8-2012

Empirical and Analytical Essays on the Relationship between Inventory and Transportation

Rodger David Swanson
University of Arkansas, Fayetteville

EMPIRICAL AND ANALYTICAL ESSAYS ON THE RELATIONSHIP BETWEEN INVENTORY AND TRANSPORTATION

EMPIRICAL AND ANALYTICAL ESSAYS ON THE RELATIONSHIP BETWEEN INVENTORY AND TRANSPORTATION

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Business Administration

By

Rodger David Swanson
David Lipscomb University
Bachelor of Science in Marketing, 1987
University of Tennessee
Master of Business Administration, 1990

August 2012
University of Arkansas

ABSTRACT

This dissertation examines the relationship between inventory cost (IC) and transportation cost (TC). The association of the two has been recognized for over a hundred years; accordingly, managers and academics have believed that these costs have offsetting properties such that combinations of inventory and transportation expenditures can be altered to fit different strategic objectives. However, the behavior of this relationship in practice has not been tested. The essays of this dissertation examine this relationship through multiple theoretical lenses and with multiple data sets. Essay 1 examines aggregate IC and TC in the United States from 1960-2009. This period coincides with the recognition of total cost management and the ensuing practice of inventory and transportation tradeoff. Essay 1 provides new insight into the macroeconomic relationship of IC and TC by providing a model of their relationship. Examination reveals distinct differences before and after transportation deregulation in the United States. Essay 2 continues the investigation of the relationship between IC and TC, this time using firm-specific, panel data that spans a five-year period from 2006-2011. Inventory theory is used to identify variables and build a model that forecasts firm inventory. To this base model, TC is added. Findings support the research in Essay 1 by confirming that firms do show indication of balancing IC and TC. Essay 3 examines the use of transportation benchmarking information and how it affects firm performance. Based on information processing theory, the impact of transportation benchmarking information on a firm's ability to reduce transportation cost (TC) is examined. A variable is created that is the ratio of a firm's transportation expenditure to the total transportation expenditure in the benchmarking consortium. Panel data is used to test the impact of this ratio on a firm's ability to reduce transportation costs. Empirical analysis shows that

transportation costs are convex in the ratio, and the results support the efficacy of transportation expenditure benchmarking.

This dissertation is approved for recommendation

to the Graduate Council.

Dissertation Director:

____

Dr. Matthew A. Waller

Dissertation Committee:

____

Dr. John Ozment

____

Dr. Brent D. Williams

DISSERTATION DUPLICATION RELEASE

I hereby authorize the University of Arkansas Libraries to duplicate this dissertation when needed for research and/or scholarship.

Agreed ______________________________________

Rodger David Swanson

Refused ______________________________________

Rodger David Swanson

ACKNOWLEDGEMENTS

My parents, Roger and Shirley, taught that education is not only important but that it is required. To help me achieve that requirement, they removed obstacles, provided encouragement, and they modeled the benefits of a good education within their own lives. Without their influence, I would have never spent nine years at a university.

My wife, Lori, is the great encourager. While in our mid-forties, with the expenses of a mortgage, children, and private school tuition, it seemed impossible for me to leave work for four years and return to school. Lori believed it could be done, and she had the courage to commit. Her positive energy and hard work have made this possible. Thank you, Lori. I am fortunate that you are my wife, and I love you.

My university focuses on being a research institution, but I found many professors who also wanted to be my teachers. Thank you, professors, for finding time to help me along.

Finally, I'd like to thank my children, Rachael and Trevor. They provide great joy for Lori and me and help me to remember that the best things in life do not include getting degrees and climbing the ladder.

DEDICATION

This dissertation is dedicated to my brother Rod, who died in the third year of my doctoral education.

Brothers have something special, a gift. For whatever reason, God decided to bring them into this world under similar circumstances. Rod and I were no exception, and we acknowledged that mysterious bond that tied us together. We were separated by two years, but we shared everything else, including a room, parents, chores, friends, vacations, teachers, coaches, secrets, and countless talks. We grew up together.

Casual observers of our lives would conclude that we took different paths at age eighteen. Even I believed that, for many years. I know now that we walked the same path. We wanted to be happy, to develop relationships with our friends and family, and to improve our living circumstances. We wanted to make our lives match our dreams. We both did our best but had different results. Rod’s path was impeded by untreated bipolar disorder. He never complained, and so I believe that his life was fulfilling. He had friends, music, strength, and a positive attitude.

I think of Rod daily. Because of that, I suppose that we are still sharing life, even after his death. He was in my heart and mind during the research and writing of this dissertation. So, it seems fitting that this dissertation be dedicated Rod and the inspiration that I and others have found from his life.

Going forward, I’ll try to live for us both. Rest in peace my brother.

LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
FFR	Federal Funds Rate
GDP	Gross Domestic Product
IC	Inventory Cost
INV	Inventory
IRF	Impulse Response Functions
JIT	Just in Time
NAICS	North American Industry Classification System
SIC	Schwarz Bayesian Criterion
SS	Sale Surprise
SCM	Supply Chain Management
TC	Transportation Cost
TLC	Total Logistics Cost
VAR	Vector Auto Regression
VECM	Vector Error Correction Model
VMI	Vendor Managed Inventory

PREFACE

Upon leaving business school, I began my career as a project manager responsible for installing logistics software and related projects. My goal was always to improve my clients' efficiency thereby ensuring a good return on their investment. Installing software does not immediately make a company better. The managers that use the newly installed tool to understand their business and to improve their operation every day are the important catalysts in the success of logistics software projects and their ability to make a company better.

Sometimes I was bothered that other professions seemed nobler. Doctors and nurses saved lives; Teachers helped young people; Social workers clothed orphans; however, business people just focused on making money. I eventually realized that even though the primary motivation of business is to make money, the indirect results are that society has more products, better products, more accessibility to products, faster delivery of products, and better quality of products, which results in a better lifestyle. When companies don't make continuous improvements (whether motivated by money or nobler intentions) for demanding customers, competitors will. The result of the continuous motivation to make money is that our currency buys more and our lives are improved. More so than any other business discipline, logistics provides outstanding potential for improving our society.

CHAPTER 1: INTRODUCTION

Dissertation Topic and Rationale

The relationship of inventory cost (IC) and transportation cost (TC) has been observed for a long time, and it is difficult to pinpoint when this relationship was first observed. Their relationship and resultant costs have probably been compared for hundreds of years. The first recorded case is from the nineteenth century (Langley, 1986), in which shippers compared the different inventory considerations involved between horse carriage and river barge transportation modes. Harris developed the EOQ formula and (Q,r) model(Harris, 1913); and later these were enhanced by Camp (Camp, 1922). These studies provided the first framework for research of IC and TC.

The importance of the relationship between IC and TC continued to grow until it reached a critical mass in the 1950s and 1960s at which time it evolved into the total cost movement and contributed to the birth of modern business logistics education. The first course in logistics management was offered in 1958 (Bowersox, 2007), and the first textbook was written by Smykay et al. (Smykay, Bowersox, & Mossman, 1961). The foundation of business logistics was built upon several concepts (Waller & Fawcett, 2012), including the notion of total cost management (Lewis, Culliton, & Steele, 1956). Total cost management stipulated that firms must consider all of the costs of logistics together, including such expenditures as warehousing, inventory service cost, inventory obsolescence, transportation spending, purchasing, etc. Furthermore, the corporation needed to approach its logistics costs systematically because these types of expenditures within a firm are interrelated. For example, purchasing in bulk to achieve reduced price has an associated increase in inventory carrying cost. Indiscriminant cost changes in one area of the company can produce disastrous effects on the bottom line (Magee, 1960).

Pioneer educators and practitioners raised the importance of this total logistics concept, and a host of studies sought to understand this new approach. Peter Drucker did much to expand the concept of what was then called physical distribution when he drew the analogy of the contemporary understanding of logistics to the understanding that Napoleon's contemporaries had of the interior of Africa; it was there and it was big (Drucker, 1962).

Since the founding of logistics management on such principles as the balancing of IC and TC, the field has grown significantly. Researchers expanded upon the initial framework of Harris (Harris, 1913) and Camp (Camp, 1922), including the addition of transportation variables (Baumol & Vinod, 1970; Buffa & Reynolds, 1979; Langley, 1980), stock-out cost, (Constable & Whybark, 1978), safety stock (Stenger, Coyle, & Price, 1977), weight breaks (Coyle & Bardi, 1976) and the expansion of inventory holding and ordering cost (Ballou, 1973). However, research of the total cost concept has mostly subsided. Almost all subsequent research has focused on either IC or TC in isolation. There have been a few studies that seek to consider these costs simultaneously (Langley, 1980; Sheffi, Eskandari, & Koutsopoulos, 1988; Tyworth, 1992). However, this effort has been limited. Despite this paucity of research on total cost management, it is still an important topic for logistics researchers, academicians, and managers (Waller & Fawcett, 2012).

Much has happened in the last 30 years to set the stage for improved, theoretically-grounded research on IC and TC. First, even though the tradeoff between IC and TC has not been studied much, other tradeoff relationships have been studied prolifically within the logistics discipline. Consequently, the education, research, and practice of logistics management is still well grounded in tradeoffs including such related topics as total cost ownership (Ellram & Siferd, 1998), total-profit approach (Poist, 1974), and synergies of collaboration and information sharing (Cavinato, 1992; Lee & Billington, 1992). In addition, we have learned that information can be a substitute for inventory (Milgrom & Roberts, 1990). Second, there are new economic methodologies for time series analysis; consequently, the methods that researchers have available today are more robust. Applying unit root, cointegration, vector auto regression (VAR), and vector error correction model (VECM) time series methods will extend our understanding of the relationship of IC and TC. Third, researchers have been collecting macro-level information on IC and TC in the United States since 1960, but the information has yet to be rigorously analyzed. From this data some observers have made generalizations about the relationship of IC and TC. Viewing a graph of IC and TC over a specific time period, one can see that they roughly move together. The most notable observation is that total logistics costs have dropped as a percentage of gross national product (GNP). This is believed to show that logistics has become more efficient (Langley, 1986). However, these discoveries are only based on anecdotal evidence and cannot be determined unambiguously. The relationship between IC and TC has not been studied empirically at the macroeconomic level.

There are numerous academic studies on either inventory or transportation alone. There have been fewer studies on TC than there have been on IC, probably because publicly traded firms are not required to disclose TC on their financial statements. Hence, researchers have a difficult time finding the data they need for robust study. Furthermore, many firms do not capture TC in the manner needed to study these costs appropriately. If a firm uses purchased transportation services, it can be relatively easy to capture transportation expense. However, for firms that use a private fleet, the calculation of TC becomes more difficult. For example, it may not be clear what percentage of a firm's labor is attributable to transportation, how much of their fuel spending is for transportation of merchandise, or what the cost is of damaged freight or equipment depreciation. This lack of transportation research further supports the rationale of this dissertation, which promises to provide more information on TC and its interaction with IC.

The study of inventory is very important to our understanding of the nation's economy and this dissertation will examine both macroeconomic and microeconomic aspects. There is tension and disagreement between microeconomic studies and macroeconomic studies of inventory (Blinder & Maccini, 1991). From a microeconomic perspective, most firms use inventory to smooth their level of production. Firms hold inventory to protect from upswings in demand, yet from a macroeconomic perspective inventory cycles are more volatile than sales output (Feldstein, Auerbach, Hall, & Lovell, 1976). Seventy-six (Feldstein et al., 1976) to eighty-seven percent (Blinder & Maccini, 1991) of the downturn in the recent recessions can be attributable to the reduction of inventory.

This sets the stage for this dissertation, which evaluates the behavior of IC and TC. By studying the aggregate and firm-level perspectives, this dissertation promises to provide robust results for interpreting the relationship of IC and TC. By viewing this dissertation through the multiple theoretical lenses of inventory theory, efficient market, and information processing, theoretical understanding is advanced. By investigating whether IC and TC are in equilibrium at the macroeconomic level, theory and practical expectations can be confirmed or rejected. The three essays in this dissertation promise to make a significant contribution to both theory and practice of the relationship between IC and TC.

Essay 1

Essay 1 provides a longitudinal analysis of IC and TC in the United States and answers the question of equilibrium between the two. Aggregate data was collected on transportation and inventory cost from 1960-2009. This is the ideal time period because this period parallels that of the birth and growth of modern business logistics and supply chain management education, theory, and practice, including regulated and de-regulated periods. This data will be observed with time series methodologies that have yet to be applied to the study of IC and TC. These methods include evaluating unit roots and cointegration, modeling with VAR and VECM, and testing for Granger causality.

The VECM will allow us to test the underlying dynamics between IC and TC. Each variable will be modeled using lags of itself and lags of the other variable. Optimum lags can be selected by adjusting the model and monitoring Akaike and Schwarz Bayesian Information Criterion (AIC and BIC, respectively). One of the relevant features of a VECM is that it can be used to analyze impulse response functions. Thus, we can study the effects of shocks and determine the length of the effects. Macroeconomic theory suggests a long adjustment period of inventory to its equilibrium levels (Feldstein et al., 1976), which can be tested with the impulse response function. Furthermore, we can study the effects of a shock on IC and TC separately and monitor the differences in the effects of each on the other.

Essay 1 Research Question: Do aggregate IC and TC show signs of an equilibrium relationship over the last fifty years?

Essay 1 finds that IC and TC are in equilibrium during the period following transportation deregulation in the United States. Prior to deregulation, this study finds that IC and TC do not behave as predicted by theory. It is concluded that policy restrictions inhibited the market from behaving efficiently.

Essay 2

Following the macroeconomic study of aggregate IC and TC in Essay 1, Essay 2 tests the same relationship at the firm level. To undergo this task, it was important to collect TC data from firms. As mentioned previously, IC is relatively easy to obtain from public companies; however, TC is not available. Hypotheses are developed from inventory theory.

Essay 2 Research Question: Do individual firms tradeoff IC and TC?

Essay 2 finds that TC is a statistically significant variable for the determination of firm inventory, even beyond the predictive power of other variables suggested by inventory theory. Inventory theory suggests that the relationship between IC and TC is positive. The relationship direction of IC and TC was found to be negative. This situation is reviewed.

Essay 3

Essay 3 examines the use of transportation benchmarking information and how it affects firm performance. Based on information processing theory, the impact of transportation benchmarking information on a firm's ability to reduce transportation costs is examined. Consider a continuum where, at one end of the continuum a firm has no transportation costs to the other end of the continuum where a firm represents all of the transportation costs in the benchmarking panel. At both ends of the continuum there are no benefits to the firm from benchmarking; but in between the two ends of the continuum, there are benefits. To describe this relationship, a variable is created that is the ratio of a firm's transportation expenditure to the total transportation expenditure in the benchmarking panel. This ratio represents the relative amount of transportation expenditure of a given firm in comparison to the size of the benchmarking panel. Panel data is used to test the impact of the ratio on a firm's ability to reduce transportation costs. Empirical analysis shows that transportation costs are convex in the ratio.

Essay 3 Research Question: Do profitable firms use transportation benchmarking information to lower TC?

Essay 3 finds that firms with higher inventory levels spend more on transportation and more profitable firms spend less on transportation, other things being equal. The results support the efficacy of transportation expenditure benchmarking.

Objectives of the Dissertation

The first objective of this dissertation is to contribute to inventory theory by testing for an equilibrium relationship between IC and TC. This is accomplished with research at the aggregate and firm-level across a fifty year time span. A model for forecasting IC is developed using IC and lagged TC.

The second objective is to introduce new theories to enhance testing and understanding of total logistics cost. In addition to inventory theory, this dissertation pulls theories from other disciplines into the logistics literature by drawing upon information processing theory from management, and efficient market theory from finance.

The third objective is to build upon existing knowledge of the interaction of IC and TC. This is accomplished with contributions from each of the three essays. Multiple datasets and methods are used to develop and test hypotheses from multiple theoretical lenses. The relationship between these costs will be examined with econometrics methods which have been commonly applied in econometrics study, but which have not yet been applied to the study of logistics costs.

Fourth, this dissertation seeks knowledge that will allow managers to operate their firms more successfully to achieve enhanced performance. It is anticipated that new understanding of IC and TC might result in new guidelines, toolsets, models, or theory which can be used by executives as an aid in decision making in logistic and supply chain management. Although some management guidelines will be gleaned from Essay 1, Essays 2 and 3 are more focused on providing insight for firm management.

The fifth objective of this dissertation is to spark a renaissance of research on the relationship between IC and TC and on the total logistics cost concept. Much can be learned from a contemporary look at the relationship between IC and TC, and other types of total logistics cost tradeoffs.

Organization of the Dissertation

This dissertation is organized by devoting the next three chapters to each of the three essays. Each chapter is comprised of one essay that will be submitted to a journal. The headings used in each of the papers are slightly different because they are tailored to different publications. However, they include most of the following segments: an introduction, literature review, theoretical bases, development of hypotheses, data, methodology, results, conclusions, and references. Chapter 5 summarizes the collective results of this dissertation and provides conclusions.

References

Ballou, R. H. (1973). *Business logistics management*. New Jersey: Prentice-Hall.

Baumol, W. J., & Vinod, H. (1970). An inventory theoretic model of freight transport demand. *Management Science, 16*(7), 413.

Blinder, A. S., & Maccini, L. J. (1991). Taking stock: A critical assessment of recent research on inventories. *The Journal of Economic Perspectives, 5*(1), pp. 73-96.

Bowersox, D. J. (2007). SCM: The past is prologue. *Supply Chain Quarterly,* (Quarter 2), 1.

Buffa, F. P., & Reynolds, J. I. (1979). A graphical total cost model for inventory-transport decisions. *Journal of Business Logistics, 1*(2), 143.

Camp, W. E. (1922). Determining the production order quantity. *Management Engineering, Vol. 2.*

Cavinato, J. L. (1992). A total cost/value model for supply chain competitiveness. *Journal of Business Logistics, 13*(2), 285-301.

Constable, G. K., & Whybark, D. C. (1978). The interaction of transportation and inventory decisions. *Decision Sciences, 9*(4), 688-699.

Coyle, J. J., & Bardi, E. J. (1976). *The management of business logistics*. St. Paul, MN: West Publishing Company.

Drucker, P. F. (1962). The economy's dark continent. *Fortune, April, 4*, 103.

