UNIVERSITY OF CALIFORNIA,

IRVINE

Real Option-based Procurement for Transportation Services

DISSERTATION

submitted in partial satisfaction of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in Civil Engineering

by

Mei-Ting Tsai

Dissertation Committee:

Professor Amelia C. Regan, Chair

Professor Jean-Daniel Saphores, Co-chair

Professor R. Jayakrishnan

2008

The dissertation of Mei-Ting Tsai
is approved and is acceptable in quality and form for
publication on microfilm and in digital formats:

Co-chair

Committee Chair

University of California, Irvine
2008

DEDICATION

To

My parents

Te-Lung Tsai and Li-Shan Lin

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to express the appreciation to my committee chair, Professor Amelia Regan, who has continually encouraged and supported me throughout my time at UCI. I also thank my committee co-chair, Professor Jean-Daniel Saphores, for his detailed advice on my research. Without their guidance and help, I could not have completed this dissertation.

In addition, a thank you to Professor Knut Solna who helped me figure out some critical challenges of my research. Also, thanks to the other professors that helped me along the way: Professor R. Jayakrishnan, Professor Will Recker, and Professor Stephen Ritchie.

This dissertation was partially supported by the University of California Transportation Center (UCTC). I gratefully acknowledge this support.

Finally, I deeply thank my husband Jeff, my two adorable sons Peter and Brian, for their love and understanding. A special thank you is given to my parents, brothers and their families for all their advice, love and support.

CURRICULUM VITAE

Mei-Ting Tsai

2008	Ph. D. in Civil Engineering, University of California, Irvine
2008	Principal Transportation Analyst, Orange County Transportation Authority
2005-2008	Graduate Student Researcher, Institute of Transportation Studies, University of California, Irvine
2005	Teaching Assistant, University of California, Irvine
2002-2004	Executive Officer, Ministry of Transportation & Communications, Taipei, Taiwan
1999-2002	Engineer, Bureau of High Speed Rail, Ministry of Transportation & Communications, Taipei, Taiwan
1994-1999	Associate Engineer, Department of Housing and Urban Development, Taiwan Provincial Government, Taipei, Taiwan
1994	M.S. in Traffic and Transportation Engineer, National Chiao Tung University, Hsinchu, Taiwan
1992	B.S. in Transportation Engineering and Management, National Chiao Tung University, Hsinchu, Taiwan

PUBLICATIONS

Tsai, M.T., Saphores, J.D., Regan, A. (2009). Freight Transportation Contracting under Uncertainty. Proceedings of the 88th Annual Meeting of the Transportation Research Board, Washington D.C.

Tsai, M.T., Saphores, J.D., Regan, A. (2008). Valuation of Freight Transportation Contracts under Uncertainty. (Submitted)

Tsai, M.T., A. Regan, and J.D. Saphores. (2008) Freight Transportation Derivatives Contracts: State of the Art and Future Developments. Transportation Research Board, 87th Annual Meeting Proceedings, Washington D.C.

Wang, J.F., Regan, A., and Tsai, M.T. (2008) Minimizing Departure Time for Outgoing Trucks in a Crossdock. Transportation Research Board, 87th Annual Meeting Proceedings, Washington D.C.

Tsai, M.T., Regan, A. and Saphores, J.D. (2007) Freight Transportation Derivatives Contracts: State of the Art and Future Developments. 2nd Annual National Urban Freight Conference Proceedings, Long Beach, CA.

Chou, Y.H. and Tsai, M.T. (2003) New Direction of Railway Transportation Development in Taiwan – Focusing on "Challenge 2008: Transportation Backbone Plan". Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 4, Japan.

Ho, M.C. and Tsai, M.T. (1996) Introduction to CKS Airport to Taipei MRT Project and Strategy Analysis of Encouraging Private Sector to Investment. Proceedings of the Cross-strait Society for New Town and Public Infrastructure Studies, p.171-178, China. (in Chinese)

Tsai, M.T. and Chen, H.C. (1996) Introduction to Financial Planning --Taichung MRT Project as An Example. Housing & Urban Development Bimonthly, No. 119, Taipei, Taiwan. (in Chinese)

Chen, T.L., Sun, C.Y. and Tsai, M.T. (1995) How to Make a Successful Proposal, Money Culture Ltd., Taipei, Taiwan. (in Chinese)

Tsai, M.T. (1995) Introduction to Joint Development for Land. Journal of Taiwan Railway, Vol. 4, No.3, TRA, Taipei, Taiwan. (in Chinese)

FELLOWSHIPS AND AWARDS

2007-2008	Fellowship Award, University of California Transportation Center (UCTC)
2006	Graduate Scholarship Award, Women's Transportation Seminar (WTS) Orange County Chapter.
2004	Employee of the Year, Ministry of Transportation and Communications, Taiwan.
1999	Research Fellowship, Ministry of Transportation and Communications, Taiwan.
1992-1994	Graduate Scholarship, National Chiao Tung University, Hsinchu, Taiwan

ABSTRACT OF THE DISSERTATION

Real Option-based Procurement for Transportation Services

By

Mei-Ting Tsai

Doctor of Philosophy in Civil Engineering

University of California, Irvine, 2008

Professor Amelia C. Regan, Chair

Professor Jean-Daniel Saphores, Co-chair

Uncertainty in transportation capacity and cost poses a significant challenge for both shippers and carriers in the trucking industry. In the practice of adopting lean and demand-responsive logistics systems, orders are required to be delivered rapidly, accurately and reliably, even under demand uncertainty. These tougher demands on the industry motivate the need to introduce new instruments to manage transportation service contracts. One way to hedge these uncertainties is to use concepts from the theory of Real Options to craft derivative contracts, which we call truckload options in this dissertation. In its simplest form, a truckload call (put) option gives its holder the right to buy (sell) truckload services on a specific route, at a predetermined price on a predetermined date.

The holder decides if a truckload option should be exercised depending on information available when the option expires.

Truckload options are not yet available, however, so the purpose of this dissertation is to develop a truckload options pricing model and to show the usefulness of truckload options to both shippers and carriers. Since the price of a truckload option depends on the spot price of a truckload move, we first model the dynamics of spot rates using a common stochastic process. Unlike financial markets where high frequency data are available, spot prices for trucking services are not public and we can only observe some monthly statistics. This complicates somewhat the estimation of necessary parameters, which we obtain via two independent methods (variogram analysis and maximum likelihood), before developing a truckload options pricing formula. Finally, a numerical illustration based on real data shows that truckload options would be quite valuable to the trucking industry.

This dissertation develops a method to create value through more flexible procurement contracts, which could benefit the trucking industry as a whole – particularly in an uncertain business environment. Truckload rates and options prices are rigorously investigated and modeled. In addition, parameter estimation for a continuous stochastic model is explored using discrete statistics. Finally, numerical examples are illustrated and a picture of truckload option trading is presented. Results suggest that truckload options have the potential of significantly benefiting the trucking and logistics industries.

CHAPTER 1 INTRODUCTION

Freight transportation contributes significantly to the U.S. economy. In 2005, the cost of business logistics was nearly $1.2 trillion and represented 9.5% of the U.S. Gross Domestic Product (GDP), up from 8.8% of the GDP in 2004 (Wilson, 2006). Trucking is the main mode of freight transportation today, and according to a recent forecast by the American Trucking Association (ATA, 2006), it will continue to dominate domestic freight movements into the next decade. Forecasts suggest that the share of trucking's total tonnage could rise to 69.2% in 2011 from 68.9% in 2005 (ATA, 2006).

A flexible freight transportation service is a critical element of any modern supply chain. Manufacturers are increasingly adopting lean, demand-responsive, and resilient supply chain structures. These require orders to be delivered rapidly, accurately and reliably, even under demand uncertainty. This complicates shipping processes and results in more outsourcing for transportation services. Manufacturers would like to procure transportation contracts that can provide flexible transportation capacity corresponding to their 'lean' schedules. Truckload carriers are currently experiencing challenges following the adoption by U.S. firms of real-time supply chain management practices (Corsi, 2005). These tougher demands on the industry create the need to introduce new instruments to manage risk and they motivate our research.

1.1 Problem Description

Freight transportation is a derived demand. Before identifying changes in freight transportation demand, we have to study the current strategies of supply chain management. A review of supply chain management in high-tech industries shows that manufacturers are faced with price volatility, demand uncertainty and insufficient availability of inputs and finished products. Hewlett-Packard (HP), for example, suffered a loss resulting from sharp price increases and insufficient supplies in 2000. The company then developed a new method of procurement risk management based on financial-engineering approaches used in financial markets (Nagali, 2005).

Demand uncertainty has also raised challenges for Intel since each of the company's products has a different life cycle. An Intel team has proposed an innovative solution based on capacity options to hedge demand risk. At maturity, these options give Intel the right to place orders at a pre-determined price, so the company benefits from the ability to postpone orders. This enables Intel to better forecast demand for its products while avoiding the need to pay order cancellation fees. Although these options are not free, they give Intel significant value by allowing flexibility (Vaidyanathan et. al, 2005).

These two case studies highlight that uncertainty is critical for the manufacturing industry. This explains the growing popularity of options. Since freight transportation is an essential part of any supply chain, these trends are very likely to affect freight transportation contracting. In fact, Vaidyanathan et. al (2005) conclude that the use of options for equipment will extend into transportation contracting at Intel.

