model supply chains in answering research questions which require the study of complete supply chains.

This dissertation also helps in using transaction cost economics to predict the direction of individual supply chains based on the the key elements of the supply chain. This could help future researchers study the impact of decrease / increase in transaction costs on individual supply chains.

One of the managerial contributions of this dissertation is to help firms decide on the nature of the industry. Firms could look at the change in average value added and governance structure for different industries and decide whether they would like to invest or remain within the supply chain. For example, a firm willing to invest in a mining activity may not do so, if they find the average value added of the entire industry decreasing over time, or worse, supply chains for a specific industry seizing to exist after some time. However, firms can also find supply chains which increase the average value added and decide to become a part of that supply chain.

8.1.2 Limitations

There are certain limitations with this dissertation. The level of analysis is a industry level supply chain. There is a paucity of data to derive complete supply chains at the level of the firm. Hence, caution should be exercised when extrapolating the conclusion for the industry to the firm.

This new approach uses only the forward linkages[1] of NACIS code while deriving the supply chains. Back linkages and same industry references in the Input–Output table have been avoided

[1] Supply chins go from a raw material to a service oriented end-user

due to the complexity of data storage and infinite loops. These conditions could be relaxed in future research to enrich the data.

This dissertation assumes that all supply chains start with primary industries. However, there could be many supply chains which have not been taken into account because there supply chains do not use primary raw materials. This condition can be relaxed in future research.

Since the supply chains used are specific to the U.S. economy, imports and exports are not looked at. Imports and exports are not captured by the supply chains generated by using the Input–Output table.

The Input–Output table does not capture transactions less than one million dollars. In case of industries whose value added is less than a million, it does not get captured by the Input–Output table. Also, the Input–Output table does not distinguish between critical inputs and non-critical inputs. Both the categories are given equal weightage in the value added.

8.1.3 Future Research

The next stage of research is to find out the industry level factors which affect the length of the supply chain. A tentative model which will be tested is as under.

Figure 8.1 presents a model that could be used to test the factors which affect the length of the supply chain.

$$\{LengthoftheSupplyChain\} = \beta_0 + \beta_1 ITSpending + \tag{8.1}$$

$$\beta_2 ClockspeedoftheIndustry + \tag{8.2}$$

$$\beta_3 PositionoftheIndustrywithintheSupplyChain + \tag{8.3}$$

$$\beta_4 ConcentrationoftheIndustryusingHHIorCR4 + \tag{8.4}$$

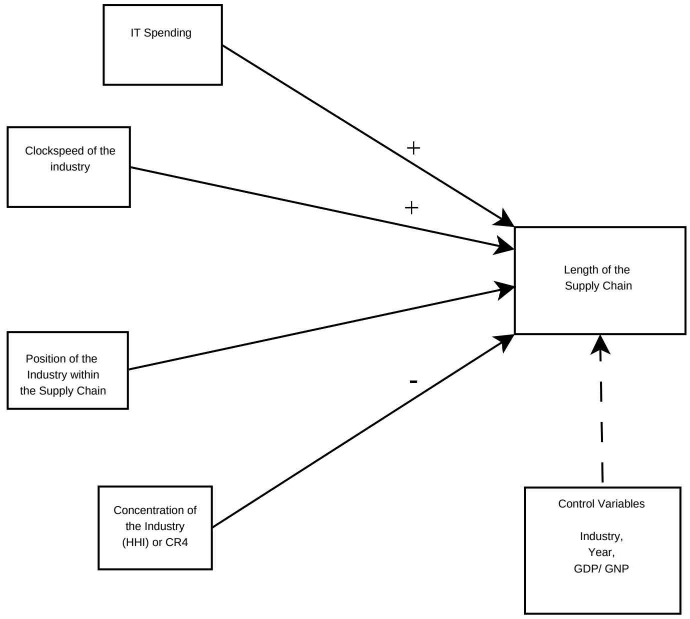


Figure 8.1: Model Linking Industry-Level Characteristics and Supply Chain Length

$$\beta_5 ControlvariableslikeGDPandYear \tag{8.5}$$

The hypotheses is that the length of the supply chain would have a positive relationship with the amount of IT spending. This is because an increase in the spending of IT would decrease overall transaction cost and hence lead to more market based transactions which would lead to an increase in the length of the supply chain. The clockspeed of the the industry would be captured by the amount of value added by the industry and would have a positive relationship with the length of the supply chain. Low clockspeed would mean industries which do not evolve fast over time and are basically the traditional industries. These industries would tend to have stable supply chains and would tend to be more vertically integrated. High concentration with the industry would also lead to high vertical integration and hence a smaller supply chain length. Hence concentration would have an inverse relationship with supply chain length.