Ellram, L., & Siferd, S. P. (1998). Total cost of ownership: A key concept in strategic cost management decisions. *Journal of Business Logistics, Vol. 19*, pp. 55-84.

Feldstein, M., Auerbach, A., Hall, R. E., & Lovell, M. C. (1976). Inventory behavior in durable-goods manufacturing: The target-adjustment model. *Brookings Papers on Economic Activity, 1976*(2), 351-408.

Harris, F. W. (1913). How much stock to keep on hand. *The Magazine of Management, Vol. 10*, p. 240.

Langley, C. J. (1980). The inclusion of transportation cost in inventory models: Some considerations. *Journal of Business Logistics, 2*(1), pp. 106.

Langley, C. J. (1986). The evolution of the logistics concept. *Journal of Business Logistics, 7*(2), pp. 1-13.

Lee, H. L., & Billington, C. (1992). Managing supply chain inventory: Pitfalls and opportunities. *Sloan Management Review, 33*(3), 65-73.

Lewis, H., Culliton, J., & Steele, J. (1956). *The role of airfreight in physical distribution*. Boston, MA: The Alpine Press.

Magee, J. F. (1960). The logistics of distribution. *Harvard Business Review, 38*(4), p. 89.

Milgrom, P., & Roberts, J. (1990). The economics of modern manufacturing: Technology, strategy, and organization. *The American Economic Review,* , 511-528.

Poist, R. F. (1974). The total cost vs. total profit approach to logistics systems design. *Transportation Journal, 14*(1), p. 13.

Sheffi, Y., Eskandari, B., & Koutsopoulos, H. N. (1988). Transportation mode choice based on total logistics costs. *Journal of Business Logistics, 9*(2), 137-154.

Smykay, E. W., Bowersox, D. J., & Mossman, F. H. (1961). *Physical distribution management: Logistics problems of the firm* Macmillan.

Stenger, A. J., Coyle, J. J., & Price, M. S. (1977). *Incorporating transportation costs and services into the inventory replenishment decision*. Columbus, OH: The Ohio State University.

Tyworth, J. E. (1992). Modeling transportation-inventory trade-offs in a stochastic setting. *Journal of Business Logistics,* (2), 97.

Waller, M. A., & Fawcett, S. E. (2012). The total cost concept of logistics: One of many fundamental logistics concepts begging for answers. *Journal of Business Logistics, 33*(1), 1.

CHAPTER 2 (ESSAY 1): The Relationship between Inventory and Transportation: A Macroeconomic Analysis of Equilibrium and Causality

Abstract

Theory suggests that firms must trade off inventory cost and transportation cost in order to minimize cost. In order to empirically investigate inventory and transportation costs at the macroeconomic level, this paper examines aggregate level cost data in the United States economy from 1960 to 2009 and employs cointegration tests and error-correction modeling. This study finds an equilibrium relationship in the long run between inventory and transportation costs in the post deregulation time period, and finds unidirectional Granger causality.

Introduction

There is a large body of academic literature supporting the relationship between inventory carrying cost (IC) and transportation cost (TC). Prior to this research, IC and TC have been compared in practice for hundreds of years. The first documented occurrence was in the mid-1800s (Langley, 1986) when managers compared the speed and inventory storage characteristics that are associated with horse carriage and river barge transportation. The equilibrium relationship between the IC and TC has been theoretically grounded and is a significant topic covered by most textbooks on business logistics, operations management, and inventory management (Ballou, 1973; Lambert, Stock, & Ellram, 1998; Nahmias, 1989). Theoretical models suggest that firms should trade these costs against one another in order to minimize total logistics cost (TLC). The primary research question in this essay asks whether there is empirical evidence that firms are trading off TC and IC at the macroeconomic level.

Most of the research on IC and TC has been analytical (Burns, Hall, Blumenfeld, & Daganzo, 1985; Langley, 1986; Sheffi et al., 1988; Tyworth, 1992). The author found neither empirical studies regarding IC and TC tradeoffs by firms nor longitudinal studies on causal relationship between IC and TC.

To investigate if there is evidence that firms are trading off IC and TC at the macroeconomic level, this essay employs cointegration tests, Granger causality, and error-correction modeling using data from 1960 to 2009. The paper makes two salient contributions to the existing literature. First, this paper is the first to examine secondary data and determine whether or not IC and TC show signs of equilibrium behavior. Second, this is the first paper to study the temporal causal relationships of IC and TC with time series methods.

Theory suggests that firms balance their cost of carrying inventory with their cost of transportation. For instance, if TC rises, firms may choose to increase cycle stock, ship less frequently, and thus hold a higher level of inventory. Similarly, if the cost of fuel and thus motor transportation rates rise, firms may choose to consolidate inventory and ship in bulk or use a less expensive transportation mode, such as railroad. However, the pursuit of low cost is not done in a vacuum. Firms routinely balance cost with customer service strategy. For instance, if a firm pursues a high-service strategy, they might not make changes to their cycle stock when TC rises and thus keep smaller, frequent deliveries to maintain high service. This study will examine the theories and equilibrium relationship between IC and TC to better understand the relationship between these important logistics costs.

The accumulation of research that relies on an assumption of an equilibrium relationship between IC and TC is large. Empirical support is provided by Defee et al. who found that among the theoretical studies in supply chain management (SCM) from 2004-2009, most use competitive theory, microeconomic theory, marketing theory, and systems theory (Defee, Williams, Randall, & Thomas, 2010). Three of these four theories are equilibrium-based.

This study begins in 1960 which shortly follows the first publication of the total logistics concept (Lewis et al., 1956) and of the influential Harvard Business Review article by Magee on the same subject (Magee, 1960). It examines secondary data over the next 50 years to determine if firms in the United States have behaved as theoretically anticipated.

Data

Sample

Data for this study spans the age of modern business logistics management from 1960 – 2009. Aggregate IC and TC for this study are taken from the "State of Logistics Report" that is published each year by the Council of Supply Chain Management Professionals (Wilson & Delaney, 2001). Inventory carrying cost is calculated from multiplying total inventories and the commercial paper rate (for the cost of carrying inventory). TC is determined from the main modes of transportation including motor, rail, air, marine, and pipeline. For this study IC and TC are converted to real 1982 dollars by dividing by the producer price index (Federal Reserve Bank of St. Louis, 2012). These variables are also transformed with the natural logarithm to allow for a multiplicative relationship between IC and TC.

Annual trends can be seen by observing observations of nominal and real IC and TC. Real value adjusts nominal value to remove effects of price changes over time. Nominal IC ranges from a low of $31 billion in 1960 to a peak of $488 billion in 2007. Real IC ranges from about $1 billion in 1960 to a maximum of $2.8 billion in 2007. Nominal TC ranges from $44 billion in 1960 to $688 billion in 2009. Real TC ranges from $1.4 billion in 1960 to a peak of almost $5 billion in 2007. Figures provide graphical representation of nominal (Figure 1) and real (Figure 2) IC and TC.

The growth rates of IC and TC routinely change lead, see Figure 3. The growth rate hints of the equilibrium relationship between the two, because the two costs never stray too far from one another. When they are separate for a couple years, they draw close together again, often overcompensating and switching lead. This two- or three-year lag that is observed is intuitive because firms do not adjust TC and IC immediately. Sometimes it takes several years for these adjustments to take place (Feldstein et al., 1976). Feldstein suggests that slow inventory adjustment reflects a variety of factors in the multiyear plans of firms. Inventory targets depend on firm warehousing facilities and personnel, which adjust slowly. Learning can be slow, and more importantly, firms must weigh the risk of running short and missing sales with the potential gain from IC savings. It is therefore not surprising that firms are slow to change their target inventories as they learn from experience about the cost and benefits of inventory policy in a changing economic market.

Structural Break

Legal changes made transportation deregulation in the United States the official policy in the latter half of the 1970s and 1980 with four significant legislations: the Railroad Revitalization and Regulatory Reform Act of 1976, Airline Deregulation Act of 1978, the Staggers Rail Act of 1980, and the Motor Carrier Act of 1980. During this period, market freedom significantly opened, giving the transportation market opportunities to act unencumbered by capacity, labor, pricing, and other constraints that were previously regulated by the Interstate Commerce Commission.

Figure 2 graphically shows real IC and TC from 1960 to 2009. A likely structural break is visible which begins around 1980 and concludes around 1984. During this transition time, IC briefly surpassed TC for the first and only time since 1960. Carriers were suddenly allowed to drop rates without boundaries and the time period was marked with unusual volatility. Notice also that IC and TC trended tightly together prior to deregulation. Following deregulation, the expanding spread between the two costs is pronounced.

Methodology

This research utilizes time series econometric analysis of secondary data. Cointegration is a useful method to study time series and longitudinal data (Narayan & Smyth, 2004; Venturini, 2009) because it allows researchers to determine if two variables have a long-term relationship. It has not been applied to the study of the macroeconomic behavior of IC and TC.

Determining the equilibrium and direction of causality between IC and TC followed a three-stage procedure. The first stage was to determine the order of integration by using unit root tests. The second stage determined cointegration via the Engle-Granger and Johansen tests. The third stage involved bi-directional Granger causality testing. There is a structural break in 1980, so unit root, cointegration, and Granger causality tests were each done separately on the two periods prior to and following transportation deregulation.

The order of integration of the variables is denoted I(x), where x is the number of differences required to obtain a stationary series. When variables are integrated of the same order they can likely be cointegrated. Tests showed that the variables are I(1) so cointegration tests were performed to examine the existence of long-term equilibrium relationships between IC and TC. Two separate cointegration tests were run including the Engle-Granger and Johansen tests. Granger causality was also tested. An integrated relationship between IC and TC in the post deregulation period was found. Then, the variables were modeled with a system of equations allowing for a common stochastic drift by using a vector error correction model (VECM).

Unit Root Tests

IC and TC are non-stationary and have increased over the last 50 years. This growth could be based on a trend that can be explained by exogenous variables such as population growth or interest rates. Otherwise, the variables could be characterized by a random walk process in which the current period observation is equal to the last period observation plus a random component. To make this determination, ADF tests were run with three separate structures: with an intercept (α), with intercept and time trend ($\alpha + a_t$), and with neither an intercept nor time trend. Also the ADF tests were run on level data and then again on the first differenced data. This allows a test of the order of integration of the variables. Table 1 reports the results of the unit root tests. For some of the tests, it was necessary to test second differenced data which concluded that some series are I(2).

IC and TC are I(1) over the entire period from 1960-2009. This conclusion is the same whether testing the unit root with drift (α), with drift and time trend ($\alpha + a_t$), or with neither drift nor time trend. For additional information, and because of the likelihood of structural break, unit root tests were performed on the regulated time period (1960-1979) and the de-regulated period (1985-2009). Even though most transportation deregulation policy was in place by 1980, the market wasn't fully adjusted to deregulation for several years following. From data observation, 1984 was selected as the year when transformation was completed, so the analysis was resumed in 1985. During the regulated environment period, IC and TC are either I(1) or I(2) when tested under varying conditions of drift, time trend, and neither. For the post de-regulation period IC and TC are I(1) only when the unit root test is done without drift and time trend.

The ADF tests reveal different results for IC and TC over the course of the three different time periods and the three different structural forms (with intercept, with intercept and drift, and without intercept). The ADF tests are based on the standard normal distribution which loses some power from lack of proper fit. Because of these inconsistencies, a more rigorous unit root test was performed. For this supplemental testing, results were compared using the empirical cumulative distribution of τ, which is the recommended distribution for unit root testing (Enders, 2010).

The tau test of unit root to test the order of integration of IC and TC follows a three-stage process (Enders, 2010). The first stage involves testing τ (H_0: λ = 0; H_1: no unit root). The second stage involves testing τ_μ (H_0: λ = a = δ = 0; H_2: time trend is necessary). The third stage involves testing τ_t (H_0: λ = a = δ = 0; H_3: stationary with time trend and drift).

$$\Delta\, IC_t = \lambda\, IC_{t-1} + \delta + at + \varepsilon_t \qquad (1)$$

$$\Delta\, TC_t = \lambda\, TC_{t-1} + \delta + at + \varepsilon_t \qquad (2)$$

Results are displayed in Table 2. Critical values for the empirical cumulative distribution of τ that are used to compare with the results from the three-stage test are provided in Table 3.

Testing proceeded with Equation 1 for IC and Equation 2 for TC. H_1 is not rejected suggesting there is a unit root. Therefore the following two stages are not required.

Cointegration Tests

Because IC and TC are integrated of the same order, cointegration testing is appropriate. An Engle Granger test for cointegration was performed by regressing IC on TC and then by testing the residuals (see Equation 3).

$$Ln\, IC_t = \alpha + Ln\, TC_t \tag{3}$$

If the residuals are found to be stationary, then the variables are cointegrated and the existence of a long run equilibrium relationship between IC and TC cannot be rejected. Because of the possibility of structural break, the Engle-Granger test was done on the regulated time period, the post de-regulated period, and on the combined years from 1960-2009. For the entire time period, IC and TC are not cointegrated and therefore do not share a common stochastic drift. This argues against an equilibrium relationship between IC and TC. However, interesting results are found when testing integration on the pre- and post-deregulation periods. IC and TC are not cointegrated during regulation. This makes intuitive sense because transportation carriers were not entirely free to adjust prices and limit cost such as abandoning unprofitable routes. Policy restrictions therefore limited the market's self-determination. However, after deregulation, there is evidence that IC and TC are cointegrated. Therefore, the hypothesis that IC and TC are in long run equilibrium in the era of deregulation cannot be rejected. Test results on the Engle-Granger test is presented in Table 4.

The Johansen test for cointegrated variables was conducted on IC and TC to provide additional rigor to the cointegration analysis. The results of the Johansen test support that cointegration does exist in the post-deregulation time period and there is at most one cointegration relationship between IC and TC. This result duplicates and supports that of the Engle-Granger test. Table 5 provides additional information on the Johansen test.

Granger Causality

Whenever a pair of I(1) time series variables are cointegrated, there must be causation in at least one direction (Granger, 1988). Granger causality testing can provide useful information on whether past movements improve short-term forecasts. Granger causality can be bi-directional or unidirectional and the presence of causality allows better predictability of the dependent variables.

It is important to include the error correction vector in the equation for testing Granger causality in the post-deregulation time period because the variables are cointegrated. Economic theory does not offer much guidance on the number of lags to include in the model (Malley, 1990), so the best fitting model was selected by monitoring the lowest Akaike Information Criterion (AIC) and Schwartz-Bayesian Criterion (BIC). Also, casual observation of Figure 3, which shows that the variables tend to react to one another in approximately a 2 to 3 year timeframe.

When examining the entire period from 1960 through 2009, there is no evidence of Granger causality in either direction between IC and TC. However, when looking at the pre- and post-deregulation time periods separately, unidirectional Granger causality is found, but in different directions. Following deregulation, there is evidence that TC Granger causes IC (0.043). There is no supporting statistical evidence that IC Granger cause TC. This is the opposite conclusion drawn from the regulated time period. Granger causality results are summarized in Table 5.

Vector Error Correction Model (VECM)

The next phase of dynamic causality testing involves modeling the post-deregulation period data with a vector error correction model (VECM). The VECM will concentrate on the post-deregulation period because the regulated period is not cointegrated. During this recent period, even though IC and TC vary widely, there is a linear combination that is stationary. Any deviation of IC or TC from this equilibrium is only temporary. This supports theoretical concepts that inventory and transportation are in equilibrium because equilibrium theories of non-stationary variables, including that of IC and TC, require that some combination of the variables to be stationary (Enders, 2010).

When variables are cointegrated, it is appropriate to include an error correction term (EC) in the vector auto-regressive model (VAR) resulting in a vector error correction model (VECM). The VECM allows an additional level of specification and often a more successful model for estimating non-stationary data by including the residuals of the cointegrating equation (Greene, 2003). This is because the dynamic specification of a VECM is more flexible and allows better estimation of an economy that is more frequently out of equilibrium because it is going through a transition stage (Kennedy 2008). When an equation is specified with an EC variable, it allows the researcher to make a distinction between short-term dynamics and long-term equilibrium (Malley, 1990). The EC term represents the long-term equilibrium relationship between IC and TC. EC is calculated by capturing the residual vector from Equation 3.

VECMs were run with 1, 2, and 3 lags. AIC shows the 2-lag VECM to be the best of the three options when the difference of IC and the difference of TC are the dependent variables. Results are summarized in Table 7. Schwartz information criterion (BIC) suggested 1 lag and 2 lags for the respective equations. Most of the lagged terms became insignificant in the 3-lag model. The final VECM equations are shown below in Equations 4 and 5.

$$\Delta IC_t = \beta_{10} + \beta_{11} \Delta IC_t + \beta_{12} \Delta IC_{t-1} + \beta_{13} \Delta IC_{t-2} + \beta_{14} \Delta TC_t + \beta_{15} \Delta TC_{t-1} + \beta_{16} \Delta TC_{t-2} + \beta_{17} EC_{t-1} + u_t \qquad (4)$$

$$\Delta TC_t = \beta_{20} + \beta_{21} \Delta IC_t + \beta_{22} \Delta IC_{t-1} + \beta_{23} \Delta IC_{t-2} + \beta_{24} \Delta TC_t + \beta_{25} \Delta TC_{t-1} + \beta_{26} \Delta TC_{t-2} + \beta_{27} EC_{t-1} + v_t \qquad (5)$$

The results of the VECM estimation are summarized in Table 8. From these results, the coefficient for β_{17} is -1.12 and the coefficient for β_{27} is -0.15. These variables can be described as the speed of response that IC and TC return to equilibrium. Equation 6 shows that TC is increasing an average of 0.2% per year in relation to IC. Most importantly, this represents the long-term relationship between the IC and TC. The cointegrating equation is: $Ln\, Y - \beta_1\, Ln\, X - \beta_0$.

$$IC = 0.213\, TC + 0.58 \qquad (6)$$

By including the EC in the vector auto regression model, the model controls for the long-term relationship and make determinations about the short-term dynamics of inventory and TC. Regarding short-term dynamics, most of the coefficients for the lagged terms in the two equations are significant. The model also has a high R^2 result of 0.61.