The common method of procuring transportation services is to bid for capacity on certain origin-destination movements ("lanes"). A shipper first announces the lanes on which to bid and communicates the details of his shipment needs with potential carriers. The shipper then obtains rate quotes from carriers and determines the winners after analyzing submitted bids. Because of the emergence of combinatorial auctions where carriers bid on bundles of lanes simultaneously and are sometimes awarded complicated joint contracts with other carriers, the process of procurement as well as bid preparation and winner determination have generated substantial interest in the research literature (Song and Regan, 2005). One issue with auctions, however, is that while demand is highly stochastic, the contracting process assumes that demand is deterministic and known. Shippers present carriers with average lane demands and carriers bid as though these are constants, although these are subject to significant swings. This means that the models used by truckers to generate bids and by shippers to award contracts overestimate the benefits of combinatorial packages of lanes (Nandiraju, 2006).

Let us examine a real world example. A leading food manufacturer conducted an auction for procuring trucking services. The manufacturer did everything right and reached the targeted saving through the bidding process. Then demand suddenly increased so much that the winning bidder could not provide service. This forced the manufacturer to turn to other carriers at higher rates. As a result, conducting the original auction did not pay off as expected (CTL, 2004). In the trucking industry these situations known as "losing the bid but winning the freight" are quite common. We suspect, however, that a well structured contract could have reduced many of the problems faced shippers and that there are win-win solutions to be found for both shippers and carriers.

In financial markets, options, futures, and other derivatives have been used to hedge risks and to accurately value flexibility. Since its development, the theory of financial derivatives has been applied to other network-type industries, such as natural gas and electricity supply (Law et al., 2003). Saphores and Boarnet (2006) and Saphores (2007) applied real options to analyze the decision to invest in urban transportation infrastructure under uncertainty. Recently, the idea of using real options to hedge transportation capacity and volatile cost has appeared in the literature (Law et al., 2003, Kavussanos and Visvikis, 2006, and Tibben-Lembke et al., 2006). However, we could not find any published academic paper that analyzes the application of options to the trucking industry even though this is the dominant freight transportation mode. This is a key motivation for our project as we believe that truck capacity options are promising tools that deserve to be studied.

1.2 Basic Ideas

The goal of this research is to model freight transportation flexibility in the trucking industry using the theory of options with an emphasis on capacity options.

Shippers and carriers are the two parties considered in this research. Shippers are firms who need to have loads transported from origins to destinations while carriers are the service providers.

Assume a shipper gets an unexpected order which requires completing a delivery in a short time window, say one week. The shipper could face one of four different scenarios (see Figure 1.1):

- First, the shipper could have a long-term contractual carrier with sufficient capacity to deliver the loads. In this case, the goods are delivered by the carrier at the contract rate.
- In the second scenario, the shipper has a long-term contractual carrier but this carrier does not have sufficient capacity, so the shipper needs to procure capacity in the spot market; total costs to the shipper are a combination of the contract rate and the spot rate.
- In the third case, the shipper does not have a long-term contract so she must procure all capacity in the spot market.
- Finally, in the fourth scenario, the shipper does not have a long-term contractual carrier and there is no capacity available in the spot market. In that case, the shipper would face a significant loss, not only in sales but also in supply reliability.

Unfortunately, today's operational environment involves less reliable lead times and uncertain demand. Therefore, all of the scenarios are possible. As a result, the high degree of uncertainty leads to significant costs for shippers. In addition, it increases the complexity of fleet management and planning for carriers.

As a starting point, this research focuses on the spot market with sufficient capacity (Scenario 3).

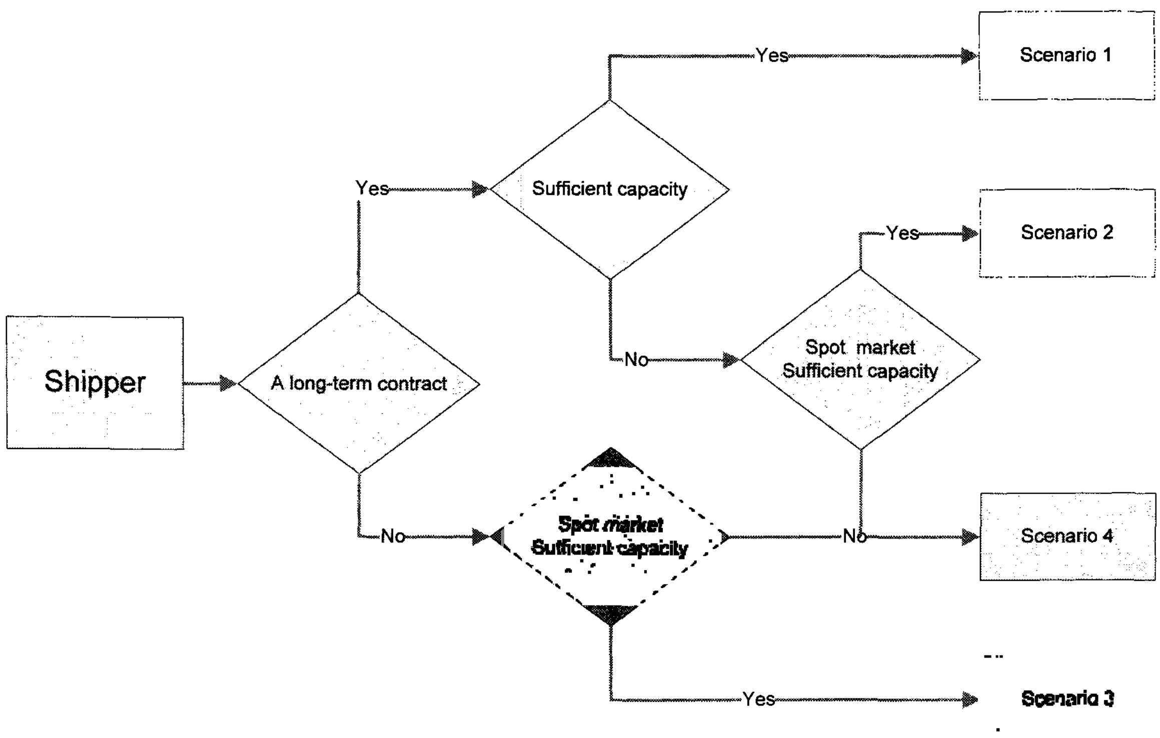


Figure 1.1 Scenarios of a Shipper Procuring Transportation Services

To illustrate how an option works, consider the following example. Shipper A predicts a demand of 100 truckloads on August 1st, two weeks from now. Since she is not sure about the demand, she does nothing about it. Suppose two weeks later, the demand appears. All Shipper A can do is purchase 100 truckloads at the spot price (denoted by ST), which is higher than the negotiated price (denoted by S0) she could have secured two weeks ago. But even if she is willing to pay the higher price, the 100 truckloads are not guaranteed.

If, instead, Shipper A wrote a trucking option contract at cost of P with Carrier B, which provides her with the right to procure 100 truckloads on August 1st at price K, she would get guaranteed capacity.

She would hedge the trucking capacity uncertainty. Furthermore, on August 1st, suppose ST is greater than K, Shipper A would exercise the options whose payoff is (ST - K). The profit for Shipper A would be (ST - K - P). Suppose ST is less than K, Shipper A would rather purchase truckloads at the spot price than exercise the option. So the payoff of the option would be 0, and Shipper A would lose P. Carrier B would gain P regardless of what happens, and would lose (ST - K) if ST is greater than K.

The type of option used above is a call option. A call option gives its holder (said to have a long call position) infinite potential profit with a limited loss. The seller of this option (said to have a short call position) gets a guarantee gain with an unbounded loss. The profits and payoffs from buying/selling a call option are shown in Figure 1.2.

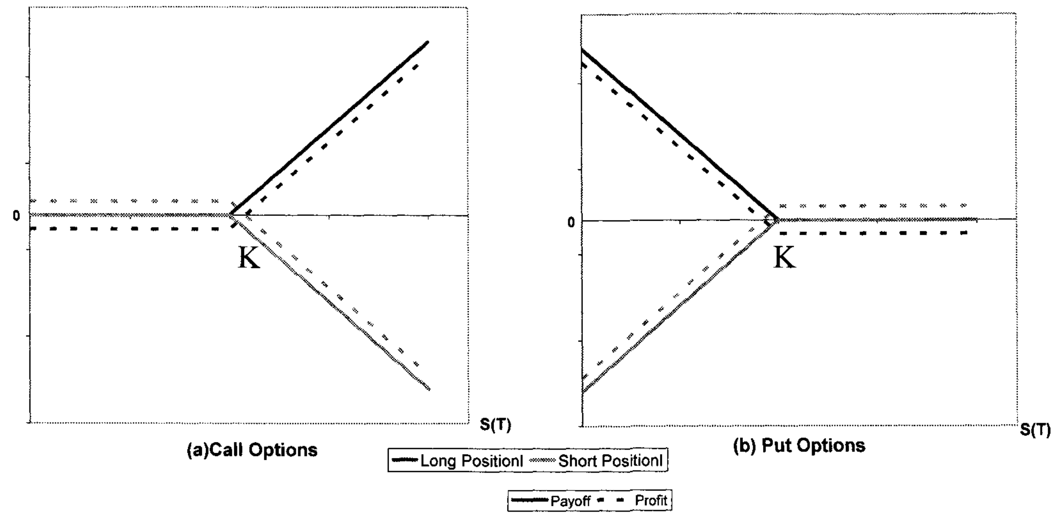


Figure 1.2 Profits and Payoffs from Buying or Selling an Option

This simple example illustrates the basic idea of this research. We propose to apply the theory of real options to hedge trucking capacity and price uncertainty. Currently, while shippers can use auction mechanisms to bid for short term contracts in the spot market, the benefits of these are nowhere near those of obtaining (serviceable) long term contracts. Moreover, auctioning the contract may take considerable time. This time consuming process does not satisfy urgent needs. Therefore, in this project we want to explore how options could help better manage risk for both shippers and carriers.