The new approach helps in identifying supply chains at the level of industry. Firms can also look at the governance structure[2] of the industry and benchmark themselves with their competi-

[2]Tending towards market based or hierarchial based.

tors. They could look at the trend of their industry becoming more hierarchial or more market based and then decide to change their strategies based on their transaction costs. Firms can also compare the average value added by their industry with their own value added, and decide on their competitiveness.

Researchers in public policy and macroeconomics can look at the effect of taxes and incentives at individual industries instead of at the macro level. For example, an increase in U.S. taxes might trigger imports in certain industries more than the others. The Input–Output approach can help in identifying specific industries and give industry specific incentives.

Also, this research needs to be extended to the level of the firm to make the data more relevant to firms. This would also help in confirming whether changes at the micro level are consistent with changes at the level of the industry.

8.2 Supply Chain Length and Coordination Costs

8.2.1 Contribution

The key question being asked in this section of the dissertation is whether under certain circumstances uncoordinated supply chains outperform coordinated supply chains in terms of demand forecasting. Standard textbooks and research in inventory management favor coordinated mechanisms to achieve supply chain optimization in demand forecasting. However, this assumption breaks down in case of suppliers which sell to products to multiple buyers. The seller cannot be expected to follow multiple coordination mechanisms[3] with multiple buyers. In this dissertation the coordination mechanism used are three heuristics; actual demand, moving average, and moving average with trend correction. For different demand distributions and three different means are used to test the robustness of the results. Net stock, which is the addition of excess stock and stockouts, is used as the performance measure. Simulation is used to test this key hypothesis as

[3]Heuristics of ordering policies.

it is very difficult to get actual data for an empirical study. This research finds that as long as supply chains minimize net stock, they may not have to harmonize their ordering policies across the individual echelons.

This dissertation also finds that disintermediated supply chains perform more efficiently than supply complete supply chains which do not add much value.

8.2.2 Limitations

Some of the limitations of this study are that certain costs such as stock-out costs have not been factored in. This was because stock-out costs differ greatly from echelon to echelon both inter- and intra-industry. Moreover, there is no agreement in the literature on how best to quantify this cost.

An important assumption in the simulation is that the optimum solution has zero net stock within the supply chain. While this assumption may be valid for “Just in Time” ordering policy, it may not be valid for other ordering policies. Other performance measures like inventory turnover ratios, total cost of owning the product in the supply chain may have to be used to make the results more generalizable.

This study uses four popular demand distributions; normal distribution with a small standard deviation, normal distribution with a large standard deviation, uniform distribution, and poisson distribution. There might be other distributions which were not used in this study which could change the results of the study.

The simulation assumes unlimited capacity of the manufacturer to produce goods and unlimited capacity of all the echelons to hold inventory. This dissertation also assumes a uniform lead time of one week between transfer of information and materials between echelons.

Another important limitation of the simulation is that like the “Beer Game”, the echelons in a supply chain have no visibility of customer demand. They only have visibility of their immediate neighbors.

8.2.3 Future Research

The model proposed in the dissertation is very simplistic in nature. This model will be extended to include parameters like inventory holding policy, safety stock, varying service levels, and costs associated with stockouts and excess stocks. The effect of introducing safety stock at each echelon will increase the average inventory held by the supply chain. This may change the amount of net stocks given by the present model, and may arrive at a different conclusion. The same is true for cost of excess stock and stockouts. In the current model, equal weightage has been given for both stockouts and excess stocks. Anecdotal evidences and analytical studies have show the cost of stockouts to be much greater than the cost of excess stocks. Future research would look into whether or not the results change substantially with the inclusion of appropriate costs.

The model has a severe restriction due to the fact that it considers zero inventory to be an optimum performance measure. This may not be a realistic assumption especially for push based supply chains. Hence, alternate performance measures like the total cost of ownership may need to be considered in future research.

Future research should empirically study the effect of different coordination mechanisms on performance measures to validate the simulation study. There is anecdotal evidence to support the simulation, but these results are less generalizable than empirical studies.

Various limitations in this study can be relaxed to see the robustness of the result. For example, capacity constraints could be placed on suppliers, plants, warehouses, and retailers. Also, the effect of EDI and Internet can be simulated by making the actual customer demand visible to all echelons of the supply chains.

The assumptions made during the disintermediation process was that echelons which did not add value were being disintermediated. Also, the lead time between echelons remain the same after disintermediation. This simulation could be used in the future to test whether results differ if supply chains which contribute value to the supply chain get disintermediated. For added complexity, lead times could be made variable. This dissertation looks at a simple supply chain. Additional complexity can be introduced by considering multi-tier echelons.

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