Impulse Response Function

Impulse-response functions trace the time paths of various shocks on IC and TC, allowing further interpretation of the relationship between the two. With this tool, it is possible to trace out the time paths of the effects of pure ε_{IC} or ε_{TC} shocks. The impulse response functions provide some interesting information. First, notice in Figure 4 that in all the graphs the direction of response from shocks to IC and TC are always positive. This supports the theory of equilibrium. It can also be seen that the effects of a shock usually means that TC and IC have a very gradual return to equilibrium, over ten years. Therefore, it takes the markets a long period of time to react and return to a stable level. See Figure 4, panels 1-4 for generalized impulse response functions.

VAR systems are under-identified, so for interpretation a restriction is often implied. For this reason, the impulse-response function was run with the Choleski decomposition which provides a minimal set of assumptions that can be used to identify the structural model (Enders, 2010). Panels 5-8 in Figure 4 summarize the results of the IRFs run with the Choleski decomposition. However, notice that the patterns of the impulse response functions with the Choleski decomposition are identical to those run with the generalized impulse response functions.
The IRFs do exhibit some limited indications of long-term equilibrium between IC and TC. Notice in panels 1 and 2 that the response of IC to a shock of IC and TC is approaching a return to zero. Although this return to zero is over a period longer than ten years. It takes a long time for inventory to adjust to target levels (Feldstein et al., 1976). Likewise, TC responds to shocks of IC with a return to equilibrium. This return to equilibrium is the only one that appears to be completed in a ten year period, see panel 3. Shocks to TC have a permanent effect on TC, as exhibited in panel 4. This means that there are fewer market and managerial events that can

react to offset a rise in TC. Firms can change modes or service level; however the TC must be paid in most instances. There are some rare exceptions that allow TC to be reduced significantly or eliminated entirely when TCs rise. For example, products that have high water content can be shipped in concentrated form, and products that can be digitized can travel electronically.
The accumulated impulse response functions, as depicted in panels 9-12, provide useful information over the course of the ten years. By examining the accumulated IRFs, observe the only shock that returns to zero is TC in response to IC shocks, see panel 11. The response of IC seems to find a new level near the level of the shock when responding to shocks of IC and TC as viewed in panels 9 and 10. Panel 12 indicates that TC shocks have a permanently increasing effect. This makes sense, when one considers that a rise in fuel cost has an ongoing and cumulative effect on total TC.

Conclusion

IC and TC were tested for long-term and short-term equilibrium. IC and TC have been cointegrated since transportation deregulation. This indicates that the two share a common stochastic drift and they do share an equilibrium relationship. Over time, the model of this equilibrium relationship shows that TCs are increasing slightly in relation to ICs.

The contribution of this analysis is extended by Granger causality tests that provide evidence of short-term causal relationships between IC and TC. IC and TC do not share immediate, bi-directional equilibrium. However some unidirectional, lagged variables are significant. Changes in TC do influence firm inventory policies. The reverse relationship is not supported. Short-term responses to an exogenous shock may take multiple years to reciprocate. This was expected because firms cannot change inventory policies quickly. Inelastic IC and policy can be caused by long-term warehousing contracts, owned real-estate, or the need to eliminate obsolete or low-demand inventory.

I believe that bi-directional Granger causality was not supported for several reasons. First, firms do not always pursue lowest cost. Firms balance cost and customer service to find the best competitive strategy that promises to give the firm a competitive advantage and increase firm performance. Second, firms do not always calculate their costs in terms that are necessary for this tradeoff analysis, such as stock-out cost or inventory carrying cost. Third, firms will by nature balance lowest cost with customer service, but this usually is done by "gut feel." Managers learn about their business from experience and this experience and the related decisions are not always the optimum. Furthermore, firms lack the knowledge of what the optimum decision would have been.

Management and Policy Implications

Managers can expect IC to increase following rises in TC in the United States. A general guideline is that IC will take about two or three years to respond to increases in TC. The other causality direction is inconclusive, meaning IC increases do not necessarily lead to increased TC. This study finds that transportation regulation restricted the ability of the market to follow the natural course of self-determination from 1960 until transportation deregulation reached full fruition in 1984. Because markets naturally migrate toward providing the most utility for the least cost, policy makers can expect that transportation regulation similar to that with which the United States has experience, can be expected to interfere with the optimum solution in the marketplace, impacting both transportation and inventory carrying costs.

Figure 1: Nominal IC and Nominal TC

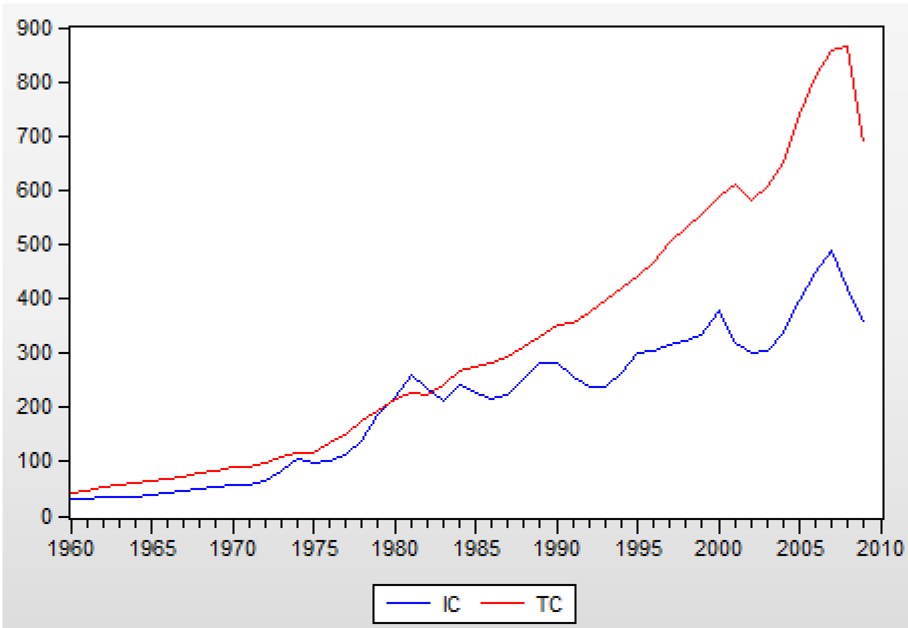


Figure 2: Real IC and Real TC

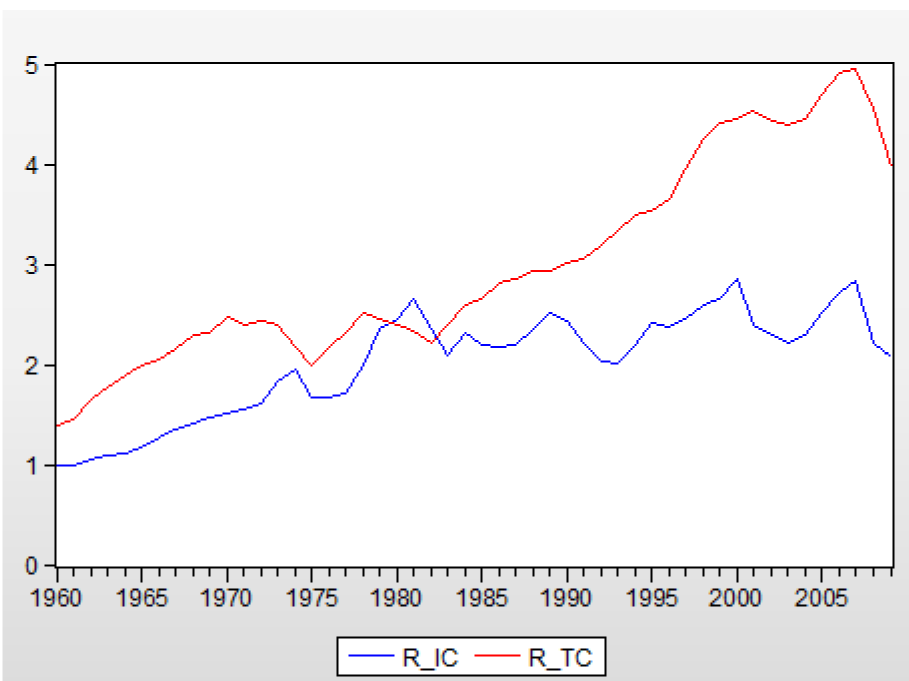


Figure 3: Growth rate of Real IC and Real TC

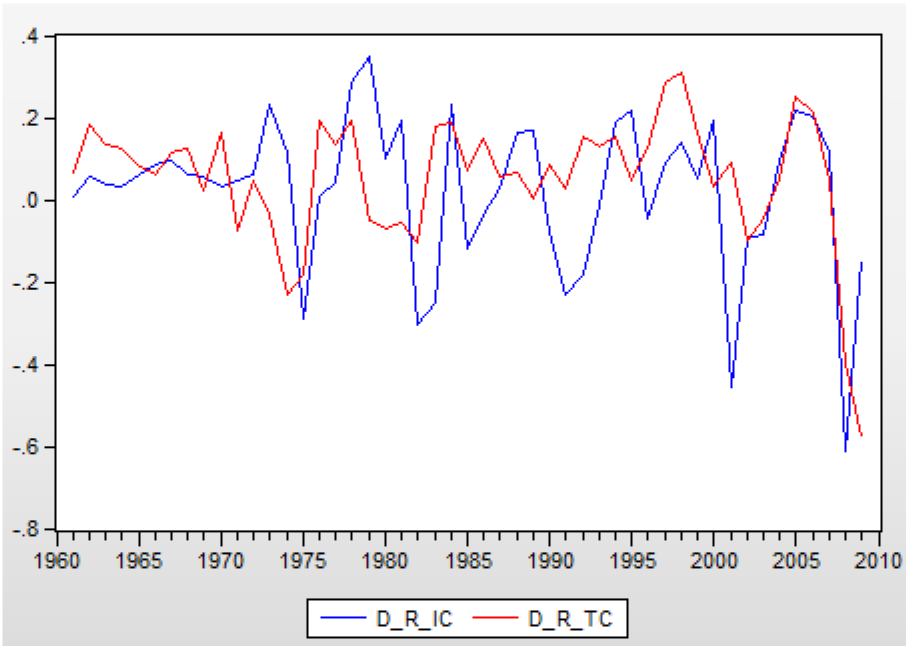
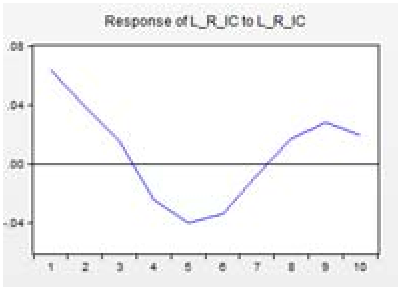
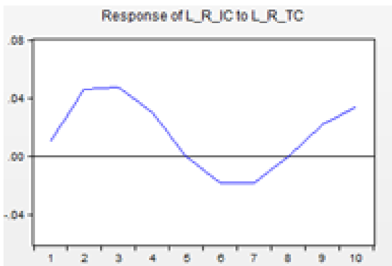


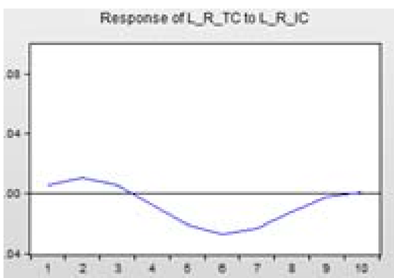
Figure 4: Impulse Response Function Results



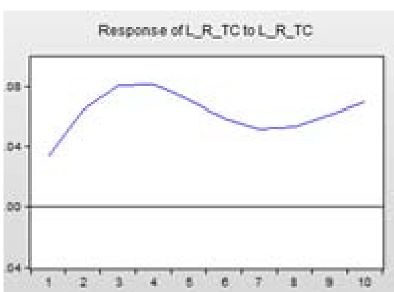
Panel 1



Panel 2

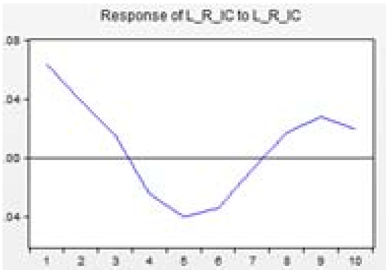


Panel 3

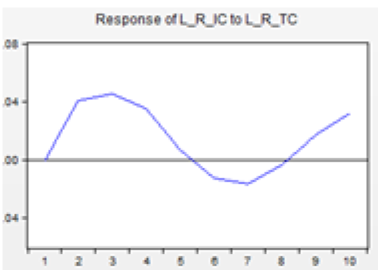


Panel 4

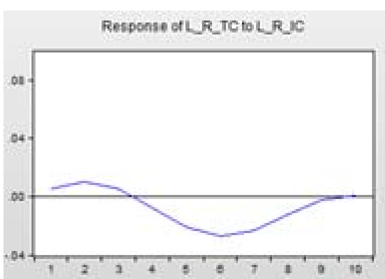
Figure 4: Impulse Response Function Results (continued)



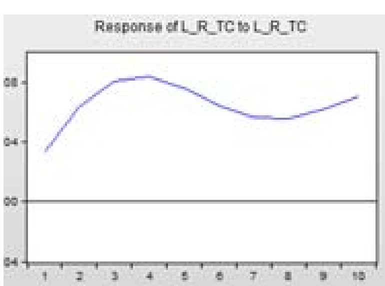
Panel 5



Panel 6

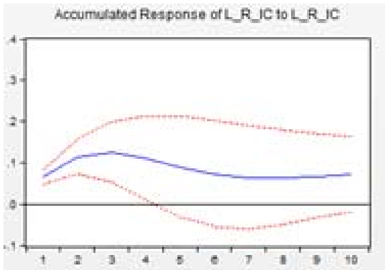


Panel 7

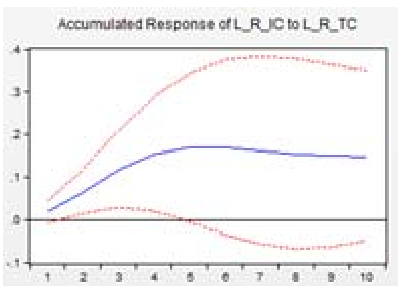


Panel 8

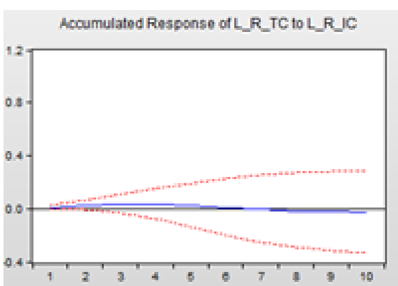
Figure 4: Impulse Response Function Results (continued)



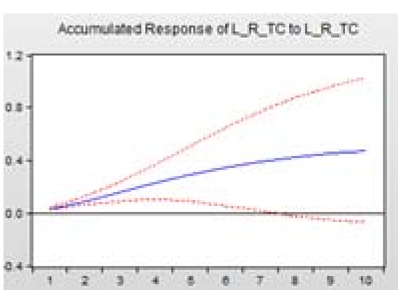
Panel 9



Panel 10



Panel 11



Panel 12

Table 1: Augmented Dickey Fuller Tests for Unit Root

	P-Values for ADF Tests (H_0: unit root is present)								
	Entire Period (1960-2009)			Regulated (1960-1979)			De-Regulated (1985-2009)		
	none	α	$\alpha + a_t$	none	α	$\alpha + a_t$	none	α	$\alpha + a_t$
IC (Order)	I(1)	I(1)	I(1)	I(2)	I(1)	I(1)	I(1)	I(0)	I(1)
Level	0.744	0.112	0.495	0.993	0.361	0.057	0.500	0.028	0.042
1st Diff	0.000	0.000	0.000	0.442	0.016	0.017	0.000	0.006	0.026
2nd Diff				0.000					
TC (Order)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)	I(1)	I(2)	I(2)
Level	0.789	0.274	0.215	0.963	0.078	0.619	0.335	0.585	0.994
1st Diff	0.002	0.019	0.047	0.017	0.094	0.146	0.206	0.862	0.914
2nd Diff					0.000	0.004	0.000	0.004	0.013

Table 2: Tau Test for Unit Root

	P-Values for Tau Tests								
	Entire Period (1960-2009)			Regulated (1960-1984)			De-Regulated (1985-2009)		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
IC							0.054	0.125	0.230
TC							0.104	0.020	n/a

Table 3: Critical values for the tau statistics (Enders 2010)

Test Statistics	1%	5%	10%
Tau	-2.62	-1.95	-1.61
Tau mu	-3.58	-2.93	-2.60
Tau tau	-4.15	-3.50	-3.18

Table 4: Engle Granger Cointegration Test Results

Test Statistics for ADF test of residuals from equation Ln $IC_t = \alpha_t +$ Ln TC_t. (H_0: unit root is present)

	Entire Period (1960-2009)			Regulated (1960-1979)			De-Regulated (1985-2009)		
	none	α	$\alpha + a_t$	none	α	$\alpha + a_t$	none	α	$\alpha + a_t$
Test Statistic	-1.570	-1.554	-1.380	-0.668	-0.595	-2.626	-3.303*	-3.8**	-4.0**

Significant at 10%*, 5% **, 1%***

Engle-Granger Critical Values (Enders 2010)

1% Critical Value	-4.123
5% Critical Value	-3.461
10% Critical Value	-3.130

Table 5: Johansen Cointegration Test

Date: 07/03/11 Time: 17:17
Sample: 1985 2009
Included observations: 25
Trend assumption: Linear deterministic trend
Series: L_R_IC L_R_TC
Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.526741	22.05617	15.49471	0.0044
At most 1	0.125527	3.353344	3.841466	0.0671

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.526741	18.70282	14.26460	0.0093
At most 1	0.125527	3.353344	3.841466	0.0671

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

L_R_IC	L_R_TC
-20.30211	4.328841
0.563576	-5.239745

Unrestricted Adjustment Coefficients (alpha):

D(L_R_IC)	0.055187	-9.85E-05
D(L_R_TC)	0.007394	0.010697

1 Cointegrating Equation(s): Log likelihood 90.29111

Normalized cointegrating coefficients (standard error in parentheses)

L_R_IC	L_R_TC
1.000000	-0.213221
	(0.05482)

Adjustment coefficients (standard error in parentheses)

D(L_R_IC)	-1.120422
	(0.24365)
D(L_R_TC)	-0.150111
	(0.14436)

Table 6: Pairwise Granger Causality Tests (3 Lags)

	Obs	Entire Period (1960-2009) F-Stat / Prob.	Regulated (1960-1979) F-Stat / Prob.	De-Regulated (1980-2009) F-Stat / Prob.
TC does not Granger Cause IC	48	1.253/0/304	2.973/ 0/065	3.319/ 0.043*
IC does not Granger Cause TC		1.088/0/365	7.304/ 0/003*	0.687/ 0.571

Evidence of Granger causality at 5% level of confidence

Table 7: VECM Comparison Statistics

	AIC	BIC
Δ Ln IC		
One Lag	-2.54	-2.34
Two Lags	-2.58	-2.29
Three Lags	-2.43	-2.04
Δ Ln TC		
One Lag	-3.74	-3.54
Two Lags	-3.63	-3.34
Three Lags	-3.48	-3.09

Table 8: VECM Results

Vector Error Correction Estimates
Date: 07/02/11 Time: 12:52
Sample: 1985 2009
Included observations: 25
Standard errors in ( ) & t-statistics in [ ]

Cointegrating Eq:	CointEq1	
L_R_IC(-1)	1.000000	
L_R_TC(-1)	-0.213221	
	(0.05482)	
	[-3.88983]	
C	-0.582690	
Error Correction:	**D(L_R_IC)**	**D(L_R_TC)**
CointEq1	-1.120422	-0.150111
	(0.24365)	(0.14436)
	[-4.59854]	[-1.03985]
D(L_R_IC(-1))	0.592398	0.151313
	(0.20694)	(0.12261)
	[2.86268]	[1.23411]
D(L_R_IC(-2))	0.438993	0.038877
	(0.20895)	(0.12380)
	[2.10096]	[0.31403]
D(L_R_TC(-1))	0.712373	0.859061
	(0.45738)	(0.27099)
	[1.55751]	[3.17004]
D(L_R_TC(-2))	0.056545	-0.285655
	(0.53422)	(0.31652)
	[0.10585]	[-0.90249]
C	-0.029447	0.003739
	(0.02120)	(0.01256)
	[-1.38877]	[0.29762]
R-squared	0.607643	0.520101
Adj. R-squared	0.504391	0.393812
Sum sq. resids	0.068412	0.024016
S.E. equation	0.060005	0.035553
F-statistic	5.885052	4.118332
Log likelihood	38.29001	51.37552
Akaike AIC	-2.583201	-3.630042
Schwarz SC	-2.290671	-3.337512
Mean dependent	-0.004626	0.017264
S.D. dependent	0.085236	0.045663
Determinant resid covariance (dof adj.)		4.33E-06
Determinant resid covariance		2.50E-06
Log likelihood		90.29111
Akaike information criterion		-6.103289
Schwarz criterion		-5.420718

References

Ballou, R. H. (1973). *Business logistics management*. New Jersey: Prentice-Hall.