1.3 Methodology

1.3.1 Modeling Dynamics of TL Rates

From option pricing theory, the fair value of an option is a function of the price of the underlying asset, which in our case is one unit of truckload. Therefore, understanding the price of a truckload is essential to price TL options.

Figure 1.3 presents the monthly percentage change in average truckload rates; it shows that the degree of volatility has increased significantly since the end of 2004. The peak observed in October, 2005 was likely due to Hurricane Katrina, while the June, 2008 peak resulted from a combination of trucking capacity tightness, driver shortages and related pay increases, as well as from high fuel prices.

The trend observed in volatile is expected to continue and possibly even increase because of unstable oil prices resulting from steady world oil demand growth, and the risks of geopolitical instability. Moreover, increasing and uncertain labor costs also contribute to the volatility since the shortage of drivers remains unresolved. We expect, however, that in the future volatility will stabilize to a long-term value, which is consistent with a mean-reverting process. Likewise, we do not expect truckload rates to increase without bound because high truckload rates would attract new transportation capacity, which would have a tendency to depress rates. Finally, we will try to account for the relatively slow pace of change of truckload spot prices. As a starting point, we therefore propose to model TL price dynamics with basic mean reverting processes. We will also explore variations of more elaborate models such Heston (1993) stochastic volatility model. To select between different competing models, we will use financial econometric techniques presented in Campbell, Lo and MacKinlay (1997).

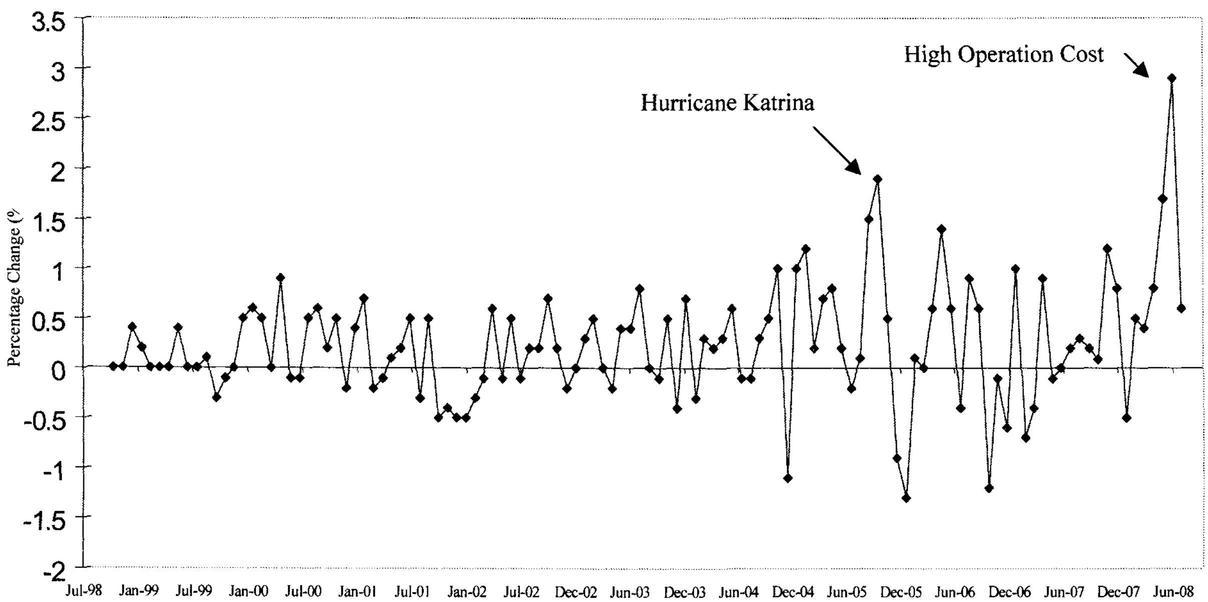


Figure 1.3 Percentage Change in Monthly TL Prices, Nov. 1998 – July 2008

Source: Author's compilation of data from Logistics Management.

1.3.2 Developing TL Options Pricing Formulas

The TL options price clearly depends on how the option can be exercised. Three types of options are commonly used: 1) European options, which can be exercised only at maturity; 2) American options, which can be exercised anytime until they mature (i.e., expire); and 3) Asian Options, (also called average options) whose payoff is linked to the average value of the underlier (here the right to transport a truckload on a specific lane) on a specific set of dates during the life of the option. We will initially investigate TL options prices using European options.

The derivation of the option price from the asset price can be illustrated through a simple example of pricing European call options on stocks. Assume the asset price $X(t)$ follows a geometric Brownian motion $dX(t) = \mu X(t)dt + \sigma X(t)dZ(t)$, where μ is the rate of exponential growth and σ represents by how much the price of X deviates from exponential growth. Let $f(X(t),t)$ designate the value of an option (to buy or sell the asset). To write the evolution of options price, we use Ito's lemma (the equivalent of Taylor's formula in stochastic formula) which gives the differential function of any "smooth" $f(x,t)$ as $df(X(t),t) = \left[\mu X(t)\frac{\partial f}{\partial X} + \frac{\partial f}{\partial t} + \frac{1}{2}\sigma^2 X^2(t)\frac{\partial^2 f}{\partial X^2} \right] dt + \sigma X(t)\frac{\partial f}{\partial X} dZ$.

Next, we construct a self-financing and replicated portfolio $\Pi(t)$ consisting of one option and α units of stocks that will give the same return as the option. The change in the value of this portfolio is given by $d\Pi(t) = df(X(t),t) + \alpha dX(t)$. In an arbitrage-free market, holding this portfolio is the same as having an investment in a bank with an interest rate r. We then equate the return on this portfolio with the return on the option and set $\alpha = -\frac{\partial f}{\partial X}$ to remove the explicit risk. We then obtain the following partial differential equation (PDE) for the option, which is known as the Black-Scholes equation:

$$\frac{\partial f}{\partial t} + \frac{1}{2}\sigma^2 X^2(t)\frac{\partial^2 f}{\partial X^2} - rf + X(t)\frac{\partial f}{\partial X} = 0.$$

The price of a European call option (right to buy the asset) can be obtained by solving this PDE with

$$f(0,t)=0, \quad f(S,t)\rightarrow S \text{ as } S\rightarrow\infty,$$

and

$f(X(T),T)=Max(0,X(T)-K)$, where X(T) is the stock price at maturity and K is the strike price.

1.3.3 Case Studies

For our empirical application, we purchased truckload spot price data for selected lanes (including Los Angeles to Dallas, as well as Laredo to Chicago, etc.) and used econometric tools to estimate the parameters in our pricing model. In fact, a key condition for successful by implementing any option pricing model is to correctly identify the dynamics of the asset price which is the TL rate in our case (Campbell et al., 1997). Accordingly, TL options prices corresponding to different expiration dates and strike prices were obtained.

1.4 Expected Research Outcomes

1. Analysis of the current spot markets for TL and their limitations
2. Understanding the conditions for the emergence of a market for TL options based on other experiences in various transportation industries
3. Introducing innovative procurement contracts for freight transportation

4. Modeling the TL price and deriving the first TL options pricing formula.
5. Providing insights from the empirical examination of the TL options

1.5 Dissertation Organization

This dissertation is organized as follow:

1. Literature review: An extensive review of both academic and industrial literatures is performed. We also review the current state of trucking contracting, application of options contracts in maritime and rail industries, and necessary conditions for the emergence of a market for TL options.
2. Truckload price dynamics models development: Based on the observation of TL prices, candidate models are developed. Applying econometrics tools, a model for TL price dynamics is suggested.
3. Pricing model development: Given the TL price dynamics model, we investigate pricing formulas for TL options for different types of options.
4. Data collection: We obtained data from service providers, collected data from the literature and also requested quotes from trucking companies and trucking associations.
5. Case studies: We applied the developed pricing model to selected lanes as case studies and analyzed the effects of TL options on shippers and carriers.
6. Conclusions and suggestions for future research

CHAPTER 2 LITERATURE REVIEW

2.1 Reviews of Option Theory

The academic literature distinguishes between two types of options: financial options and real options (Mittal, 2004). A financial option is an option on a financial asset, i.e., an asset whose value arises not from its physical embodiment (such as a building, a piece of land, or capital equipment) but from a contractual relationship (examples: stocks, bonds, bank deposits, or currency). By contrast, a real option is an option on a physical (as opposed to a financial) asset, such as commodities, buildings, plant, and equipment (Hull, 2006).

Since this research studies a particular financial instrument, a truck option, that deals with the trucking rate in a similar manner to a stock option, the literature review starts with financial options.

2.1.1 Overview

An option is a legal document that gives the buyer a right to buy or sell something at the predetermined price on or before a predetermined date. There two basic types of options, a call option and a put option. A call option gives the holder of the option the right to buy the underlying asset by a given date for a given price. A put option, by contrast, gives the seller the right to sell the underlying asset by a given date for a given price. 'A given date' is referred to as the expiration date or the maturity date, while 'a given price' is known as a strike price or an exercise price. Options can be American or European. American options can be exercised anytime up to the expiration date whereas European options can be exercised only on the expiration date. There are two sides to an option contract. On one side is the investor who has taken a long position, i.e. who has bought the option. On the other side is the investor who has taken a short position, i.e. who has sold the option. We must emphasize here that either type of option gives the *right* instead of the *obligation* to do something. So the payoffs for European option positions are as below, where K is the strike price and S_T is the final price of the underlying asset (Hull, 2006):

- A long position in a call: payoff = max (ST - K, 0);
- A short position in a call: payoff = - max (ST - K, 0) = min (K - ST, 0);
- A long position in a put: payoff = max (K - ST, 0); and
- A short position in a put: payoff = - max (K - ST, 0) = min (ST - K, 0).

The options we have discussed so far are referred to as "vanilla options." Options where the payoff is calculated differently are categorized as "exotic options." Exotic options can pose challenging problems in valuation and hedging. An example of exotic option is an Asian option (Wilmott et al., 1995).

Asian options appeared in financial markets at the end of the 1980s. An Asian option is an option where the payoff is not determined by the underlying price at maturity but by the average underlying price over some prescribed period of time. The average price can be either geometric or arithmetic averaging, shown as equations (2.1) and (2.2), respectively.

$$\frac{1}{t}\int_{0}^{t} S(\tau)d\tau \tag{2.1}$$

$$\exp\left(\frac{1}{t}\int_{0}^{t} \ln S(\tau)d\tau\right) \tag{2.2}$$

There are two basic forms. If the strike price of vanilla option is replaced by the average price, then this type Asian option is called an average strike option. If the asset price at maturity is replaced by the average price, then the Asian option is an average rate option. An Asian option can be European or American, although it is generally European. For an average strike option, the strike price is payoffs of European style and American style are shown as equations (2.3) and (2.4), respectively. For an average rate option, the payoffs of European style and American style are shown as equations (2.5) and (2.6), respectively.

$$Max[S - \frac{1}{T}\int_{0}^{T} S(\tau)d\tau, 0] \tag{2.3}$$

$$Max[S - \frac{1}{t}\int_{0}^{t} S(\tau)d\tau, 0] \tag{2.4}$$

$$Max[\frac{1}{T}\int_{0}^{t} S(\tau)d\tau - K, 0] \tag{2.5}$$

$$Max[\frac{1}{t}\int_{0}^{t} S(\tau)d\tau - K, 0] \tag{2.6}$$

Asian options are attractive in currency and commodity markets. One reason is that the price of an Asian option is cheaper than a European option, since the volatility in the average value of the underlying asset tends to be lower than the volatility of the value. Another reason is that, in practice, many indexes are given as arithmetic averages of the underlying spot price. Generally, wherever the underlying asset is thinly traded or there is potential for price manipulation, Asian options are preferred.

To compare an Asian option and a vanilla option, a simple example of the Asian call option (an average rate option) and the European call option with the same strike price and the same maturity date is given as following (Geman, 2005). Suppose the stock prices are \$80, \$60, and \$40 at t1, t2, and t3, respectively. The strike price is \$40 and the expiration is at t3. For an Asian option, the payoff is the maximum of 0 and the difference between the average price of the last two stock prices and the strike price. In this case, it is \$10. For a European Call option, the payoff is the maximum of 0 and the difference between the stock price at expiration and the strike price, which is 0 in this case. Therefore, the payoff of an Asian Call option is higher than that of a similar European Call option.

$$S(t_1) = 80, S(t_2) = 60, S(t_3) = 40$$

$$E = 40$$

$$\text{Payoff (A)} = Max(0, \frac{40+60}{2} - 40) = 10$$

$$\text{Payoff (E)} = Max(0, 40 - 40) = 0.$$

However, if the stock prices are increasing, i.e. $S(t_1) = 40, S(t_2) = 60, S(t_3) = 80$, and the strike price remains \$40, then

$$\text{Payoff (A)} = Max(0, \frac{80+60}{2} - 40) = 30$$

$$\text{Payoff (E)} = Max(0, 80 - 40) = 40.$$

In this situation, the payoff of the European Call, which is \$40, is higher than that of the Asian Call, which is \$30.

2.1.2 Stochastic Processes and Ito's Lemma

Before moving to options pricing models, we first review stochastic processes and Ito's Lemma (Dixit and Pindyck, 1994); both are essential parts of pricing models.

2.1.2.1 Generalized Brownian Motion

To describe its evolution, an asset price is modeled as a random variable. A generalized Brownian motion given by equation (2.7) is commonly used to model stochastic variables.

$$dX = a(X,t)dt + b(X,t)dZ \tag{2.7}$$

In equation (2.7), $a(X,t)$ and $b(X,t)$ are known (nonrandom) functions which are typically assumed to be continuous. And dZ is an increment of a Wiener process, shown as equation (2.8).

$$dZ = \mathrm{E}_t \sqrt{dt} \tag{2.8}$$

where E_t is a random variable with a standard normal distribution, i.e. $\mathrm{E}_t \sim N(0,1)$. Accordingly, dZ is normally distributed with a mean of 0 and a standard deviation of $\sqrt{dt}$. And $\frac{dZ}{dt} = \mathrm{E}_t (dt)^{-\frac{1}{2}}$ which means that dZ goes to infinity as dt approaches to 0.

Two important special cases of the generalized Brownian motion are the geometric Brownian motion, and the mean-reverting process. In the geometric Brownian motion, $a(X,t) = \alpha X$, and $b(X,t) = \sigma X$, where α and σ are constants. So the geometric Brownian motion (GBM) is given by

$$dX = \alpha X dt + \sigma X dZ. \tag{2.9}$$

The GBM is frequently used to model securities prices, wage rates, and other economic and financial variables. It is attractive because it often yields close form solutions in simple pricing problems. Dixit and Pindyck (1994) observe the sample paths of BM and GBM and indicate that "Brownian motions tend to wander far from their starting point." However, if a variable fluctuates up and down, but tends to go back to a set level, then it is better modeled by a mean-reverting process.

The simplest mean-reverting process is the Ornstein-Uhlenbeck process:

$$dX = \eta(\bar{x} - X)dt + \sigma dZ \, , \tag{2.10}$$

where η is the speed of reversion, $\bar{x}$ is the "normal" level of X, and σ is the volatility parameter.

2.1.2.2 Ito's Lemma

The value of an option is some function of the asset price. To write the equation that defines the function of a random variable, we need a mathematical tool known as Ito's lemma. Consider a "smooth" function $f(x,t)$. First recall from the Taylor series expansion for the function $f(x,t)$.

$$f(x,t) - f(x_0,t_0) \approx$$

$$\frac{\partial f}{\partial x}(x-x_0) + \frac{\partial f}{\partial t}(t-t_0) + \frac{1}{2!}\frac{\partial^2 f}{\partial x^2}(x-x_0)^2 + \frac{\partial^2 f}{\partial x \partial t}(x-x_0)(t-t_0) + \frac{1}{2!}\frac{\partial^2 f}{\partial t^2}(t-t_0)^2$$

which leads to

$$df(x,t) \approx \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial t}dt + \frac{1}{2!}\frac{\partial^2 f}{\partial x^2}(dx)^2 + \frac{\partial^2 f}{\partial x \partial t}dxdt + \frac{1}{2!}\frac{\partial^2 f}{\partial t^2}(dt)^2 .$$

We ignore that the terms go to zero faster than dt, such as $(dt)^2$ and $(dt)^{\frac{3}{2}}$. Hence Ito's Lemma gives the differential $df(x,t)$ as

$$df(x,t) \approx \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial t}dt + \frac{1}{2}\frac{\partial^2 f}{\partial x^2}(dx)^2 . \tag{2.11}$$

Ito's Lemma for generalized Brownian motion dX given as equation (2.7) is

$$df(X,t) \approx \left[a(X,t)\frac{\partial f}{\partial X} + \frac{\partial f}{\partial t} + \frac{1}{2}b^2(X,t)\frac{\partial^2 f}{\partial X^2} \right]dt + b(X,t)\frac{\partial f}{\partial X}dZ . \tag{2.12}$$

2.1.3 Option Pricing Models

The option pricing theory has been studied extensively since the ground-breaking paper by Fischer Black and Myron Scholes (1973).

2.1.3.1 Black-Scholes Pricing Model

In deriving the valuation formula of an option in terms of the price of the stock, Black and Scholes make the following assumptions:

(a) The interest rate is constant.

(b) The distribution of stock prices is log-normal.

(c) No dividends.

(d) The option is European.

(e) No transaction costs.

(f) It is possible to borrow and lend cash at a constant interest rate.

(g) There are no penalties for short sale.

Five variables in the valuation formula are

(a) the price of the stock, S

(b) the variance of the price of the stock, σ2

(c) the strike price, K

(d) the risk-free interest rate, r

(e) the time to maturity, T

Let us assume that the underlying stock price is continuous and follows a GBM with constant drift rate, μ, and constant variance rate, σ. If f is the price of a call option on S, then

$$df = (\frac{\partial f}{\partial S}\mu S + \frac{\partial f}{\partial t} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)dt + \frac{\partial f}{\partial S}\sigma S dz . \tag{2.13}$$

At equilibrium, the drift rate is the risk-free interest rate, which results in the Black-Scholes differential equation:

$$\frac{\partial f}{\partial t} + rS\frac{\partial f}{\partial s} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2 = rf . \tag{2.14}$$

Solving the differential equation at the boundary conditions, the Black-Scholes pricing formulas for a call option and a put option are shown as equation (2.15) and (2.16), respectively.

$$c = S_0 N(d_1) - Ke^{-rT} N(d_2) \tag{2.15}$$

$$p = Ke^{-rT}N(-d_2) - S_0N(-d_1) \tag{2.16}$$

where $d_1 = \dfrac{\ln\left(\dfrac{S_0}{K}\right) + (r + \dfrac{\sigma^2}{2})T}{\sigma\sqrt{T}}$ and $d_2 = \dfrac{\ln\left(\dfrac{S_0}{K}\right) + (r - \dfrac{\sigma^2}{2})T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$ (Hull, 2006),

and N(x) is the cumulative probability distribution of a standardized normal distribution.