Burns, L. D., Hall, R. W., Blumenfeld, D. E., & Daganzo, C. F. (1985). Distribution strategies that minimize transportation and inventory costs. *Operations Research, 33*(3), pp. 469-490.

Defee, C. C., Williams, B., Randall, W. S., & Thomas, R. (2010). An inventory of theory in logistics and SCM research. *International Journal of Logistics Management, the, 21*(3), 404-489.

Enders, W. (2010). *Applied econometric time series*. United States: John Wiley & Sons, Inc.

Federal Reserve Bank of St. Louis. (2012). Retrieved August 2011, 2012, from http://research.stlouisfed.org/fred2/

Feldstein, M., Auerbach, A., Hall, R. E., & Lovell, M. C. (1976). Inventory behavior in durable-goods manufacturing: The target-adjustment model. *Brookings Papers on Economic Activity, 1976*(2), 351-408.

Granger, C. W. J. (1988). Some recent development in a concept of causality. *Journal of Econometrics, 39*(1-2, September-October), 199.

Greene, W. H. (2003). *Econometric analysis* (Fifth ed.). Delhi/India: Pearson Education Inc.

Lambert, D. M., Stock, J. R., & Ellram, L. (1998). *Fundamentals of logistics management*. United States: McGraw-Hill Higher Education.

Langley, C. J. (1986). The evolution of the logistics concept. *Journal of Business Logistics, 7*(2), pp. 1-13.

Lewis, H., Culliton, J., & Steele, J. (1956). *The role of airfreight in physical distribution*. Boston, MA: The Alpine Press.

Magee, J. F. (1960). The logistics of distribution. *Harvard Business Review, 38*(4), p. 89.

Malley, J. R. (1990). Dynamic specification in econometric estimation. *Journal of Agriculture Economics, 42*(2), 52.

Nahmias, S. (1989). *Production and operations analysis*. United States of America: Irwin.

Narayan, P. K., & Smyth, R. (2004). Temporal causality and the dynamics of exports, human capital and real income in china. *International Journal of Applied Economics, 1*(1), 24-45.

Sheffi, Y., Eskandari, B., & Koutsopoulos, H. N. (1988). Transportation mode choice based on total logistics costs. *Journal of Business Logistics, 9*(2), 137-154.

Tyworth, J. E. (1992). Modeling transportation-inventory trade-offs in a stochastic setting. *Journal of Business Logistics,* (2), 97.

Venturini, F. (2009). The long-run impact of ICT. *Empirical Economics, 37*(3), 497-515.

Wilson, R., & Delaney, R. V. (2001). *12th annual state of logistics report.* (No. June 4). Washington DC: National Press Club.

CHAPTER 3 (ESSAY 2): The Relationship between Inventory and Transportation: An Inventory-Theoretic Study with Firm-Level Inventory and Transportation Cost

Abstract

This essay tests the relationship between inventory cost (IC) and transportation cost (TC) at the firm level based on an inventory-theoretic perspective. Inventory theory posits that firms will trade off IC and TC to minimize the sum of their cost (Baumol & Vinod, 1970). Studies in macroeconomics (Swanson, 2012) indicate tradeoff properties of IC and TC. Firm-level IC and TC and their relationship have not been tested. This essay tests this theory.

Panel data involving transportation and inventory expenditures of 41 firms and 22 quarters from 2006 through 2011 was collected as the sample for this study. A model was specified to predict firm inventory with independent variables suggested from inventory-theoretic literature. A contribution was made by including TC in the inventory model. Firms do trade off IC and TC in the course of logistics management. Also found is a negative relationship between a one-period lag of TC and inventory. TC is shown to be a useful variable for predicting inventory.

Introduction

One type of business cost, total logistics cost (TLC), often exceeds 25% of sales (Ballou, 2000; Stock, Lambert, & Lambert, 1987). Technology and human resources applied to improving supply chain performance have never been higher (Fisher, 1997). Accordingly, logistics expenditures are highly scrutinized by firm managers.

The theory of TLC management posits that firms will seek to minimize total logistics cost (Lewis et al., 1956) by managing key logistics functions as a system (Lambert et al., 1998).

Furthermore, firms will trade off key logistics cost (Bowersox, 2007); two of which are IC and TC, to minimize TLC.

This essay shows first that there exists a predictable relationship between IC and TC, and second that the relationship can be measured. These demonstrations provide valuable contributions that increase our understanding of inventory and transportation which can be used to enhance management performance. For example, if a firm expects TCs to increase 5% in the future, then one could expect inventory expenditure and its associated costs to increase as well by a measurable amount. With this knowledge, firms can optimize their mix of transportation and inventory cost more quickly in response to exogenous cost increases and in response to competitor strategies. This allows the firm to be more proactive in meeting a TLC objective.

Theory and anecdotal evidence suggest that firm management does trade off expenditures of inventory and transportation to fit its strategy and to adjust to external factors. For example, if TC falls, firms may choose to decrease cycle stock, ship more frequently, and thus reduce their inventory carrying costs. Similarly, if TC rises, firms may choose to take advantage of transportation economies of scale and volume shipping incentives that are provided by carriers and suppliers to lower their transportation expenditures (Simchi-Levi, Kaminski, & and Simchi-Levi, 2003). The previously unconfirmed, conventional knowledge suggested this would cause IC to rise. The first essay of this dissertation (Swanson, 2012) finds supporting empirical evidence that IC and TC share a long term relationship when this relationship was examined with aggregated costs in the United States. However, there has been little empirical research on management behavior regarding the tradeoff potential of IC and TC. It is important and interesting to extend research on management behavior because macroeconomic and firm-level results are often different (Pilat, 2004). An empirical analysis of firm-level data may provide different results than the macroeconomic results and could benefit management.

Although theory posits firms balance IC and TC and pursue minimum TLC, there are reasons that firms may not choose to balance IC and TC and thus pursue a lowest total cost. Firms may choose to pursue alternate transportation or inventory service strategies (Porter, 1980), may be bound by contractual agreements (Phillips, 1991), may suffer from lack of information or the accurate interpretation of it (Ferguson, 2001; Lieberman, Helper, & Demeester, 1999), or they may have inferior or inappropriate resources (Barney, 1991) or capabilities (Teece, Gary, & Amy, 1997). Firms may choose to seek lowest cost, but immediate cost adjustment can be difficult in the near term. Regarding TC, firms may have private fleet investments which are difficult to divest (Maltz, 1993). Regarding IC, firms also may have service-level commitments with customers or may have difficulty liquidating large amounts of inventory (Feldstein et al., 1976). Additionally, many logistics cost variables are not within the control of management, such as fuel prices, interest rates, inflation (Chen, Frank, & Wu, 2005) and consumer preferences.

The question remains whether firms show evidence of trading off these key logistics costs or if it is merely a macroeconomic artifact. The objective of this essay is to analyze whether the insights from the macroeconomic level of equilibrium between IC and TC are consistent when analyzing the IC and TC at the firm level using inventory theory.

This essay begins with a review of two streams of related literature. The first of which explores the theoretical relationship of IC and TC. The second stream is inventory theory. From this theoretical foundation, this essay develops and hypothesizes the relationship between IC and TC at the firm level. At the same time, this essay tests TC as a predictor of firm inventory. Following hypothesis development, this essay describes the data sampling process, the descriptive statistics, and introduces a model. This is followed with results and discussion. The essay ends with conclusions, management implications, limitations, and future research possibilities.

Literature Review

Theoretical Relationship of Inventory and Transportation Cost

Economic theory has been commonly applied to the inventory-theoretic literature supporting that tradeoffs exist between IC and TC (Blinder & Maccini, 1991). Theory suggests that when firms are operating at the most efficient TLC that inventory holding cost equals inventory ordering (transportation) cost, IC = TC (Baumol & Vinod, 1970; Harris, 1913). Suppose firms experience an increase in inventory carrying cost, such as an interest rate increase. The above theory suggests that firms will spend more on ordering cost (transportation) for more frequent deliveries and lower inventory carrying cost because IC > TC. Likewise, if TC increase, such as by an increase in fuel prices, the balance is upset again. This time TC > IC so firms react by spending less on TC, which might involve, for example, less frequent deliveries. Less frequent deliveries lead to larger inventories, ceteris paribus, which also act to return IC = TC.

Logistics cost tradeoffs, including that of IC and TC, have been theorized for a century beginning with the development of the basic economic order quantity (EOQ) model (Camp, 1922; Hendricks & Singhal, 2003) and production lot size model (Taft, 1918). Initially, the EOQ model and theory focused on inventory carrying cost and ordering cost. However, in the early 1970s comprehensive comparisons of freight options considered the inventory holding cost in association with transportation (Zeng & Rossetti, 2003). The basic model was enriched to explain more of the relationships between logistics variables including the expansion of ordering cost to include TC (Chen, Frank, & Wu, 2007), additional transport-related variables (Buffa & Reynolds, 1979), safety stock formulations (Stenger et al., 1977), enhanced stock-out modeling (Constable & Whybark, 1978) and more accurate TC (Langley, 1980). See (Sandlin, 2010) for an extensive literature review.

The question of how to determine logistics cost has been an important and prolific source of literature that provides information accounting for IC and TC. Maltz et al. provide a logistics cost categorization framework. (Maltz & Ellram, 1997) . Another costing approach was studied in a dissertation by Knipper (Knipper, 2011). Studies on the total cost approach (Ellram, 1994) and total profit approach (Poist, 1974) have been applied. Activity-based costing is prevalent in logistics costing (Pirttila & Hautaniemi, 1995). This paper, however, concentrates on the relationship of IC and TC and does not delve into the issues of costing methods.

Further support for the tradeoff potential of key logistics variables comes from the concept of TLC management which was a founding pillar of the discipline of business logistics management in the 1950s (Bowersox, 1969; Bowersox, 2007; Langley, 1986; Lewis et al., 1956; Magee, 1960). Scholars warned about indiscriminate changes in one functional area of the firm without assessing the potential changes to another related functional area (Magee, 1960). Areas such as warehousing, transportation, and logistics administration had costs that were interrelated. For example, minimizing purchase cost by pursuing economies of scale can adversely affect warehouse storage cost and capacity. Because of the importance of integrated logistics functions and TLC management, university programs in business logistics have taught tradeoff principles since the first college class at Michigan State University in 1958 and the first logistics management textbook (Smykay et al., 1961). Since this beginning, there are now over 65 universities that offer a degree or concentration in business logistics or supply chain management and many universities offer doctoral education (Ozment & Keller, 2011). All of these programs are based on the principles of functional area tradeoff inside the company (Magee, 1960) and between supply chain partners (Cooper, Lambert, & Pagh, 1997). The discipline continues to grow.

There has not been an analysis of secondary data to study the tradeoff of IC and TC. Studies primarily focus on either inventory or transportation (Mason, Mauricio Ribera, Farris, & Kirk, 2003). This essay is relevant because if TC is related to decisions about inventory, then its use in models that predict inventory can be added to the inventory-theoretic literature. That literature is summarized next.

Inventory-Theoretic Literature

The study of inventory is important because it is directly related to firm and economic performance (Feldstein et al., 1976). High levels of inventory cause lower performance or it is perceived to yield lower performance (Chen et al., 2005; Chen et al., 2007; Lai, 2006). Retailers are less likely to go bankrupt (Randall, Netessine, & Rudi, 2005) if they operate in accordance with classical inventory models.

The classical inventory models, including the EOQ, are derived at the product level and intended to be used for stock-keeping unit (SKU) level analysis and optimization. Rumyantsev et al. extend these theories, testing inventory-theoretic variables on inventory-level data and show that these product-based models can apply to aggregated levels of SKUs (Rumyantsev & Netessine, 2007). Rumyantsev et al. go on to show that aggregate firm inventory is related to demand uncertainty, lead times, margins and economies of scale similar to single-product inventory.

The classic economic lot size model (Harris, 1913) is a simple framework that illustrates the trade-offs between ordering and inventory holding costs, without the effect of demand uncertainty. The EOQ theory assumes that firms will seek to minimize their TLC. TCs are an example of ordering cost. Holding cost includes maintenance cost such as taxes and insurance, obsolescence, and opportunity cost (Lambert et al., 1998). These logistics costs are a sum of holding cost (H (Q/2)) and TC (K (D/Q)). Where: H = annual holding cost, Q = optimal order quantity, K = transportation cost per order, and D = annual demand.

Since demand is uncertain, the sales forecast is critical for the determination of what and when to order (Simchi-Levi et al., 2003). If a firm forecasts too much demand, it is left with costly inventory. If the firm forecast is less than demand, it loses sales. Demand is primarily stochastic, so it is estimated using forecasting, with uncertainty often measured by the standard deviation (Simchi-Levi et al., 2003). The impact of lost sales is largely unknown because lost sales are difficult to measure.

Average lead time and uncertainty are included in the inventory-theoretic literature. When studying the effects of lead time and lead time uncertainty on inventory values, the TC of the firm is indirectly studied, because, generally shorter and less certain lead times are more expensive. Yet theory suggests that TC should be measured directly because of its tradeoff relationship with inventory (Baumol & Vinod, 1970; Swanson, 2012).

Empirical inventory research has revealed information regarding the relationship of inventory levels and key variables. Studies have shown that firms hold more inventory when they have higher sales demand and higher demand uncertainty (Rumyantsev & Netessine, 2007; Zinn, Levy, & Bowersox, 1989), longer lead times, (Evers, 1999; Rumyantsev & Netessine, 2007), lower capital cost, higher gross margins (Gaur, Fisher, & Raman, 2005), and higher stock-out cost (Constable & Whybark, 1978). Other studies have also shown that firms carry more inventory when the stock market puts a premium on inventory (Lai, 2006), when product variety increases (Fisher & Ittner, 1999), when information systems are inadequate (Ferguson, 2001), or a firm may increase inventory simply because they don't know it is costly (Timme, 2003). Just-in-time (JIT) inventory operations reduce inventory levels for manufacturers but not in other sectors of the supply chain (Rajagopalan & Malhotra, 2001). All of this empirical research can be summarized in three reasons firms hold inventory: to satisfy demand during lead time, to protect against uncertainty in lead time and demand, and to balance annual inventory holding cost and annual supply cost (Simchi-Levi et al., 2003). Transportation has an impact on all of these reasons that firms hold inventory.

Some limitations of classic inventory models include that they do not account for factors such as competition, business cycles, industry dynamics, and do not represent some other decisions that could be handled endogenously by the firm such as pricing and product variety (Rumyantsev & Netessine, 2007). Even many simple heuristics that are used for decision making can outperform the classic EOQ approach; for an overview of these heuristics see Silver et al. (Silver, Pyke, & Peterson, 1998).

Hypothesis Development

Economists have tracked aggregate IC and TC in the United States since 1960 (Wilson & Delaney, 2001). This data suggests that TLC has decreased as a measure of GDP (Langley,

1986) and the behavior of aggregate IC and TC in times of GDP expansion and contraction is different (Wilson & Delaney, 2001). The first empirical test of the relationship of IC and TC (Swanson, 2012) demonstrated that IC and TC are cointegrated, and that they share a long-term relationship at the macroeconomic level. This is consistent with inventory theory which suggests that firms trade these costs to achieve lowest TLC (Swenseth & Godfrey, 2002; Tyworth, 1991). Just as the theory was tested on macroeconomic data, the behavior of firm-level IC and TC should also be empirically tested.

Firms hold inventory for several reasons including demand uncertainty, transportation uncertainty, and because production does not perfectly coincide with customer demand (Simchi-Levi et al., 2003). In previous research, scholars have verified drivers of inventory holdings (Fisher & Ittner, 1999; Gaur et al., 2005; Rajagopalan & Malhotra, 2001). This essay reproduces the drivers of inventory suggested by extant literature as a foundation, and then tests the model with the addition of TC.