Option pricing theory has been extended to value many other assets. Since in many cases, options are traded on commodities contracts, Black (1976) applied his model to valuate commodity options. He created a riskless hedge by taking a long position in the option and a short position in the futures contract with the same transaction date. The procedure of deriving a pricing formula for a commodity option is similar to that for a stock option, except the value of a stock is positive, while the value of a futures contract is zero because a futures contract is rewritten every day at a new price. The pricing of a commodity option is given by equations (2.17) and (2.18).

$$c = e^{-rT}[S_0N(d_1) - KN(d_2)] \tag{2.17}$$

$$p = e^{-rT}[KN(-d_2) - S_0N(-d_1)] \tag{2.18}$$

where now $d_1 = \dfrac{\ln\left(\dfrac{S_0}{K}\right) + \dfrac{\sigma^2 T}{2}}{\sigma\sqrt{T}}$ and $d_2 = \dfrac{\ln\left(\dfrac{S_0}{K}\right) - \dfrac{\sigma^2 T}{2}}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$ (Hull, 2006).

Black-Scholes pricing model is applicable to European options. Next, we are going to review a model that is widely used to model American options.

2.1.3.2 Binomial option pricing model

Cox, Ross, and Rubinstein (1979) first proposed a simplified approach for options pricing, which is known as the binomial option pricing model. Contrary to the Black-Scholes pricing model, the binomial option pricing model valuates options on a discrete-time base. They assume:

(a) The interest rate is constant.

(b) The stock prices follow a multiplicative binomial process.

(c) No dividends.

(d) No taxes, no transaction costs, or margin requirements.

(e) It is possible to borrow and lend cash at a constant interest rate.

(f) There are no penalties for short sale.

(g) Arbitrage opportunities do not exist.

Five variables in the valuation formula are

(a) the price of the stock, S

(b) the movement parameters of the price of the stock, u when the price moves up, and d when the price moves down

(c) the strike price, K

(d) the risk-free interest rate, r

(e) the length of the time step, Δt

If the current price of the stock is S_0, then in next period the price will be

$$
S_0 \begin{cases} S_{up} = uS_0 & \text{with probability } q \\ S_{down} = dS_0 & \text{with probability } 1\text{-}q \end{cases}
$$

Expanding the one-step binomial tree structure, the call option price for a multi-step binomial model at each node is

$$C_{t-1,i} = e^{-r\Delta t}[pC_{t,i} + (1-p)C_{t,i+1}] \tag{2.19}$$

where $C_{t,i}$ is the call option price for the ith node at time step t, and $p = \dfrac{e^{r\Delta t} - d}{u - d}$.

Due to the assumption of the absence of arbitrage opportunities, the inequality d<(1+ r)<u must hold. Since the option price for each node can be obtained, the binomial option pricing model is not only good for valuating European options, but also for American options. In addition, as the number of time steps increases, so does the accuracy of option prices. In fact, for European options, the binomial model converges to the Black-Scholes model when the number of time steps increases. Let us now review how option theory was applied to transportation.

2.2 Applications of Option Theory in Transportation

2.2.1 Options in the Maritime Industry

Shipping markets can be characterized as capital intensive, cyclical, volatile, seasonal and exposed to the international business environment. The parties involved in the market, ship owners, charterers, and shipbrokers, all face significant risks. Therefore, risk management in shipping has been critical for a long time. Freight derivatives contracts are popular and effective tools for hedging freight rates in the shipping industry.

To date, ocean transportation is the only area of transportation where a contract of options, also known as a derivatives contract, has been applied. In this section, the practice of derivative contracts markets in the maritime industry is reviewed, and pricing models applied in this industry follow.

2.2.1.1 Derivatives Contracts Markets in the Maritime Industry

Kavussanos and Visvikis (2006) survey the recent evidence of the shipping freight derivatives. Since the Baltic International Freight Futures Exchange (BIFFEX) was established in 1985, the shipping freight derivatives have been commonly used to manage risk. There are different types of freight derivatives including forward freight agreements (FFAs), freight futures, and freight options. FFA is a contract between a seller and a buyer to settle a freight rate for a specified quantity and route over a defined future period. Freight futures are traded in an organized exchange, such as the International Maritime Exchange (IMAREX) and the New York Mercantile Exchange (NYMEX). Freight options were introduced in 1991 with European options contracts on Baltic Freight Index (BFI). They traded at London International Financial Futures and Options Exchange (LIFFE), but they ceased to trade due to insufficient trading volume in April 2002. Instead, freight options with Asian options contracts where the payoffs are determined by the average underlying price over a period of time, on individual routes have been launched.

2.2.1.1.1 Past Derivatives Markets

The Baltic International Freight Futures Exchange (BIFFEX), a London-based exchange for trading ocean freight futures contracts with settlement based on the Baltic Freight Index (BFI), was the world's first freight futures market. At the beginning, BIFFEX worked well. However, trading volumes began to fall in 1989 (see Figure 2.1). In 1992, the appearance of new contracts, namely freight options on BFI, over-the-counter forward freight agreements (FFAs) etc, led to an increase in BIFFEX trading for a couple of years. Eventually, though market agents switched completely to FFAs and the volume of trading on BIFFEX steadily declined until the contracts ceased to exist in 2002.

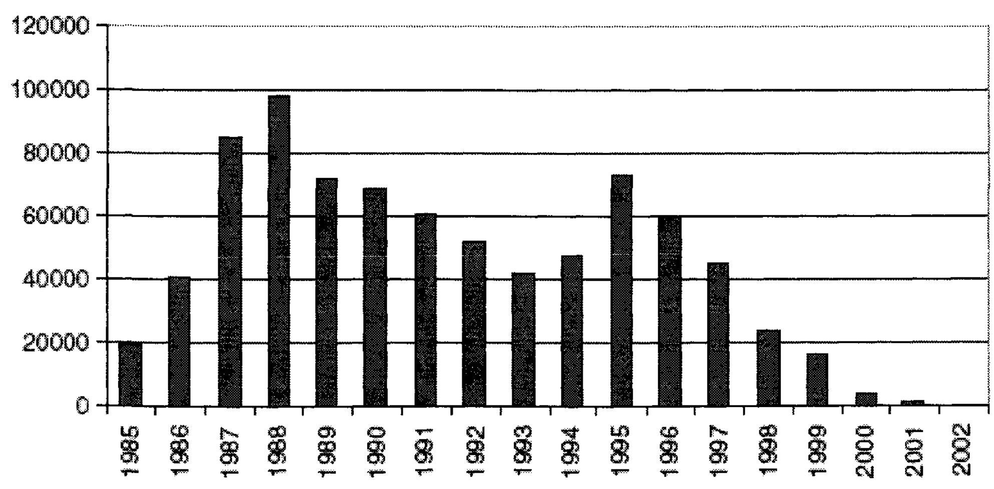


Figure 2.1 Yearly Volumes of the BIFFEX Contracts (May 1985 – April 2002)
Source: Kavussanos and Visvikis (2006)

The termination of BIFFEX was mainly due to low liquidity (Koekebakker and Adland, 2004) due to the poor hedging performance of BIFFEX contracts (Kavussanos and Nomikos 2000, Dalheim 2002, Haigh and Holt 2002, Kavussanos and Visvikis 2006). The underlying asset of BIFFEX contracts, the Baltic Freight Index (BFI), is a weighted average of the spot prices from 11 shipping routes. Dalheim (2002) argues that the weighting and composition of the index changed over the years. If a market player wants to hedge his particular freight rate risk during the transportation of a specific commodity on a specific route, then a derivative written on a weighted price index of other routes and commodities may not be a good hedging instrument. The two risks may not be strongly correlated. Kavussanos and Nomikos (2000) point out that the routes included in the BFI were diverse in terms of cargoes, vessel sizes etc, which implies cross-hedging. Consequently, BIFFEX contracts did not perform well as hedging instruments. They were much less effective in eliminating spot market risk (4-19%) than contracts in other commodity and financial futures markets (98%). Most market agents work on specific routes, so they demand contracts tailored to their specific needs. Hedging performance is improved if contracts are based on an individual route rather than on an underlying index. It is therefore not surprising that FFA contracts, which trade on specific routes rather than on the entire index, have become popular.

2.2.1.1.2 Current Derivatives Markets

Even though BIFFEX ceased to trade in 2002 due to low liquidity, the hedging function of freight derivatives contracts is regarded positively by many in this industry. Different types of contracts have been launched since 1995, and FFAs, Futures, and Options are currently available for trading. The Baltic Exchange, NYMEX, and IMAREX are the three main market places for these contracts. Each has specific products and trading rules, but their common characteristic is increasing trading volumes.

1. The Baltic Exchange

The Baltic Exchange provides daily freight market prices, maritime shipping cost indices, and a market for FFAs. Based on market segmentation, the principal daily indices it publishes are the Baltic Panamax Index (BPI), the Baltic Capesize Index (BCI), the Baltic Supramax Index (BSI), the Baltic Exchange Dirty Tanker Index (BDTI) and the Baltic Exchange Clean Tanker Index (BCTI) (Baltic Exchange, 2007). Each index has a specific composition. For instance, the composition of BPI is shown in Table 2.1.

Table 2.1 Baltic Panamax Index (BPI) Composition, 2006.

Routes	Vessel size (dwt)	Cargo	Route description	Weights
P1	55,000	Light grain	1–2 safe berths/anchorages US Gulf (Mississippi River not above Baton Rouge) to ARA	10%
P1A	74,000	T/C	Transatlantic (including east coast of South America) round of 45/60 days on the basis of delivery and redelivery Skaw–Gibraltar range	20%
P2	54,000	HSS	1–2 safe berths/anchorages US Gulf (Mississippi River not above Baton Rouge)/1 no combo port to South Japan	12.5%
P2A	74,000	T/C	Basis delivery Skaw–Gibraltar range, for a trip to the Far East, redelivery Taiwan-Japan range, duration 60–65 days	12.5%
P3	54,000	HSS	1 port US North Pacific/1 no combo port to South Japan	10%
P3A	74,000	T/C	Transpacific round of 35/50 days either via Australia or Pacific (but not including short rounds such as Vostochy (Russia)/Japan), delivery and redelivery Japan/South Korea range	20%
P4	74,000	T/C	Delivery Japan/South Korea range for a trip via US West Coast—British Columbia range, redelivery Skaw–Gibraltar range, duration 50/60 days	15%

Source: Kavussanos and Visvikis (2006)

In light of the BIFFEX experience, the underlying asset of an FFA is the market rate of a specific route or an index of a small basket of routes. This is an improvement over the hedging performance of BIFFEX instruments. As a result, trading volumes have steadily increased (see Figure 2.2).

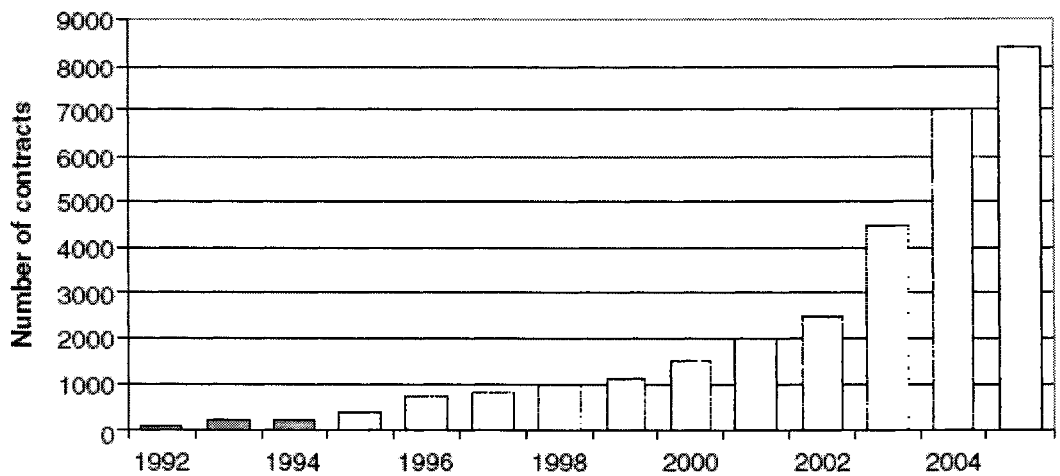


Figure 2.2 Yearly Volumes of Dry-Bulk FFA Contracts (Jan. 1992 – Sept. 2005)
Source: Kavussanos and Visvikis (2006)

2. New York Mercantile Exchange (NYMEX)

NYMEX provides a flexible, internet-based system of trading and clearing freight Futures. Currently, nine tanker routes are available for trading. Each freight futures contract may be listed for up to 36 consecutive months forward, depending on demand. The trading unit is 1,000 metric tons. Trading ceases on the last business day of the contract month. The price for each contract month equals the arithmetic average of the rates for each business day as published either by the Baltic Exchange or by Platts Oilgram Price Report for the corresponding route. Details are summarized in Table 2.2.

Table 2.2 NYMEX Freight Futures

Route Description	Price Index
TC1 Ras Tanura to Yokohama for 75,000 metric tons	Platts
TC2 Rotterdam to USAC for 37,000 metric tons	Baltic
TC4 Singapore to Japan for 30,000 metric tons	Platts
TC5 Ras Tanura to Yokohama for 55,000 metric tons	Platts
TD3 Middle Eastern Gulf to Japan for 250,000 metric tons	Baltic
TD5 West Africa to U.S. Atlantic for 130,000 metric tons	Baltic
TD7 North Sea to Europe for 80,000 metric tons	Baltic
TD9 Caribbean to U.S. Gulf for 70,000 metric tons	Baltic
TD10D Caribbean to U.S. Atlantic Coast for 50,000 metric tons	Baltic

Source: NYMEX (2007)

Figure 2.3 illustrates numerically how to hedge freight rates using NYMEX Futures. Assume a charterer needs to ship 10,000 metric tons (mt) from Europe to the U.S. Atlantic Coast in October, 2007. On June 25, the freight rate for the TC2 tanker route in the physical market is $30.5457/mt, and the contract price of for this route in the October 2007 Futures is $25.2241/mt (see Table 2.3 for the settlement (closing price) for this route). In order to lock the freight rate at $25.2241/mt, she buys 10 units (i.e., 10,000 mt) of October Futures. Suppose that the settlement of October Futures, which is the average of the rates for each business day within October, is $26.5328/mt, while the actual freight rate in the physical market is $26.5973/mt. Then the charterer gains $13,087 = ((26.5328- 25.2241) * 10,000) from the Futures market and she pays $265,937 = (26.5973 * 10,000) to the physical market. Finally, the realized shipping cost is $256,283 or $25.6283/mt. Note that it is slightly higher than her expected rate, $25.2241, because the settlement of the Futures is an average of the rates instead of the spot rate.

On the other hand, in a falling market, if the spot rate and the settlement are $23.5937 and $23.5328 respectively, then the charterer has to pay $16.913 (= (23.5328-

23.5937)*10000). As a result, the final cost for shipping is $252,825 or $25.2825/mt which is higher than the spot rate.

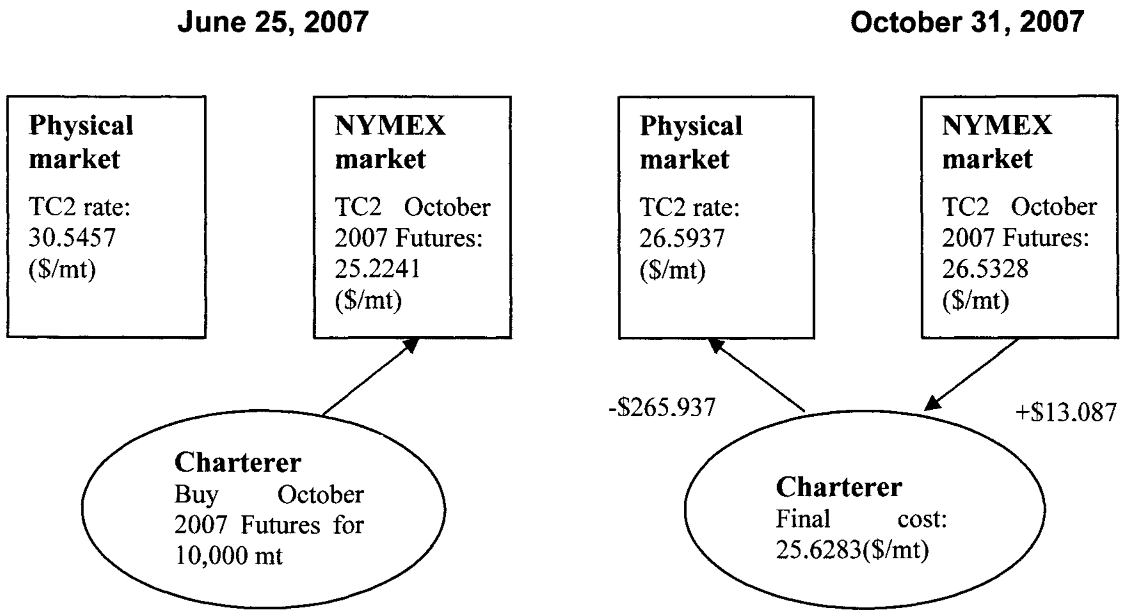
Table 2.3 Settlement (closing price) of TC2 Rotterdam to USAC 37k ($/mt)

Contract	June 25	June 22	June 21
June 2007	30.5457	29.3466	31.1746
July 2007	24.4265	24.6259	24.6259
August 2007	25.7226	25.5232	25.5232
September 2007	25.5232	25.2241	25.5232
October 2007	25.2241	25.1244	25.2241