Rumyantsev and Netessine address two crucial aspects of firm-level inventory analysis: time and space aggregation and the difference between the prescriptive inventory models and the descriptive parameters seen commonly in practice (Rumyantsev & Netessine, 2007). These authors also test multiple hypotheses related to whether inventory models that are designed for use at the product level can also be useful for firm-level analysis. Similar to this previous research, this essay must overcome two challenges. First, several of the inventory variables in this study come from classical inventory models and those models are designed for use at the product level. This poses complications (Rajagopalan & Malhotra, 2001) for studies done at the aggregate level (Gaur et al., 2005). However, there is precedence and support for the validity of classical inventory models to be used on aggregate data (Rumyantsev & Netessine, 2007).

Secondly, this study is done with accounting data that managers use as the basis for inventory management decisions. Similar to Gaur et al. (Gaur et al., 2005), this study must overcome the discrepancy between observation of the data and the behavior of the managers after they observe, interpret, and respond to the data. Firm behavior results from the relative relationships of the variables, including transportation expenditures, inventory, sales, cost of goods sold (COGS), interest rates, and accounting practices (Rajagopalan & Malhotra, 2001).

Inventory theory suggests that IC and TC share an equilibrium relationship and that firms will tradeoff IC and TC (Tyworth, 1991). Yet, TC is missing from the empirical models in the extant literature. Studies have shown that firms increase inventory when they have higher sales demand, longer lead times, higher gross margins, lower capital cost, higher stock-out cost, and higher demand uncertainty (Rumyantsev & Netessine, 2007). In these models, TC is partially reflected in the variables of lead times and higher lead time uncertainty. However, theory suggests that TC should be measured directly for the purpose of predicting inventory (Baumol & Vinod, 1970).

The classic EOQ model explains that firms optimize TLC by adjusting the amounts they spend on inventory and transportation to find the right mix for the market which will yield the lowest TLC (Fisher, 1997; Harris, 1913). Subsequent research supports that firms will balance their transportation and inventory carrying cost to achieve the lowest TLC (Campbell, 1990; Ellram & Siferd, 1998). EOQ theory (Harris, 1913) defines the lowest total cost to be achieved when inventory carrying cost equals ordering and TC. Therefore, if a firm must spend more on one cost (IC or TC), they should spend more on the other as well in an attempt to keep TLC at a minimum.

The inventory theory of the EOQ is not without controversy (Silver et al., 1998; Speranza & Ukovich, 1994). Practitioners complain about the model's simplicity and that in most instances inventory is managed at an aggregate level instead of at the product level (Bishop, 1979). In the long-term, firms may not always pursue the lowest cost (Porter, 1980). A mathematical programming model of the cost and service tradeoff is available (Das & Tyagi, 1997). Firm capabilities may match strategies other than lowest cost particularly well and accordingly firms may elect to pay more to provide a premium service (Lynch, Keller, & Ozment, 2000).

Inventory theory suggests that firms will minimize TLC when a firm's inventory holding cost equals its ordering cost (Harris, 1913). Since ordering cost includes TC (Chopra & Meindl, 2004), a positive relationship between IC and TC is expected. Theory suggests that if a firm increases inventory they must have a corresponding rise in TC in order for the firm to rest at its new minimum TLC. See Figure 1. This leads to the following hypothesis.

Hypothesis: Transportation cost is positively related to inventory.

Data

Sample Selection

The sample includes weekly TC from September 2006 through March 2011 for 126 firms. Weekly TCs were summed by quarter so that there was a match between TC and the quarterly inventory levels. Quarters that included more than two vacant weeks were deleted because there was insufficient data to track the quarterly total. In some cases the first week of data provided by the firm was considerably less than the following weeks. In such cases it was possible that a firm began tallying TC mid-week, so these partial weeks were removed from the database.

Firms without at least three years of data were deleted to allow study of time effects. This data cleanse process left 50 firms with at least 12 quarters of TC.

Inventory and other company-related variables were extracted from the Standard and Poor's Compustat database. Three firms did not provide quarterly inventory data and so they were removed from the sample. There were also five firms which could not be unambiguously linked to the transportation data. This was usually due to mergers, divestment, or multiple company divisions that made the matching unclear. These five firms were removed from the sample.

Quarterly data was chosen instead of annual data because this provided substantially more data observations, which is desirable for analyzing inventories due to their highly dynamic properties (Carpenter, Fazzari, Petersen, Friedman, & Kashyap, 1994). Had annual data been used, three more companies could be included in this analysis; however, this would have been relatively small because, by using quarterly data, observations increased from 160 to 564. After removing firms for inventory data issues the sample was left with 42 firms. When calculating the inventory variables for the model, additional observations were sacrificed. For example, ($Uncertainty_{it}$) is measured by using the forecast error from the previous three quarters. Calculating some inventory variables reduced total observations in my sample to 322 quarters.

Descriptive Statistics

Descriptive statistics and pairwise correlations are summarized in Table 1 and Table 2. The mean IC is about one-third of TC, a sizeable difference. This is consistent with our expectations (Wilson & Delaney, 2001). Also, the standard deviations are all lower than the mean which indicate low data uncertainty.

From examination of the descriptive statistics, it was decided to keep the data in its purest form. Taking the natural logarithm was unnecessary because the data wasn't highly skewed. The histogram of the dependent variable ($Inventory_{it}$) demonstrated that the data follows a normal distribution.

The firms in this sample represent 18 industry groups as measured by the first three North American Industry Classification System (NAICS) numbers. They represent 10 industry groups if measured by the first two NAICS numbers. Twenty-five percent of the NAICS classifications in the sample data come from retailers and seventy-five percent come from suppliers. Detailed NAICS representations are provided in Table 2.

Methodology

Model Specification

OLS assumptions of homoscedasticity and independence are often not met when dealing with panel data (Greene, 2003). Therefore tests for homoscedasticity and autocorrelation of the errors were implemented prior to selecting the appropriate estimation procedure.

Residuals from the model were plotted across time and examined for evidence of heteroscedasticity. The test showed minor evidence of heteroscedasticity and since the structure is not known, the use of OLS with White robust standard errors is recommended to control for the expanding variances (Kennedy, 2008).

Residuals from the model were examined for evidence of autocorrelation with the Durbin-Watson statistic (2.44). Since the statistic is not near the values of 1 or 4, this indicates no abnormal evidence of serial correlation and OLS will provide consistent and robust results.

Inventory theory states that a firm's inventory level is a function of several different variables. Foremost among these are sales, sales forecast, the order quantity (Camp, 1922; Gaur et al., 2005; Harris, 1913), safety stock level, sales surprise (Gaur et al., 2005), and inventory accounting methods (Carpenter et al., 1994; Rumyantsev & Netessine, 2007). Extant literature suggests Equation 1.

$$Inv = f(Q, SS, SSP, S, SF, A) \tag{1}$$

Where Q is order quantity, SS is safety stock level, SSP is sales surprise, S is sales, SF is sales forecast, and A is used to designate accounting methods.

The order quantity is a function of the expected demand, and the costs of holding inventory, ordering, and stock-out costs. Safety stock is a function of lead times, expected sales, the degree of demand and lead time uncertainty, and the safety factor (k). The safety factor is determined by the managers as an acceptable level of the probability of a stock-out. Empirically this has been measured by minimizing the sum of inventory holding and stock-out costs (Carpenter et al., 1994; Rumyantsev & Netessine, 2007). Combining these equations suggests Equation 2.

$$Inv = f(S, SF, U, S\%, HC, OC, SOC, LT, A). \tag{2}$$

Where S = Sales, SF = Sales forecast, U = demand lead time uncertainty, S% = safety factor, HC = holding cost, OC = ordering cost, SOC = stock-out cost, LT = lead time, and A = inventory accounting method.

This model has been used to empirically estimate firm-level inventory (Hofer & Waller, 2012). The variables in Equation 2 can be estimated from easily attained financial data with the exception of order placement costs. Hofer et al. (Hofer & Waller, 2012) justify the elimination of this variable because a prior empirical study that has measured order costs was not found, and the widespread use of EDI has reduced the costs associated with placing and processing orders (Avery, 1998; Hofer & Waller, 2012; W. Min & Pheng, 2006a; W. Min & Pheng, 2006b). In this model, TC is used for partial representation of total order placement cost. This will allow for at least some portion of the ordering costs to be accounted.

Model Variables and Measurement

The dependent variable ($Inventory_{it}$) for this study is total firm-level inventory (i) in period (t) and is measured in U.S. dollars. Prior research supports use of absolute inventory values (Rumyantsev & Netessine, 2007).

Firms use expected demand ($SalesForecast_{it}$) as the basis for their replenishment decisions. In line with previous research (Hofer & Waller, 2012), annual sales for each firm and time period can be forecast by $\hat{S} = S_{t-1} * (1 + \overline{g})$, where the average growth rate from the previous two years ($\overline{g}$) is defined as follows.

$$\overline{g} = ((S_{t-2} - S_{t-3}) \,/\, S_{t-3} + (S_{t-1} - S_{t-2}) \,/\, S_{t-2}) \,/\, 2 \qquad (3)$$

Firms make decisions based on expected demand, but also they base their decision on the accuracy of their forecast during the previous period. This is determined by the net of expected demand and actual demand. If firms under forecast their demand, the magnitude of inventory on hand at the end of the quarter is lower. If firms over forecast their demand, the magnitude of inventory on hand at the end of the quarter is higher. Sales surprise (SS_{it}) is the variable that measures the difference between expected and actual demand (Gaur et al., 2005). A procedure from prior research was used to measure this variable (Hofer & Waller, 2012; Rumyantsev & Netessine, 2007).

Forecast uncertainty (*Uncertainty*$_{it}$) can be estimated by the magnitude of variability in forecast errors. It is commonly measured as the coefficient of variation of forecast errors (Watson, 1987), or the ratio of the standard deviation of forecast errors over the previous three years and the current period forecast (Hofer & Waller, 2012).

$$Uncertainty_{it} = (\sigma_{ForecastError\ i(t-1,t-2,t-3)}) \ / \ SalesForecast_{it} \qquad (4)$$

The capital cost of holding inventory is a function of the capital interest rate (Timme, 2003). This represents both the opportunity cost of internally financing inventory and the cost to borrow money to finance inventory. The cost of capital (*CostofCapital*$_{it}$) can be estimated by dividing the firm's interest expense by total debt.

$$CostofCapital_{it} = IntExp_{it} \ / \ TotalDebt_{it} \qquad (5)$$

A measurement of the lead time for physical distribution is difficult to attain. However, it is believed that the payment of goods is highly correlated with the shipment of goods. Therefore, in line with previous research (Hausman, 2002; Rumyantsev & Netessine, 2007) the cash conversion cycle is used as a proxy variable to represent firm lead times (*LeadTime*$_{it}$).

$$LeadTime_{it} = \frac{365 * AP_{it}}{COGS_{itf}} \qquad (6)$$

Where accounts payable is denoted as AP and cost of goods sold is denoted as COGS.

The measure of stock-out cost (*StockoutCost*$_{it}$) is approximated by gross profit margin because it is in proportion with the foregone profit (Dulaney & Waller, 2002).

Inventory data is collected from balance sheet filings of publicly traded companies. The accounting principles of inventory costing have an effect on the inventory value used in this model. Specifically last-in-first-out (LIFO), first-in-first-out (FIFO), average cost (AC), or a combination (MC) of these accounting measures can be used to determine book value of inventory. LIFO inventory means that the purchase price of the oldest products determine the value; FIFO valuation means the latest purchase prices determine the inventory value; AC provides an average value calculated from all purchases. In times of purchase price inflation or TC changes, these values can be substantially different. Therefore, inventory accounting methods are measured with dummy variables ($FIFO_{it}$, $LIFO_{it}$, $AveCost_{it}$, and $MixCost_{it}$).

Ordering cost is composed of the item cost and the handling (including transportation) cost (Simchi-Levi et al., 2003). For this essay we use quarterly TC ($TransCost_{it}$) as a variable to represent ordering cost. TC includes the payments made to carriers. This does not include cost of private fleets that are maintained by some of the companies in the dataset.

The resulting empirical estimation equation is:

$$Inventory_{it} =$$
$$\beta_0 + \beta_1 SalesForecast_{it} + \beta_2 SS_{it} + \beta_3 Uncertainty_{it} + \beta_4 HoldingCost_{it} +$$
$$\beta_5 StockoutCost_{it} + \beta_6 LeadTime_{it} + \beta_7 TransCost_{it} + \varepsilon_{it} \qquad (3)$$

The model (Equation 3) is implemented with cross-sectional or firm fixed effects. This provided control for the alternative inventory accounting methods among other unknown fixed effects. Thus, the inventory valuation dummy variables were unnecessary and omitted.

Results

The results from testing this model using the panel data set and linear regression appear in Table 3. The model's F statistic (F=1.56) is statistically significant (p = 0.05), and the overall R-squared statistic is 0.20, which indicates that the model explains approximately 20 percent of the variability in the dependent variable ($Inventory_{it}$).

The hypothesis, that inventory level is positively associated with TC, is not supported because the sign on *(TransCost(-1))* is negative indicating an inverse relationship between IC and TC. However, (*TransCost(-1))* is a significant variable for the prediction of inventory, and we conclude that firms do trade off IC and TC. This conclusion provides information about the association of IC and TC. The association doesn't indicate causality because of the difficulty making specific causal conclusions without the specific population data that is used by inventory decision makers.

Discussion

Management tradeoff of inventory and transportation cost

This essay demonstrates that firms do trade off IC and TC in the process of managing the logistics operations of their firms (p=0.0158). When a firm experiences a TC increase, the first reaction of managers is not to spend more on inventory rather, managers will attempt to lower costs that can offset the TC increase (Lambert et al., 1998). For example, if fuel prices increase, they can counter this increase by shipping on longer trailers or delivering less often. A spike in TC may also raise the priority of changing inventory policies that could reduce the cost of inventory and help to offset the rise in TC. Some examples of such inventory policy changes include consolidating warehouses or urging suppliers to accept more of the inventory cost burden with projects such as vendor managed inventory (Waller, Johnson, & Davis, 1999) or just-in-time (JIT) manufacturing.

The negative relationship between inventory and transportation

A positive relationship was not found between IC and TC. TC (lagged) has a negative influence on inventory ($p=0.0158$), so firms are spending too much on logistics cost in the short-term. This conclusion is contrary to our hypothesized result from inventory theory. Theory suggests that an increase in TC should result in policy changes by the firm that have a net increase in IC so that TLC can be minimized, such as an increase in the order quantity.

Explanation for the negative relationship between IC and TC

This essay suggests five possible reasons for the negative relationship between TC and inventory. First, firms do not necessarily have equal control over changing IC and TC because of operational, contractual, or environmental reasons. Second, budget constraints may limit firm options. Third, irrational behavior may be a possible explanation. Fourth, the relationship between IC and TC may not be purely unidirectional. Fifth, management may be driven by other goals rather than merely lowest cost.

Firms do not necessarily have equal control over IC and TC changes. Consequently, the adjustments to IC and TC are not necessarily consistent or predictable in the short-term. Regarding IC, the firm can make inventory policy changes to reduce IC, such as implementing smaller manufacturing lots (Silver et al., 1998) or consolidating warehouses (Zinn et al., 1989). However, the firm will still have to pay the higher interest rates. Regarding TC changes, the firm can alter policy such as shipping on longer trailers or negotiating a lower priced contract. However, they still have to pay the higher fuel cost. After the firm makes adjustments, the short-term TLC may rest higher or lower than the starting point. It depends on the mix of TC and IC changes that are inherent in the policies that firms pursue.

Firm management often has to make operational decisions based budget constraints. For example, when interest rates rise, then IC increases; and theory suggests ordering smaller quantities and shipping more often. However, because of short-term budgetary constraints, managers may be unable to increase transportation expenditure or may be unable to forego lower item prices that were based on a larger order quantity.

Another possible explanation is irrational behavior. This could originate from lack of skill, lack of information, or poor decisions. Managing a business by minimizing TLC is difficult. Managers may lack skills in some functional areas of logistics which limit their ability to meet lowest TLC. Firms may lack the knowledge or information systems that are required to summarize complex business operations. Managers may make decisions that are less than the optimum. Irrational behavior may take many forms, which in turn, might explain the negative short-term relationship between IC and TC.

The short-term behavior of these variables is sporadic and not purely unidirectional. A positive relationship is not always found because firms are adjusting to their new market circumstances which take several iterations of fluctuation (Feldstein et al., 1976). Even though a positive relationship between IC and TC, suggested by inventory theory, is not supported in the short-term, a positive relationship could be found in the long-term. It is likely that firms require multiple quarters to reach equilibrium; however, in each quarter of observation, individual firms are at different stages in the process. Some are in the first quarter of responding to a TC shock, other firms are in the 10^{th} quarter of response. The different stages of reaction (lags) represented by multiple firms is averaged. Models with additional and alternative lags were tested. However, the model with the best fit was found when observing the immediate, one-period lag of TC. When observing additional lags, the variables become insignificant. The initial reaction to a rise in transportation cost (*TransportationCost(-1)*) is an immediate reduction in inventory ($Inventory_{it}$). The negative coefficient on IC indicates that, in the near term, the firm brings IC cost down to offset the increase in TC.

Management does not always pursue lowest cost in the short-term. Premium service is often a management goal and is seldom the lowest cost option. Also, management may pursue lowest cost with a longer term perspective. For example, when sourcing additional tractor equipment, management may decide that it is less expensive to buy newer, more expensive tractors than to save money on the purchase price, but pay more during the ensuing months with higher maintenance costs and lower fuel economy.

Conclusion

This study draws on inventory theory to test whether firms trade off IC and TC. Specifically, it argues that the inventory-theoretic literature supports that firms manage inventory and transportation expenditures in concert, always monitoring the effect on one to changes in the other. Analysis with a large sample of firms provides suitable empirical support for testing the relationship between IC and TC. This research provides evidence that managers do trade off IC and TC in an effort to effectively manage their firms.