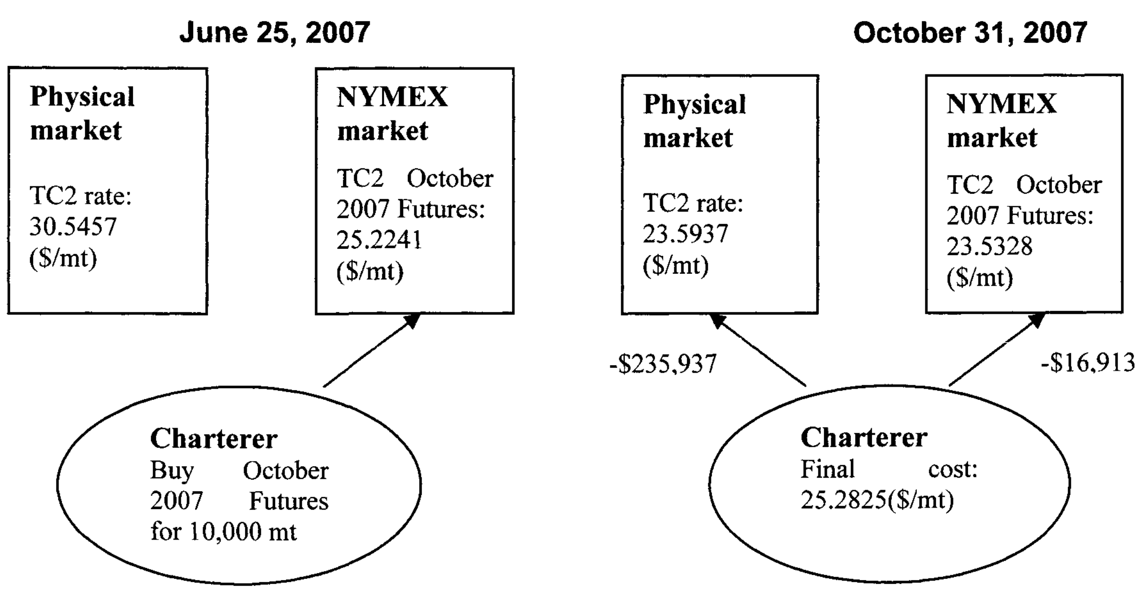
Source: NYMEX (2007)

3. International Maritime Exchange (IMAREX)

IMAREX is a market offering FFAs, freight futures as well as freight options trading in both the tanker market and the dry bulk market, while NYMEX only offers freight futures trading in the tanker market. The value of dry freight derivatives trading on IMAREX in June grew 376 percent from a year earlier to a record $776 million (Ambrogi, 2007). Each contract can be traded monthly, quarterly, or yearly. The last trading day is the 20th day of a given month, the last day of the first month of a quarter and the last day of the first month of a year for monthly contracts, quarterly contracts, and yearly contracts, respectively. The settlement of each contract is the average of the spot prices over the given period. Table 2.4 shows the tanker and dry bulk FAAs and freight futures available traded at IMAREX, respectively.



Panel (a): Rising price scenario



Panel (b): Falling price scenario

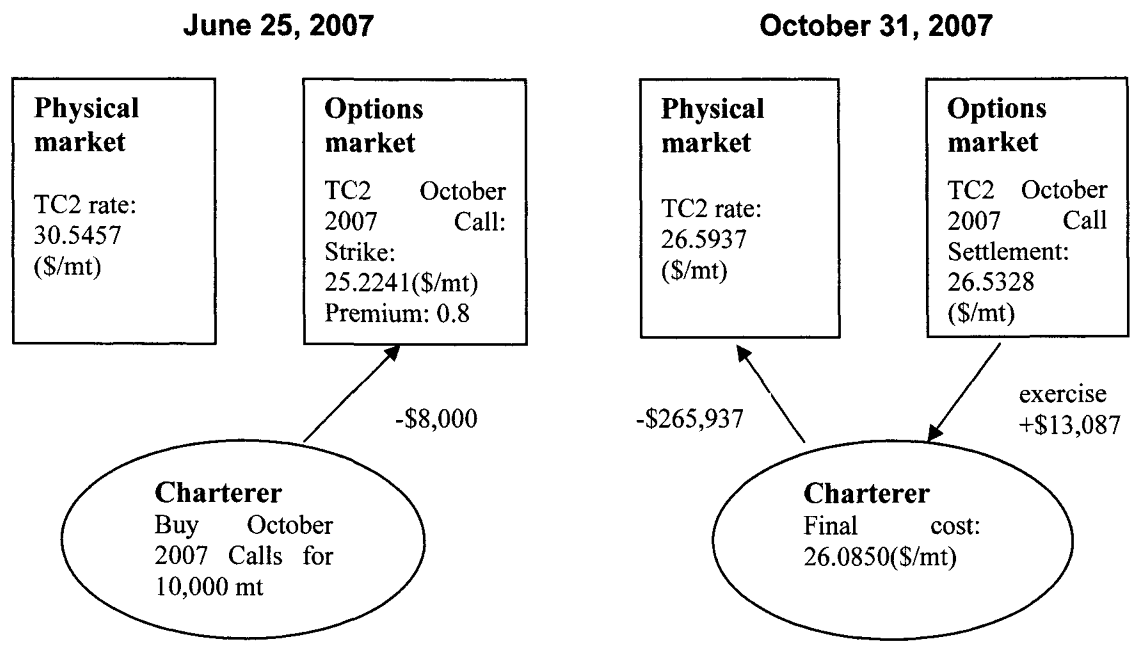
Figure 2.3 An Example of Hedging Freight Rate Using NYMEX Futures

Table 2.4 IMAREX Tanker FFAs and Freight Futures

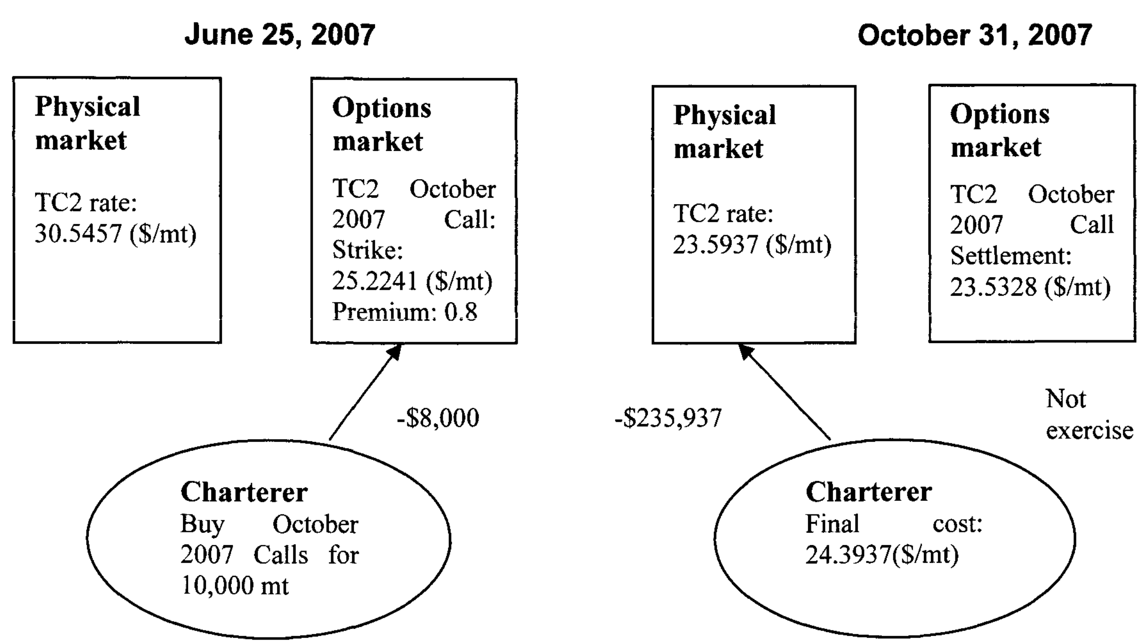
Tanker		Dry Bulk	
Route	Price Index	Route	Price Index
TC1 Ras Tanura to Chiba, 75,000 metric tons	Platts	**C4** Richards Bay to Rotterdam, 150,000 metric tons	Baltic
TC2 Rotterdam to New York, 37,000 metric tons	Baltic	**C7** Bolivar Roads to Rotterdam, 150,000 metric tons	Baltic
TC4 Singapore to Chiba, 30,000 metric tons	Platts	**CS4TC** Combination of C8 (Gibraltar to Hamburg, 172,000 mt) C9 (Continent to Mediterranean, 172,000 mt) C10 (Pacific RV, 172,000 mt) C11 (China to Japan, 172,000 mt)	Baltic
TC5 Ras Tanura to Chiba, 55,000 metric tons	Platts		
TC6 Skikda to Lavera, 30,000 metric tons	Baltic		
TD3 Ras Tanura to Chiba, 260,000 metric tons	Baltic	**P2A** Skaw Gibraltar to Far East	Baltic
TD4 Bonny to Loop, 260,000 metric tons	Baltic	**P3A** S. Korea to Japan	Baltic
TD5 Bonny to Philadelphia, 130,000 metric tons	Baltic	**PM4TC** Combination of P1A (Transatlantic RV, 74,000 mt) P2A (SKAW to Far East, 74,000 mt) P3A (Japan to Pacific, 74,000 mt) P4 (Far East to Nopac, 74,000 mt)	Baltic
TD7 Sullom Voe to Wihelmshaven, 80,000 metric tons	Baltic		
TD8 Mina al Ahmadi to Singapore, 80,000 metric tons	Baltic	**SM6TC** Combination of S1A (Antwerp to SKAW Trip Far East) S1B (Canakkale Trip Far East) S2 (Japan via S. Korea to Australia) S3 (Japan via S. Korea to SKAW range) S4 (US Gulf via SKAW to Passero) S4B (Passero via SKAW to US Gulf)	Baltic
TD9 Puerto La Cruz to Corpus Christi, 70,000 metric tons	Baltic		
TD12 Antwerp to Houston, 55,000 metric tons	Baltic		

Source: IMAREX (2007)

Freight options traded at IMAREX give the holder the right to buy or sell an FFA at a predetermined price. They are either over the counter (OTC) or are cleared at the clearinghouse (the Norwegian Futures and Options Clearinghouse for the international commodities markets known as NOS) by paying a fee equal to 1.25% of the option premium. Following the example of futures, Figure 2.4 illustrates how to hedging freight rate using freight options.