The essay concludes that managers will trade off IC and TC in an attempt to reduce total logistics cost. However, the changes to IC and TC are dynamic. The first period of adjustment demonstrates a negative relationship, meaning that if a firm's TCs increase, then management decreases IC in the next period to offset the TC increase. The next several quarters are not statistically significant and the association in subsequent periods cannot be determined unambiguously.

This is the first research that could be found that empirically tests management behavior related to IC and TC trade off. This research advances the inventory-theoretic literature by demonstrating empirical support for the inclusion of TC as a variable for the prediction of firm inventory. The most important practical implications from this study include enhanced information and support for managers to predict and react to IC changes more effectively and efficiently.

Management Implications

In practice, most firms have an organizational structure that divides transportation and inventory departments and they operate separately. Through daily activities, inventory planners forecast, source, store, and ultimately serve the fulfillment of customer requests. Transportation planners, likewise, plan their present and future transportation requirements based on forecasts of consumer demand. Cross-functional management collaboration between logistic functions appears to be rare in practice (Ellinger, 2000). These functions usually aren't managed collectively until the senior management level, where a firm may have a vice-president of operations who presides over both transportation and inventory divisions. Such an organizational structure impedes interaction between lower and mid-level managers that make transportation and inventory decisions. However, this study finds evidence that costs incurred in the transportation division of the company will have effects on inventory in the following quarter. This information can be used to suggest alternate organization structures and management behavior to better manage total logistics cost.

Future Research

The effect of customer service strategy on the behavior of IC and TC

The pursuit of low cost does not occur in a vacuum. Firms routinely balance cost with customer service strategy. For instance, if a firm pursues a high-service strategy, they may choose not to alter their cycle stock when TCs rise and thus keep smaller frequent deliveries to maintain high service. Consequently, customer service strategy is believed to mediate the management behavior regarding transportation and inventory. Future studies should research the impact of customer service strategy on IC and TC.

Elasticity of inventory and transportation cost adjustments

Since management can use the information in this essay regarding the association of IC and TC to react to their environment, it would be relevant to find whether firms can adjust their TC or their IC more quickly. Inventory carrying cost is often at the mercy of interest rates, long-term building leases, owned real-estate, or the need to eliminate obsolete inventory. TC is at the mercy of contractual arrangements with carriers and long-term capital depreciation. Some firms have equipment investment, such as trucks, trailers, and terminals, which may not be liquid. Transportation contracts and unneeded trucks and trailers may be more confining than the inventory of a manufacturer because manufacturers can often slow or stop production to reduce inventory. More research concerning management control over IC and TC is needed.

The long-range dynamics of inventory and transportation cost

This essay establishes the relationship between IC and TC, and provides a predictive model for inventory using a one-period lag of TC. However, inventory theory predicts a positive relationship between IC and TC. The results of this research show a negative relationship between the variables when observing a one-period lag. Inventory theory suggests that the behavior of IC and TC changes is dynamic and changes frequently over subsequent periods. If this dynamic behavior can be modeled, academics and managers stand to learn more about the behavior of these variables. Vector auto regression is an effective methodology to model the dynamics of variables when the structure is not known (Sims, 1980). This methodology provides impulse response functions which also promise to provide insightful information about how these variables react to one another beyond the first period lag.

Limitations

Firms will measure IC and TC differently. For example some firms will embed the TC in the cost of inventory. Care has been taken to keep the data in this essay accurate and consistent. However, there may still be some inconsistencies because of the way firms account for their transportation expenditures.

Inventory data that has been collected from Compustat may or may not be from the same division of a corporation that coincides with the collected transportation expenses. Care has been taken to assure that IC and TC data are for the same divisions of the companies.

Aggregated Compustat data can cause space (company division) and time aggregation biases. This is a frequent limitation in inventory research (Gaur et al., 2005; Rajagopalan & Malhotra, 2001).

Many factors outside firms' control also affect inventory (Rajagopalan & Malhotra, 2001). Accordingly, this study cannot assume causality between TC and inventory (Rajagopalan & Malhotra, 2001; Rumyantsev & Netessine, 2007).

Effort was made to select firms and industries that put a premium focus on inventory and transportation management. This allowed us to exclude companies in which inventory and transportation expenditures are not a major focus of the business and a critical component of company success. Therefore, by design, this sample does not represent the entire range of industry segments and therefore care must be taken when generalizing results to other industries.

Table 1: Descriptive Statistics

Variable	Mean	Std. dev.	N	Coded 1
Inventory*	3332	366	545	
Transportation Cost*	9569	1022	564	
Sales Forecast*	-327	211	441	
Uncertainty*	0.08888	0.00518	282	
Holding Cost**	0.01660	0.00122	521	
Stockout Cost***	0.31725	0.00561	563	
Lead Time****	215.2	6.1	562	
Sales Surprise Dummy			441	208
Firms Using FIFO			40	21
Firms Using LIFO			40	9
Firms Using Average Cost			40	6
Firms Using a Mix of Methods			40	4

** measured in millions of US dollars*
*** measured as rate of cost of US dollars*
****measured in US dollars*
***** measured in days*

Table 2: NAICS Descriptions

2-Digit NAICS Code and Description	3-Digit NAICS Code and Description
11 Agriculture, Forestry, Fishing	111 Crop Production
31 Manufacturing	311 Food Manufacturing
	312 Beverage and Tobacco Product Manufacturing
	314 Textile and Product Mills
32 Manufacturing	321 Wood Product Manufacturing
	322 Paper Manufacturing
	324 Petroleum and Coal Products Mfg
	325 Chemical Manufacturing
	326 Plastics and Rubber Products Manufacturing
33 Manufacturing	334 Computer and Electronic Product Manufacturing
	337 Furniture and Related Products Manufacturing
	339 Miscellaneous Manufacturing
42 Wholesale Trade	424 Merchant Wholesalers, Nondurable Goods
44 Retail Trade	441 Motor Vehicle and Parts Dealers
	444 Building Material and Garden Equipment and Supplies Dealers
	445 Food and Beverage Stores
45 Retail Trade	452 General Merchandise Stores
48 Transportation and Warehousing	488 Support Activities for Transportation

Table 3: Model

Inventory	Model *Coef.*
Constant	-3624
	(2397)
TransCost (-1)	-49.14 **
	(20.24)
SalesForecast (-1)	0.7 ***
	(0.117)
Uncertainty (-1)	-13514
	(9714)
HoldingCost (-1)	6511 **
	(3107)
StockoutCost (-1)	9018 *
	(4770)
LeadTime (-1)	-5.00
	(4.7)
SS (-1)	0.606 ***
	(.123)
Number of observations	322
R-sq. overall	0.20
F-statistic	1.56 **

References

Avery, S. (1998). Online buying systems must meet needs of real users. *Purchasing, 124*(1.)

Ballou, R. H. (2000). Evaluating inventory management performance using a turnover curve. *International Journal of Physical Distribution & Logistics Management, 30*(1), p.72.

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

Baumol, W. J., & Vinod, H. (1970). An inventory theoretic model of freight transport demand. *Management Science, 16*(7), 413.

Bishop, J. E. (1979). Integrating critical elements of production planning. *Harvard Business Review, 57*(5), 154.

Blinder, A. S., & Maccini, L. J. (1991). Taking stock: A critical assessment of recent research on inventories. *The Journal of Economic Perspectives, 5*(1), pp. 73-96.

Bowersox, D. J. (1969). Physical distribution development, current status, and potential. *The Journal of Marketing, 33*(1), 63-70.

Bowersox, D. J. (2007). SCM: The past is prologue. *Supply Chain Quarterly,* (Quarter 2), 1.

Buffa, F. P., & Reynolds, J. I. (1979). A graphical total cost model for inventory-transport decisions. *Journal of Business Logistics, 1*(2), 143.

Camp, W. E. (1922). Determining the production order quantity. *Management Engineering, Vol. 2*.

Campbell, J. F. (1990). Designing logistics systems by analyzing transportation, inventory and terminal cost tradeoffs. *Journal of Business Logistics, 11*(1), 159-179.

Carpenter, R. E., Fazzari, S. M., Petersen, B. C., Friedman, B. M., & Kashyap, A. K. (1994). Inventory investment, internal-finance fluctuations, and the business cycle; comments and discussion. *Brookings Papers on Economic Activity, 1994*(2), 75.

Chen, H., Frank, M., & Wu, O. (2007). U.S. retail and wholesale inventory performance from 1981 to 2004. *Manufacturing & Service Operations Management, 9*(4), 430.

Chen, H., Frank, M. Z., & Wu, O. Q. (2005). What actually happened to the inventories of american companies between 1981 and 2000? *Management Science, 51*(7), 1015.

Chopra, S., & Meindl, P. (2004). *Supply chain management: Strategy, planning, and operation* (2nd ed.). Upper Saddle River, NJ: Pearson Education, Inc.

Constable, G. K., & Whybark, D. C. (1978). The interaction of transportation and inventory decisions. *Decision Sciences, 9*(4), 688-699.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: More than a new name for logistics. *International Journal of Logistics Management, 8*(1), 1-14.

Das, C., & Tyagi, R. (1997). Role of inventory and transportation costs in determining the optimal degree of centralization. *Transportation Research.Part E, Logistics & Transportation Review, 33*(3), p. 171.

Dulaney, E. F., & Waller, M. A. (2002). *System, method and article of manufacture to optimize inventory and merchandising shelf space utilization* Google Patents.

Ellinger, A. E. (2000). Improving marketing/logistics cross-functional collaboration in the supply chain. *Industrial Marketing Management, 29*(1), 85-96.

Ellram, L. (1994). A taxonomy of total cost of ownership models. *Journal of Business Logistics, 15*(1), 171.

Ellram, L., & Siferd, S. P. (1998). Total cost of ownership: A key concept in strategic cost management decisions. *Journal of Business Logistics, Vol. 19*, pp. 55-84.

Evers, P. (1999). The effects of lead time on safety stocks. *Production & Inventory Management Journal, 40*(2), 6-10.

Feldstein, M., Auerbach, A., Hall, R. E., & Lovell, M. C. (1976). Inventory behavior in durable-goods manufacturing: The target-adjustment model. *Brookings Papers on Economic Activity, 1976*(2), 351-408.

Ferguson, R. W. (2001). *Speech on productivity and information technology* The Federal Reserve Board, Hague.

Fisher, M. L. (1997). What is the right supply chain for your product? *Harvard Business Review, 75*(2), 105-116.

Fisher, M. L., & Ittner, C. D. (1999). The impact of product variety on automobile assembly operations: Empirical evidence and simulation analysis. *Management Science, 45*(6), 771.

Gaur, V., Fisher, M. L., & Raman, A. (2005). An econometric analysis of inventory turnover performance in retail services. *Management Science, 51*(2), 181.

Greene, W. H. (2003). *Econometric analysis* (Fifth ed.). Delhi/India: Pearson Education Inc.

Harris, F. W. (1913). How much stock to keep on hand. *The Magazine of Management, Vol. 10*, p. 240.

Hausman, W. H. (2002). *Supply chain performance metrics.* (No. June 21,). Stanford, CA: Management Science & Engineering Department, Stanford University.

Hendricks, K. B., & Singhal, V. R. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management, 21*(5), pp. 501-522.

Hofer, C., & Waller, M. A. (2012). *Toward an organizational theory of inventory: A resource dependence theory perspective on the power-inventory relationship.* (Working Paper). Fayetteville, AR: University of Arkansas.

Kennedy, P. (2008). *A guide to econometrics*. Malden, MA: Blackwell Publishing.

Knipper, M. (2011). *Developing an integrated supply chain costing approach for strategic decision making.* (Ph.D., University of North Texas). , 190. . (Accession Number: 3436534.).

Lai, R. (2006). Inventory and the stock market. *Manufacturing & Service Operations Management, 8*(1), 107.

Lambert, D. M., Stock, J. R., & Ellram, L. (1998). *Fundamentals of logistics management*. United States: McGraw-Hill Higher Education.

Langley, C. J. (1980). The inclusion of transportation cost in inventory models: Some considerations. *Journal of Business Logistics, 2*(1), pp. 106.

Langley, C. J. (1986). The evolution of the logistics concept. *Journal of Business Logistics, 7*(2), pp. 1-13.

Lewis, H., Culliton, J., & Steele, J. (1956). *The role of airfreight in physical distribution*. Boston, MA: The Alpine Press.

Lieberman, M. B., Helper, S., & Demeester, L. (1999). The empirical determinants of inventory levels in high-volume manufacturing. *Production and Operations Management, 8*(1), pp. 44-55.

Lynch, D. F., Keller, S. B., & Ozment, J. (2000). The effects of logistics capabilities and strategy on firm performance. *Journal of Business Logistics, 21*(2), p. 47.

Magee, J. F. (1960). The logistics of distribution. *Harvard Business Review, 38*(4), p. 89.

Maltz, A. (1993). Private fleet use: A transaction cost model. *Transportation Journal, 32*(3), 46-46.

Maltz, A., & Ellram, L. (1997). Total cost of relationship: An analytical framework for the logistics outsourcing decision. *Journal of Business Logistics, 18*(1), 45.

Mason, S. J., Mauricio Ribera, P., Farris, J. A., & Kirk, R. G. (2003). Integrating the warehousing and transportation functions of the supply chain. *Transportation Research Part E: Logistics and Transportation Review, 39*(2), 141-159.

Min, W., & Pheng, L. S. (2006a). EOQ, JIT and fixed costs in the ready-mixed concrete industry. *International Journal of Production Economics, 102*(1), 180.

Min, W., & Pheng, L. S. (2006b). EOQ, JIT and fixed costs in the ready-mixed concrete industry. *International Journal of Production Economics, 102*(1), 167.

Ozment, J., & Keller, S. B. (2011). The future of logistics education. *Transportation Journal, 50*(1), 65-83.

Phillips, L. T. (1991). Contractual relationships in the deregulated transportation marketplace. *Journal of Law and Economics, 34*(2, Part 2, Contracts and the Activities of Firms: A Conference Sponsored by the John M. Olin Foundation and the Lynde and Harry Bradley Foundation), pp. 535-564.

Pilat, D. (2004). The ICT productivity paradox: Insights from micro data. *OECD Economic Studies, 38*(1), 37-65.

Pirttila, T., & Hautaniemi, P. (1995). Activity-based costing and distribution logistics management. *International Journal of Production Economics, 41*(1-3), 327.

Poist, R. F. (1974). The total cost vs. total profit approach to logistics systems design. *Transportation Journal, 14*(1), p. 13.

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

Rajagopalan, S., & Malhotra, A. (2001). Have U.S. manufacturing inventories really decreased? an empirical study. *Manufacturing & Service Operations Management, 3*(1), 14.

Randall, T., Netessine, S., & Rudi, N. (2005). *An empirical examination of the decision to invest in fulfillment capabilities: A study of internet retailers.* (Working Paper).

Rumyantsev, S., & Netessine, S. (2007). What can be learned from classical inventory models? A cross-industry exploratory investigation. *Manufacturing & Service Operations Management, 9*(4), 409.

Sandlin, D. E. (2010). *Three extensions to the inventory theoretic approach.* (Unpublished PhD). The Ohio State University, Columbus, OH.

Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling*. Hoboken, NJ: John Wiley & Sons.

Simchi-Levi, D., Kaminski, P., & and Simchi-Levi, E. (2003). *Managing the supply chain: The definitive guide for the business professional*. United States of America: McGraw-Hill Companies.

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica (Pre-1986), 48*(1), 1.

Smykay, E. W., Bowersox, D. J., & Mossman, F. H. (1961). *Physical distribution management: Logistics problems of the firm* Macmillan.

Speranza, M. G., & Ukovich, W. (1994). Analysis and integration of optimization models for logistic systems. *International Journal of Production Economics, 35*(1-3), 183.

Stenger, A. J., Coyle, J. J., & Price, M. S. (1977). *Incorporating transportation costs and services into the inventory replenishment decision*. Columbus, OH: The Ohio State University.

Stock, J. R., Lambert, D. M., & Lambert, D. M. (1987). *Strategic logistics management*. Homewood, Ill.: Irwin.

Swanson, D. (2012). *Empirical and analytical essays on the relationship between inventory and transportation.* (University of Arkansas). *Dissertation, Vol. 1*, 1.

Swenseth, S. R., & Godfrey, M. R. (2002). Incorporating transportation costs into inventory replenishment decisions. *International Journal of Production Economics, 77*(2), 113.

Taft, E. W. (1918). Iron age 101: The most economical production lot. *Iron age 101* (pp. 1410-1412.)

Teece, D. J., Gary, P., & Amy, S. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal (1986-1998), 18*(7), 509.

Timme, S. G. (2003). The real cost of holding inventory. *Supply Chain Management Review, 7*(4), 30.

Tyworth, J. E. (1991). The inventory theoretic approach in transportation selection models: A critical review. *Logistics and Transportation Review, 27*(4), 299.

Waller, M. A., Johnson, M. E., & Davis, T. (1999). Vendor-managed inventory in the retail supply chain. *Journal of Business Logistics, 20*(1), 183-203.

Watson, R. B. (1987). The effects of demand-forecast fluctuations on customer service and inventory cost when demand is lumpy. *The Journal of the Operational Research Society, 38*(1), 75.

Wilson, R., & Delaney, R. V. (2001). *12th annual state of logistics report.* (No. June 4). Washington DC: National Press Club.

Zeng, A. Z., & Rossetti, C. (2003). Developing a framework for evaluating the logistics costs in global sourcing proceses: An implementation and insights. *International Journal of Physical Distribution & Logistics Management, 33*(9/10), 785.

Zinn, W., Levy, M., & Bowersox, D. J. (1989). Measuring the effect of inventory centralization/decentralization on aggregate safety stock: The'square root law'revisited. *Journal of Business Logistics, 10*(1), 1-14.

CHAPTER 4 (ESSAY 3): The Relationship between Inventory and Transportation: Information Processing Theory Provides Insight into Transportation Cost Benchmarking

Abstract

This study examines the use of transportation benchmarking information and how it affects firm performance. Based on information processing theory, the impact of transportation benchmarking information on a firm's ability to reduce transportation cost (TC) is examined. Firms in a benchmarking consortium have varying degrees of participation, which may extend from zero to one-hundred percent. At one end of this continuum a firm has no transportation cost and at the other end of the continuum a firm represents all of the transportation cost in the consortium. At both ends of the continuum there are no benefits to the firm from benchmarking; but in between the two ends of the continuum, there are benefits. To describe this relationship, a variable is created that is the ratio of a firm's transportation expenditure to the total transportation expenditure in the benchmarking consortium. This ratio is referred to as *SIG*, which represents the relative amount of transportation expenditure of a given firm in comparison to the size of the benchmarking consortium. *SIG* values range from zero to one. Panel data is used to test the impact of *SIG* on a firm's ability to reduce transportation costs. Empirical analysis shows that transportation costs are convex in *SIG*. As expected, firms with higher inventory levels spend more on transportation and more profitable firms spend less on transportation, other things being equal. The results support the efficacy of transportation expenditure benchmarking.

Introduction

Transportation costs have increased 300% over the last 50 years, even after adjustments for inflation, (Wilson, 2011), and up to 50% of product cost can be attributed to transportation (Norden & van de Velde, 2005). Firms that require transportation to deliver their products and services know this all too well. Logistics managers focus on continuous cost reduction which is a primary reason that firms join benchmarking consortiums. In a benchmarking consortium, firms can monitor the rates, volumes, and markets that other firms are securing for their freight transport. Benchmarking services provide an important tool that firms can use to gauge their success, know what is possible in the marketplace, and monitor tactics and strategies of other firms in the marketplace.

The amount of information that a firm acquires and uses as a basis for learning has a profound effect on the performance of the firm (Smith, Grimm, Gannon, & Chen, 1991). This essay monitors information under controlled conditions by testing hypotheses by using transportation data that is voluntarily shared by the firms as a part of a benchmarking consortium. Under these conditions, all firms in the consortium have the same information at the same time. This benchmarking environment sparks interesting questions such as how transportation benchmarking information contributes to firm profitability. Consistent with theory, this study finds that benchmarking information can be used to reduce TC.

Managers stand to gain from this study with an increased understanding of the benefits that can be attained from the use of benchmarking consortiums. Following this introduction, the relevant literature is reviewed. Then, theoretical basis and the hypothesis are developed. Next are the data and methodology sections, followed by the results, discussion, and conclusions of the study. This paper ends with management implications, limitations, and some suggestions for future research.

Background

The Transportation Marketplace

Firms strive to secure the lowest possible transportation rates because this increases firm performance (Thompson, 1967). Since transportation rates are negotiated, there is not one lowest price given to all firms. Transportation companies provide lower rates for the following reasons including: expanding into new markets, using idle equipment, filling backhaul trailers, winning new customers, pleasing existing customers, and offering economies of scale pricing incentives (Coyle, Novack, Gibson, & Bardi, 2011). When one shipper secures a lower rate for a certain transportation lane or market, that firm has won a competitive advantage because carriers can't afford to give lowest prices to all shippers. Consequently, firms that use transportation services must negotiate for the lowest rates.

Benchmarking Consortiums

The firms involved in this study are all part of a benchmarking consortium. The purpose of the consortium is to provide for its members visibility into the transportation rates that are secured by the other consortium members. Members can compare their performance by lane and transportation service level relative to other firms.

Benchmarking consortiums provide a unique environment for studying transportation information. Since TC reporting is not regulated by accounting principles, firms are not required to report any of these costs. When TC is reported, there are no standard methods practiced that would allow the costs to be compared across firms. Benchmarking consortiums remove this barrier by collecting and standardizing TC so that the information can be compared across firms and industries. Another important feature of the consortium is that identical information is known by all the members concurrently.

There has been little published research on how firms use benchmarking (Sweeney, 1994). There are some related studies in the information systems literature focusing on inter-organizational systems that link organizations to suppliers, distribution channels, or customers in such a way that firms can benchmark partners' best practices (Johnston & Vitale, 1988). Similarly, there are information systems used for benchmarking transportation prices, such as those in use by the airline industry to monitor thousands of daily changes in airfare (Breath and Ives 1986). Benchmarking financial ratios and monitoring prices are different than benchmarking operational processes (Sweeney, 1994). It is believed that characteristics of both of these types of benchmarking apply to this study. Porter and Millar identify the advantages of information for gaining a competitive advantage and establish a framework which can be used to classify benchmarking consortiums as information technology which can lead to strategic advantages (Porter & Millar, 1985).

Theoretical Development

Why would firms engage in transportation expenditure benchmarking consortiums? One obvious answer is to deal with uncertainty (Galbraith, 1973; Lawrence & Lorsch, 1967). That is, they do not know what other firms are paying on various lanes, and, therefore, they may be paying too much. Uncertainty is defined as the absence of information (Daft & Lengel, 1986;

Garner, 1962), and it can be reduced by collecting more data (Daft & Lengel, 1986).

A second possible answer is equivocality reduction (Weick, 1979). Equivocality is slightly different than uncertainty, meaning that a solution is ambiguous. Whereas uncertainty can usually be resolved by collecting and analyzing more data, equivocality cannot because organizations are confused on which questions to ask. Some issues in transportation management are the result of ambiguous information that cannot easily be understood with simple transportation cost numbers. For this reason, equivocality is believed to be present in the transportation marketplace. For example, if a firm monitors transportation rates and determines that a competitor doesn't respond to a particular transportation rate reduction, the reason is often unclear. It may be that the competitor is uninformed, that they emphasize service instead of cost reduction, that they reduce rates in other markets, or that they deem the rate reduction unimportant and not worthy of further consideration. Just monitoring transportation rates cannot usually help firms decipher the ambiguity in the transportation marketplace.

When equivocality is high, managers usually resolve problems with more face-to-face meetings and work together to create questions and solutions (Daft & Weick, 1984), because human beings have the capacity to interpret and respond to ambiguity (Daft & Lengel, 1986). Within a benchmarking consortium, participants discuss ambiguous situations in transportation and how to innovate solutions together, which may not have been discovered by simply monitoring transportation expenditures in isolation. Such task forces can provide a greater amount of information within an organization than a singular face-to-face meeting (Daft & Lengel, 1986).

Daft and Lengel provide an organizational framework which can be used by managers to classify organizational structures that are appropriate for information processing along a spectrum of uncertainty to equivocality (Daft & Lengel, 1986). For information processing under high amounts of uncertainty, rules and regulations and formal information systems are two organizational structures that provide the best impact. Under conditions of high equivocality, group meetings, integrators, direct control, planning, and special reporting provided the best structures to process information. Transportation benchmarking consortiums offer several of these types of structures that are used both for uncertainty and equivocality reduction including: formal information systems, special reporting, integration, and group meetings.

Similar to uncertainty and equivocality, firms can be overwhelmed by too much information. Even the most complex organizations have boundaries on information capacity (March & Simon, 1958). At high levels, processing information becomes increasingly difficult (Daft & Lengel, 1986). There is a lot of information in the transportation industry and transportation managers must reduce data to the relevant and most important information. Benchmarking consortiums can help managers reduce and summarize large amounts of information and provide consultative assistance.

Tushman and Nadler find that sources of uncertainty and equivocality can originate from three areas, including: technology, from managing interdependence, or from the external environment (Tushman & Nadler, 1978). Each of these will be discussed.

Technology is knowledge, tools, and techniques used in information processing (Daft & Lengel, 1986). Task variety and task analyzability are two antecedents of information processing technology (Perrow, 1967). Task variety is the frequency of unexpected changes, and task analyzability is the manner in which managers respond to problems. Task variety has been prevalent in the transportation industry with examples such as: constant safety regulations, sustainability practices, ways to increase operational productivity, and government policies. Firms must change rapidly to keep pace with technology. Task analyzability is also frequently observed in the transportation industry, because transportation managers often respond differently to information processing needs including, choosing alternate levels of service, implementing different backhaul strategies, and instigating different guidelines for upgrading equipment.

Another reason for increased uncertainty and equivocality in the transportation industry is interdependence between firms (Van de Ven, Delbecq, & Koenig, 1976). Interdependence results from imbalance on lanes. Interdependence increases uncertainty because action by one firm can unexpectedly force adaptation by other firms in the transportation market. For example, if many firms are moving product in one direction, it may allow a given firm to move freight in the other direction and achieve lower rates. Such information might suggest network changes such as new distribution center locations.

Theory supports a third reason for increased uncertainty and equivocality, the external environment. The environment is a major factor in organizational structure (Duncan, 1972; Pfeffer & Salancik, 1978). Many environmental factors are inherently unclear to transportation managers including interest rates, fuel prices, and marine weather.

In summary, the benefits of joining a benchmarking consortium can be explained theoretically by a few propositions. If firms can reduce uncertainty and know they are paying more than others, it will help them negotiate with carriers. If firms can decipher equivocal transportation strategies that are instigated by their competitors, they can be better positioned for competitive advantage and for increased performance. If firms can better manage the prolific databases of information that is available to them, they are better aware and this leads to performance (Hult, Ketchen Jr, & Slater, 2004). If firms can better understand the interdependencies of shippers and transportation carriers as shipment volumes and directions change (Van de Ven et al., 1976), they will process information more effectively. Finally, information about the environment and competition can be provided by formal systems (Parsons, 1983), including benchmarking systems.

Hypothesis Development

Theory of organizational information processing attempts to explain organizational behavior by examining information within and surrounding a firm (Knight & Mcdaniel, 1979), because the type of action, the sensory systems of responding firms, their information processing and analyzing mechanisms, and their decision-making process (Egelhoff, 1982) have different results.

Increased awareness leads to better performance (Hult et al., 2004). However, information delivered by technical processes doesn't automatically provide immediate returns to all firms; the information must be managed and used successfully (Keen, 1993). Firms can use their heightened awareness to alter transportation strategies (Smith et al., 1991), such as lowering TC which leads to better performance. Lowering TC is the most obvious firm strategy, because firms seek to maximize profits (Shapiro, 1989) and lowering cost has a direct impact on profits. To that end TC is often kept to a minimum by firm managers (Lambert et al., 1998).

Consider a continuum where, at one end of the continuum a firm contributes no transportation information to the other end of the continuum where a firm contributes all of the transportation information in a benchmarking consortium. At both ends of the continuum there are no benefits to the firm from benchmarking; but in between the two ends of the continuum, there are benefits.

To describe this relationship, a variable is created that is the ratio of a firm's transportation expenditure to the total transportation expenditure in the benchmarking consortium.

H: TC is convex in the ratio of a firm's transportation expenditure to the total transportation expenditure in a benchmarking consortium.

Methodology

Model Specification

Consider the following model development:

Transportation cost is a function of rate, volume (Coyle et al., 2011) and inventory cost (Swanson, 2012).

$$TC = f\,(\text{rate, volume, IC}) \tag{1}$$

Rate is a function of fuel, distance, commodity, and transportation information about the marketplace that firms can acquire and use effectively. *SIG* represents the transportation information about the marketplace that firms can acquire and use effectively.

$$\text{Rate} = f\,(\text{fuel, distance, commodity, and SIG}) \tag{2}$$

Volume is a function of a firm's revenue, industry, the economy, and transportation information about the marketplace that firms can acquire and use effectively.

$$\text{Volume} = f\,(\text{revenue, industry, GDP, and SIG}) \tag{3}$$

Inventory cost is a function of inventory-theoretic variables (*ITV*) (Swanson 2012) and transportation information about the marketplace that firms can acquire and use effectively.

IC = f (ITV, SIG) (4)

By substituting Equations 2, 3, and 4 into Equation 1, we arrive at Equation 5.

TC = f (fuel, distance, commodity, industry, revenue, IC, SIG) (5)

Distance, commodity, and industry are modeled in this essay with fixed firm effects, resulting in Equation 6.

TC = f (fuel, revenue, IC, SIG, fixed effects) (6)

Model Variables and Measurement

The dependent variable, *TC,* is firm weekly transportation cost and is measured in U.S. dollars. This variable aggregates all of the strategies of the firm across product lines and geographical areas, and allows testing of hypotheses that give us a rich understanding of transportation benchmarking information through the lens of information processing theory.

The benchmarking information variable (*SIG*) is used to represent the value of the benchmarking information to each firm. *SIG* is calculated by dividing the firm weekly TC by the total transportation expenditure *(∑TC)* by all members of the consortium.

The *TC* of each firm, when used as a component of (*SIG*), is used to proxy the transportation management informational processing and utilization characteristics of the firm. Managers are evaluating many factors as they form their transportation strategy. There are many shipping lanes, competitive moves, rate structures, and customer preferences to monitor. Managers consider and use all this information to alter their transportation strategy or to renegotiate contracts with carriers. The usage of this information is reflected in the expenditures of each firm.

The sum of the *TC* of all member firms in the consortium *(∑TC)* is used to proxy the total information potential of the benchmarking consortium each week. This variable includes the rates, volumes, and lane information resulting from a week of transportation contracts and activity; but more so, this variable is a proxy for total potential transportation information that can be gleaned from the consortium. Examples of such information includes determining: where might transportation rates favor company expansion into new markets, or where might the firm build a new distribution center.

SIG is not meant to be a measure of transportation management efficiency of the firm. Firm efficiency, and other management characteristics like prowess and education, is controlled by firm fixed effects. Rather, the objective of the (*SIG*) variable is to mimic the information that is available to and used by managers, and this is calculated by including the total information processing capabilities of the firm and the total potential information the consortium is capable of offering each week.

As firms enter and exit the consortium, the volume of transportation information changes. For that reason, dividing the *(∑TC)* by the number of participants was considered. However, this would bias the measurement by essentially saying there is less information when there are more participants. This is clearly not true.

Altering *SIG* to be a relative measure by dividing *TC* by firm sales was also considered. However, an absolute measure of the ratio of firm transportation expenditure to total benchmarking expenditure is used for two reasons. First, larger firms have more resources and can thus use the benchmarking information more effectively. It is believed that larger firms will have more resources and better resources (Schumpeter, 1942). Second, larger firms have more to gain from the benchmarking information because they have more skin in the game. Thus, the ratio ($TC/\sum TC$) represents the total amount of information the firm is able to garner from the benchmarking consortium and use toward its operation, and is the best measurement for this study.

The remaining set of independent variables consists of those suggested by theory for the prediction of TC. Unless otherwise stated, all data come from Standard & Poor's Compustat database.

NI is net income measured in thousands of U.S. dollars.

INV is quarterly inventory of the firm measured in thousands of U.S. dollars. This variable represents the relationship that inventory has with transportation expenditures that was established in the second essay of this dissertation (Swanson, 2012). *INV* also controls for firm size, which has generally been found to be positive and to be significantly associated with profitability (Fiegenbaum & Karnani, 1991). The quarterly reported inventory amount is used for all of the 13 weekly observations in the quarter.

Models were tested that include both *INV* and a variable for firm revenue, and these models were found to have excessive multi-collinearity (0.88). A better model fit was obtained by using *INV* instead of revenue. It is believed that *INV* is a better control variable for firm size, primarily because it also controls for the importance of transportation to firms that have similar revenue.

GDP is gross domestic product measured in millions of U.S. dollars. The data for this variable were obtained from the Economic Research database provided by the Federal Reserve Bank of

St. Louis.

FUEL an index for energy cost. The data for this variable were obtained from the Economic Research database provided by the Federal Reserve Bank of St. Louis.

FFR is the federal funds rate. The data for this variable were obtained from the Economic Research database provided by the Federal Reserve Bank of St. Louis.

Data

The tests of the hypotheses proposed in the previous section were performed on firm-level data from a cross-section of U.S. firms and industries. Details regarding the data sample, variable measurement, and model specification appear next.

Sample Selection

The empirical tests rely on panel data from U.S. manufacturing and retail firms that participate in a transportation benchmarking consortium in which each participating company shares its TC for examination by other members. Weekly TC from September 2006 through March 2011 for 126 firms was obtained. Firms were members of the benchmarking consortium for varying lengths of time. This resulted in 235 weekly periods of information and 17,003 observations.

For this study, weekly data instead of quarterly or annual data was chosen because it provided more observations. Weekly data also provides a highly aggregated measure of transportation strategies by each company, because weekly TC summarizes hundreds of decisions and transactions which have occurred within the week of business operations. Therefore, the TC variable used in this study can be considered an aggregate variable representing the transportation strategies of each firm.

Inventory and other company-related quarterly variables were paired with each weekly observation of TC. Of the 126 firms, 59 were private firms, so inventory numbers were not available. Of the remaining 77 firms, three firms did not provide quarterly inventory data and so they were removed from the sample. There were also five firms which could not be unambiguously linked to the transportation data, due to mergers, divestment, or multiple company divisions that made the matching unclear. These five firms were also removed from the sample. A final firm was removed because it held no inventory. Sixty-eight firms remained in the study covering various parts of the 235 weekly periods. The total firm by week observation count is 4,627. After examination of the descriptive statistics, the data was kept in its purest form.

Descriptive Statistics

Descriptive statistics and pairwise correlations are summarized in Tables 1 and 2. The mean TC is about 17% higher than IC. This is consistent with our expectations for this dataset because the importance of inventory and transportation for these firms is high. However, examining macroeconomic data for the U.S. reveals that TC is usually twice as large as IC (Wilson & Delaney, 2001). Pairwise correlations, in Table 2, show minimally correlated independent variables. The independent variables with the highest correlations were *INV* and *NI* (0.44), *FUEL* and *GDP* (0.57), and *FFR* and *GDP* (-0.38).

A model based on ordinary least squares is used to examine panel data and test the hypotheses. The data meet the requirements of linear, unbiased, and consistent and therefore OLS is appropriate (Greene, 2003).

The Durbin-Watson statistic suggested high serial correlation in this panel dataset (DW=0.7). A one-period lag of the dependent variable, TC, was applied in the model as an autoregressive term to capture the correlated effect of variables across subsequent periods. The auto regressive term (AR(1)) was significant in all models (p=0.01) and the Durbin Watson statistic is normal (DW=2.27).

Residual analysis on the data indicated that the error variances from the models increased as the values of the independent variables increased. To control for this heteroscedasticity, White's efficient standard errors was applied in two separate tests to control for both period heteroscedasticity and cross-sectional heteroscedasticity. These tests provided no improvement to the model fit. It is believed the data observations (>4000) are too high to see an effect from the application of White's standard errors and are thus not necessary to control for heteroscedasticity.

A Hausman test was used to determine whether fixed or random effects are best for the data. Whenever random effects are significant, this is preferred to fixed effects (Greene, 2003). This dataset showed random effects to be significant (p=0.01). However, random effects are not allowed for a distributed lagged model (Greene, 2003). A model with fixed effects and retaining the autoregressive term (AR(1)) proved to be the best model with the lower Durbin-Watson (2.27) higher overall R^2 (.97).

The hypotheses were tested following a two-step procedure. First, the base model for predicting TC was set, including independent variables *INV*, *NI*, *GDP*, *FUEL*, and *FFR*. See Model 1 in Table 3. Next, the first-order variables were included to test the properties and effects of benchmarking information, including *SIG(-1) and* $SIG(-1)^2$. See Model 2 in Table 4.

Results

The results from testing these models using the panel data set and the linear regression estimation method outlined above appear in Table 3. Each of the models has high overall R-squared (0.97), which indicates that the model explains approximately 97% of the variability in the *TC*. The two models also have a significant F-statistic (p=0.01). The coefficient estimates for four of six of the control variables, *INV* (p=0.1), GDP (p=0.01), *FUEL* (p=0.05), and the auto-regressive term *AR(1)* (p=0.01) are significant. The signs and values of these coefficients are in line with theory and expectations.

The benchmarking information signal *(SIG(-1))* and the squared benchmarking information signal ($SIG(-1)^2$) are statistically significant (p=0.01). Since ($SIG(-1)^2$) is significant; the hypothesis is supported. The results from this model suggest that the benchmarking information follows a non-linear relationship with TC. The optimum value of *SIG* can be calculated by taking the derivative of the equation that includes the benchmarking information variables with respect to $SIG(-1)^2$. The initial equation and the solution are shown in Equations 6 and 7.

$$TC = \beta_1 SIG(-1) + \beta_2 SIG(-1)^2 \qquad (6)$$

$$SIG(-1) = {}^{-\beta_1}/_{2\,\beta_2} = {}^{3.6}/_{140} = 0.03 \qquad (7)$$

Discussion

The results indicate that firms can use benchmarking information to reduce their TC. The relationship of the benchmarking information to transportation cost, however, is non-linear because for firms to receive the information, they have to reveal their own transportation information. So, the higher the percentage of contribution by a firm to the consortium, the lower is the available new information that firm can potentially process.

This suggests several related ideas. It is advantageous for firms to collect and use benchmarking information. Firms can use benchmarking data to improve performance. Transportation cost information from other firms can be used for lowering TC or for pursuing other means of lowering logistics cost.

Conclusion

This study theoretically and empirically examines the use of transportation benchmarking information and how it affects firm performance. Based on concepts from information processing theory, the transportation expenditure of firms, which is shared in conjunction with other firms in a benchmarking consortium, is information that can be used to improve financial performance. It is hypothesized that firms use transportation benchmarking information to lower transportation cost. Results based on data from a broad cross-section of U.S. manufacturing and retail firms, and controlled for relevant drivers of TC, provide ample empirical support for the hypothesis and indicate that firms do use transportation benchmarking information to reduce TC. A non-linear relationship between the benchmarking information and transportation cost is also found.

This study contributes empirical testing that supports several concepts of information processing theory including the concepts of uncertainty and equivocality. Theory also supports that technology change, interdependence of companies, and environmental factors that are prevalent in the transportation industry causing high levels of uncertainty and equivocality in the transportation marketplace. As expected, firms with higher inventory levels spend more on transportation. The results support the importance of transportation cost benchmarking.

Management Implications

This paper demonstrates the nature of benchmarking information and how they can be used by management to increase performance. Interesting practical implications can be drawn. First, the relationship between benchmarking information and lowering transportation cost is non-linear, indicating that the transportation information is beneficial to the firm, but at a decreasing rate. So, when a firm becomes larger relative to the other participants, or if the benchmarking consortium loses membership, a firm will see decreasing benefits from the consortium information. Second, it can be seen that as firm profitability increases, ceteris paribus, firms spend more on TC. Finally, the results of this paper imply that collecting data on transportation rates may oversimplify information management within organizations because the problem may be a lack of problem clarity, not a lack of explicit data.

Limitations

The firms which have been included in this research are not perfectly heterogeneous and, as a sample, do not represent the population of all firms. This is by design because it was important for this study to concentrate on firms that consider both transportation and inventory management important. Some firms have relatively little inventory, such as financial service firms; and some firms have relatively little transportation requirements, such as software sales and installation firms. Since not all firms consider inventory and transportation important, the firms selected for this study are firms which regard inventory and transportation strategy as critical aspects of their business. Therefore, any generalization of this research should be limited to firms that do consider inventory and transportation strategy to be important.

The TC utilized in this study includes rates paid to transportation providers for transportation services. This study does not include expenses for private fleets. It is likely that firms will utilize their own transportation fleet differently than purchased transportation for many reasons, one of which is because the marginal cost of using private transportation may be lower if fixed costs have already been allocated.

Table 1: Descriptive Statistics (Quarterly)

Variable	Mean	Std. dev.	N
Transportation Cost*	3470	3987	8883
Inventory*	2970	5626	8883
Net Income*	529	1919	8883
Fuel	3.04	0.60	8883
FFR	1.54	2.00	8883
SIG (-1)	0.0107	0.012	8883

** measured in thousands of U.S. dollars*

Table 2: Pairwise Correlations

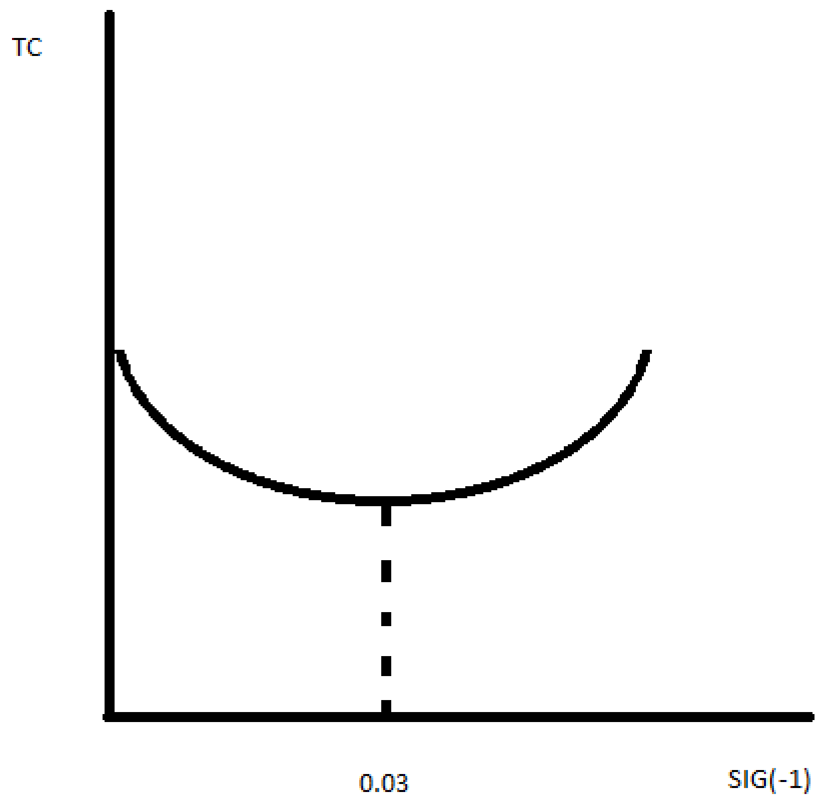
		1	2	3	4	5	6
1	Inventory	1.000					
2	Net Income	0.438	1.000				
3	GDP	-0.002	0.009	1.000			
4	FUEL	-0.004	0.007	0.566	1.000		
5	FFR	0.000	0.000	-0.381	0.099	1.000	
6	SIG (-1)	0.003	0.003	-0.095	0.006	0.150	1.000

Table 3: Model Summary

	Model 1	Model 2
Constant	-1942776	-2263196
	(1658294)	*(1655089)*
INV	3.2	3.4
	*(1.8)**	*(1.8)**
NI	-1.1	-1.0
	(5.0)	(4.9)
GDP	313	350
	*(119)****	*(119)****
FUEL	289227	281555
	*(113898)***	*(110834)***
FFR	24556	24515
	(45307)	*(43850)*
AR(1)	0.878	0.871
	*(0.007)****	*(0.008) ****
SIG (-1)		-35032346
		*(10354633)****
SIG $(-1)^2$		6.84E+08
		(1.30E+08) ***(H)
Observations	4663	4627
R^2	0.97	0.97
F-Statistic	1130 ***	1119***

** Significant alpha = 10%*
***Significant alpha = 5%*
****Significant alpha = 1%*
SE is shown in parentheses

Figure 1: Benchmarking Information Variable (SIG) and Transportation Cost (TC)



References

Coyle, J. J., Novack, R. A., Gibson, B. J., & Bardi, E. J. (2011). *Transportation: A supply chain perspective*. Mason, OH: South-Western Cengage Learning.

Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. *Management Sc, Vol. 32*(5), 554-571.

Daft, R. L., & Weick, K. E. (1984). Toward a model of organizations as interpretation systems. *Academy of Management Review, Vol. 9*, 284-295.

Duncan, R. B. (1972). Characteristics of organizational environment and perceived environmental uncertainty. *Administrative Science Quarterly, Vol. 17*, 313-327.

Egelhoff, W. G. (1982). Strategy and structure in multinatinoal corporatins: An information-processing approach. *Administrative Science Quarterly, Vol. 17*, 313-327.

Fiegenbaum, A., & Karnani, A. (1991). Output flexibility—a competitive advantage for small firms. *Strategic Management Journal, 12*(2), pp. 101-114.

Galbraith, J. (1973). *Designing complex organizations*. Reading, MA.: Addison-Wesley.

Garner, W. R. (1962). *Uncertainty and structure as psychological concepts*. New York, NY: Wiley.

Greene, W. H. (2003). *Econometric analysis* (Fifth ed.). Delhi/India: Pearson Education Inc.

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

Johnston, H. R., & Vitale, M. R. (1988). Creating competitive advantage with interorganizational information systems. *Mis Quarterly,* , pp. 153-165.

Keen, P. G. W. (1993). Information technology and the management difference: A fusion map. *IBM Systems Journal, 32*(1), 17-39.

Knight, K. E., & Mcdaniel, R. R. (1979). *Organizations: An information systems perspective*. Belmont, CA.: Wadsworth Publishing Company.

Lambert, D. M., Stock, J. R., & Ellram, L. (1998). *Fundamentals of logistics management*. United States: McGraw-Hill Higher Education.

Lawrence, P. R., & Lorsch, J. W. (1967). New managerial job: The integrator. *Harvard Business Review, November-December*, 142-151.

March, J. G., & Simon, H. A. (1958). *Organizations*. New York, NY: John Wiley.

Norden, L. v., & van de Velde, S. (2005). Multi-product lot-sizing with a transportation capacity reservation contract. *European Journal of Operational Research, Vol. 165*, 127-138.

Parsons, G. L. (1983). Information technology: A new competitive weapon. *Sloan Management Review, Vol. 25*(1), 3-14.

Perrow, C. (1967). A framework for the comparative analysis fo organizations. *American Sociological Review, Vol. 32.*

Pfeffer, J., & Salancik, G. R. (1978). *The expternal control fo organizations: A resource dependence perspective*. New York, NY: Harper and Row.

Porter, M. E., & Millar, V. E. (1985). How information gives you competitive advantage. *Harvard Business Review, 63*(4), 149-160.

Schumpeter, J. A. (1942). *Capitalism, socialism, and democracy*. New York, NY: Harper.

Shapiro, C. (1989). The theory of business strategy. *The Rand Journal of Economics, 20*(1), pp. 125-137.

Smith, K. G., Grimm, C. M., Gannon, M. J., & Chen, M. J. (1991). Organizational information processing, competitive responses, and performance in the US domestic airline industry. *Academy of Management Journal, 34*(1), pp. 60-85.

Swanson, D. (2012). *Empirical and analytical essays on the relationship between inventory and transportation.* (University of Arkansas). *Dissertation, Vol. 1*, 1.

Sweeney, M. T. (1994). Benchmarking for strategic manufacturing management. *International Journal of Operations & Production Management, 14*(9), 4-15.

Thompson, J. D. (1967). *Organizations in action*. New York, NY: McGraw Hill Book Company.

Tushman, M. L., & Nadler, D. A. (1978). Information processing as an integrating concept in organizational design. *Academy of Management Review, Vol. 3*, 613-624.

Van de Ven, A. H., Delbecq, A. L., & Koenig, R. (1976). Determinants of coordination modes within orgznizations. *American Sociological Review, Vol. 41*, 322-338.

Weick, K. E. (1979). *The social phycology of organizing*. Reading, MA: addison-Wesley.

Wilson, R. (2011). *2010 state of logistics and mid-2011 outlook.* (No. October 3,). Washington, DC: CSCMP Annual Conference.

Wilson, R., & Delaney, R. V. (2001). *12th annual state of logistics report.* (No. June 4). Washington DC: National Press Club.

Chapter 5: Dissertation: Conclusion

Summary

This dissertation seeks more knowledge and tests theory relating to the total cost concept of logistics, one of the important founding principles of logistics (Bowersox, 2007). It has been recognized since the beginning of the business logistics discipline; yet because of its modeling complexity, it has not seen significant research about its antecedents, conditions, properties, behavior, or performance per se. For that reason, additional research on the total cost concept of logistics is relevant and timely (Waller & Fawcett, 2012).

The discussion of TLC is often illustrated with the tradeoffs of IC and TC, such as with the awareness that firms may need to spend alternate amounts of IC or TC to get a lowest TLC (Bowersox, 2007). Accordingly, this dissertation focuses on IC and TC to provide insight into the tradeoffs involved in the total logistics concept of firms. Inventory and transportation data, with observations from a broad fifty year timeframe to a narrow weekly firm level, provide testing ground for hypotheses derived from inventory theory, information processing theory, and efficient market theory.

The first essay of this dissertation takes a macroeconomic perspective of logistics practice in the United States spanning from 1960-2009. This period of time envelops the development and managerial practice of the total cost concept of logistics. Specifically, this dissertation explores whether or not firms show signs of balancing two key logistics costs, IC and TC. Inventory-theoretic literature suggests that firms manage inventory and transportation expenditures together to minimize total logistics cost for a given level of customer service desired. Prior to transportation deregulation in the United States, IC and TC were not in equilibrium and thus the data do not show signs that firms manage these expenditures in concert. However, following deregulation, firms did pursue policies that sought to balance IC and TC to achieve lowest TLC for a given service level. Government restrictions inhibited the transportation market thus interfering with the theorized behavior of IC and TC.

The second essay of this dissertation once again tests the relationship of IC and TC. It is likely that the balance of IC and TC is only visible in the aggregate, so the question of IC and TC equilibrium is studied in Essay 2 with firm-specific data. Quarterly inventory and transportation data from 2006-2011, and from forty-two firms, was examined for evidence that firms seek to balance IC and TC to pursue lowest TLC for a given service level. This test proceeded with a base model for predicting IC with variables suggested by inventory-theoretic literature. TC was then added to the model and found to be statistically significant and a valuable predictor of IC. Theory suggests that IC and TC will be positively related, however an inverse relationship was found. It is believed that the negative sign is observed because IC and TC do not adjust immediately within one quarter, and that this adjustment is an interactive process which can take several years.

After confirming the relationship between IC and TC that was established in Essays 1 and 2, the third essay of this dissertation seeks to understand more about transportation management behavior while controlling for inventory management strategies. Specifically, Essay 3 tests the effectiveness of transportation benchmarking panels. Data from sixty-nine firms that share competitive TC information as a part of a benchmarking consortium are used as the sample. Under the consortium arrangement, firms have access to their competitors' TC by shipping lane.

Conclusions include firms with higher inventory levels spend more on transportation and more profitable firms spend less on transportation, other things being equal. The results support the efficacy of transportation expenditure benchmarking.

Review of Contributions

This dissertation contributes to the theoretical development and understanding of the relationship between IC and TC, and accordingly, advances our understanding of the total cost concept of logistics. Contributions have been made in theory development, theory testing, methods application, managerial implications, and policy implications.

This dissertation provides empirical support for the inclusion of TC in the inventory-theoretic literature. It was found that the costs that firms spend on transportation can be used to predict the amount of inventory which will need to be carried by the firm.

This dissertation provides a macroeconomic study of IC and TC that spans the fifty-year period of the total logistics concept and it provides empirical evidence that firms do balance IC and TC to minimize TLC.

The inventory and transportation expenditures of individual firms are studied which reinforces the macroeconomic study with further empirical evidence that individual firms balance their IC and TC to minimize TLC.

This study provides transportation policy implications with empirical support that transportation regulation in the United States inhibited the free market. Prior to deregulation, firms did not balance IC and TC as theory suggested they should. Following deregulation, IC and TC are cointegrated and their tradeoff potential can be utilized by firms to increase performance.

This dissertation uses advanced econometric methods to evaluate, for the first time, the fifty-years of macroeconomic IC and TC data. This includes tests for unit root, cointegration, Granger causality, VAR, VECM, and evaluation of impulse response functions.

Management implications include suggested operating strategies to adjust to rising (or falling) IC or TC to minimize TLC, improvements to inventory forecasting, and suggestions for using transportation benchmarking information to increase firm performance.

Management can expect that if IC rises, such as when interest rates spike, real-estate costs increase, inventory level increases, or if any other factor raises their cost of inventory, that they will need to pay more for transportation to minimize their total cost. This activity is contrary to the first reaction of management which is to reduce costs to offset the costs which are increasing.

Similarly, management can expect that if the TC costs of the firm spike, such as when fuel prices increase, drivers require higher pay, or the government requires updated safety equipment, that they will need to pay more for inventory to minimize their total cost. This expenditure is also is contrary to the first reaction of management.

As a result of managements' first reactions to increases in IC and TC, this dissertation finds that firms, on average, are paying too much for their logistics costs immediately following increases in IC or TC.

This dissertation finds that TC can be used to improve the accuracy of forecasting the level of inventory that firms will carry in the following period. Potentially this can be used by management to improve operations.

References

Bowersox, D. J. (2007). SCM: The past is prologue. *Supply Chain Quarterly,* (Quarter 2), 1.

Waller, M. A., & Fawcett, S. E. (2012). The total cost concept of logistics: One of many fundamental logistics concepts begging for answers. *Journal of Business Logistics, 33*(1), 1.