Panel (a): Rising price scenario



Panel (b): Falling price scenario

Figure 2.4 An Example of Hedging Freight Rate Using Options

Assume the strike price of TC2 October 2007 Options is $25.2241/mt and the premium (the price of options) is $0.8/mt. To hedge the freight rate, the charterer pays $8,000 to buy the October options for shipping 10,000 mt. Suppose that the settlement of October Options, which is the average of the rates for each business day within October, is $26.5328/mt, while the actual freight rate in the physical market is $26.5973/mt. Since the spot rate is higher than the strike price ($26.5937>$25.2241), the charterer exercises her options. She gains $13,087 (=(26.5328-25.2241)*10,000) from the Options market while she pays $265,937 (= 26.5973*10,000) to the physical market. Taking the cost of Options into account, the actual shipping cost is $260,850 or $26.085/mt. Obviously, under those prices, Options have less hedging ability than Futures because of the premium charged.

However, if market prices are falling so that the spot rate and the settlement are respectively $23.5937 and $23.5328, then the charterer does not exercise her options because the spot rate is lower than the strike price ($23.5937 < $25.2241). Consequently, she does not need to pay anything to the Options market, while in the Futures case, she would pay $16.913 = ((23.5328-23.5937)*10000). With the premium, her final shipping cost is $243,937 or $24.3937/mt, which is lower than the spot rate. In this scenario, Options show their strength over Futures. Consequently, with corresponding hedging ability and risk exposure, it is hard to say which kind of derivatives contracts is best. The choice of derivatives depends on the users' specific needs and their perception of the future markets.

2.2.1.2 Option Pricing Models in the Maritime Industry

For the freight options on BFI, Tvedt (1998) argues that the Black-Scholes formula adopted by practitioners is not appropriate. Thus, Tvedt develops a pricing formula for these options based on their characteristics. First, as observed, the BFI fluctuated between 553.5 and 2000 from 1986 to 1995. It is reasonable. When the freight rate is high, more ships enter the business, but the demand for shipping goes down. As a result, the freight rate decreases. In the long run, the freight rate tends to revert. Therefore, the index most probably does not follow a geometric Brownian motion, but a mean reversion process. Second, the lay-up level of vessels should be taken into account. When freight rates are too low to cover variable sailing costs, a ship owner may consider mothballing his vessel. Assuming the index less the absorbing level is log-normally distributed, the increment of the index could be given by

$$dX_t = k(\alpha - \ln(X_t - \lambda))(X_t - \lambda)dt + \sigma(X_t - \lambda)dZ_t \qquad (2.20)$$

where X_t is the index value at time t; λ is an absorbing level; dZ_t is the increment of a standard Brownian motion; k is the "speed of the adjustment" parameter; α is a "level" parameter; and σ is the standard derivation of X_t.

Accordingly, Tvedt derives a pricing formula for a call option as:

$$C_t = e^{-r(\tau-t)}\{(\Phi_t - \lambda)N(d_1) - (\Psi - \lambda)N(d_2)\} \qquad (2.21)$$

where $d_1 = \dfrac{\ln\left(\dfrac{\Phi_t - \lambda}{\Psi - \lambda}\right) + 1/2e^{-2k(T-\tau)}\sigma^2(\tau - t)}{e^{-k(T-\tau)}\sigma\sqrt{(\tau - t)}}$ and $d_2 = \dfrac{\ln\left(\dfrac{\Phi_t - \lambda}{\Psi - \lambda}\right) - 1/2e^{-2k(T-\tau)}\sigma^2(\tau - t)}{e^{-k(T-\tau)}\sigma\sqrt{(\tau - t)}}$.

In the above, r is a constant risk-free interest rate; τ is the settlement date; Φ_t is the futures price at time t; Ψ is the exercise value; and N(x) is the standard cumulative normal distribution function.

In addition, Tvedt suggests a possible improvement to equation (2.20) such that the seasonal fluctuation could be considered. The improvement includes a sine term and is shown as equation (2.22).

$$dX_t = k(\alpha + \varphi \sin(\gamma t + \theta) - \ln(X_t - \lambda))(X_t - \lambda)dt + \sigma(X_t - \lambda)dZ_t \qquad (2.22)$$

where φ, γ, and θ are new parameters.

More recently, Koekebakker et al. (2007) value the current traded freight options with Asian options contracts, which settle the difference between the average spot freight rate over a defined period of time and an agreed strike price. They model the freight rate options conditional on the observed freight forward curve and its volatility, rather than on the spot rate. Assuming spot and forward prices are log-normally distributed, and spot freight rates follow a geometric Brownian motion, the dynamics of the freight forward price is derived as:

$$\frac{dF(t,T_1,T_N)}{F(t,T_1,T_N)} = \sigma(t)dW^Q(t) \qquad (2.23)$$

where $\sigma(t)=\begin{cases} \sigma & t \le T_1 \\ \sigma \cdot \dfrac{\dfrac{S_t}{N}\sum\limits_{i=M+1}^{N} e^{\lambda(T_i-t)}}{F(t,T_1,T_N)} & T_M < t < T_{M+1}, M=1,2\ldots,N-1 \end{cases}$

In the above: $F(t,T_1,T_N)$ is the freight forward price in the period [t, TN];

$W^Q(t)$ is the Brownian motion under the risk-neutral measure;

λ is the risk neutral freight rate drift; and

S_t is the freight spot price at time t.

The freight option pricing for a call option, therefore, is

$$C(t,T_N)=e^{-r(T_N-t)}D(F(t,T_1,T_N)\phi(d_1)-K\phi(d_2)) \qquad (2.24)$$

where
$$d_1=\frac{\ln\left[\dfrac{F(t,T_1,T_N)}{K}\right]+\dfrac{1}{2}\sigma_F^2}{\sigma_F},$$

$$d_2=d_1-\sigma_F$$

$$\sigma_F^2=(T_1-t)\sigma^2+\frac{1}{3}(T_N-t)\sigma^2$$

D is a constant;

K is the strike price; and

ø(x) is the standard cumulative normal distribution function.

Compared to the results generated by a Monte Carlo simulation experiment, Koekebakker et al. conclude that their proposed pricing formula gives quite accurate prices.

2.2.2 Options in the Rail Industry

After reviewing the deregulated rail industry in North America, Law et al. (2003) indicate that the rail capacity auction contracts used in the current market have little or no competition. Those auction programs ask bidders bid 6 months ahead and the auctions are held monthly or bi-weekly. Though the capacity won could be sold in the second market, bidders are still under risks of paying more than the realized demand. In order to help the rail industry become more competitive, they suggest a new pricing mechanism, a call option contract, which is derived from the theory of financial options.

The underlying asset is freight capacity and the rail car is as the unit of capacity to be traded in the market. A multi-step binomial pricing model is applied (see Figure 2.5). Under the assumptions of knowing the price of a car capacity, the maturity date of the option and its exercise price, the price for a call option is obtained.

Data from two rail corridors for transporting coal during 1997 and 1998 are chosen as a case study. One is from Lincoln, Nebraska to Corpus Christi, Texas, and the other is from West Virginia to the state of New York. Law et al. adopt the historical price volatility in the 50-step binomial pricing model and outline the call option prices with different issue dates, maturity and strike prices as Table 2.5. Due to the insufficient price volatility, about one third of options are without value. However, they expect to see increased uncertainty in the prices once the market for rail capacity is completely deregulated. They further conclude that the growth of such market will accelerate and that this growth is a favorable outcome.

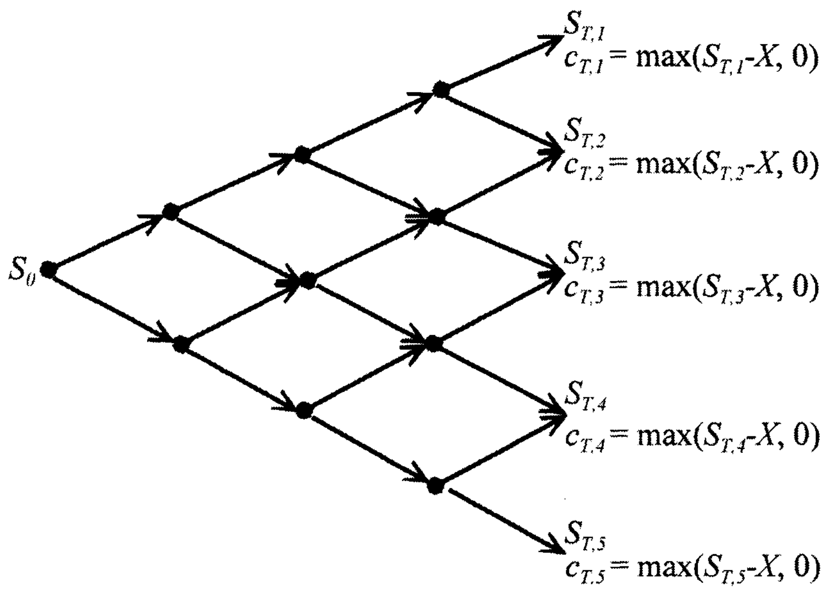


Figure 2.5 A Multi-Step Binomial Tree

Source: Law et al. (2003)

Table 2.5 Call Option Prices

Panel A: Lower West Virginia to New York

	Option Maturity Date	Exercise Price of Call Option				Spot Price of Underlying ($/ton)
		16	17	18	19	
Jul 1997	Sep 97	1.119	0.205	0.000	0.000	16.92
	Dec 97	1.351	0.518	0.084	0.000	
Jan 1998	Mar 98	2.084	1.089	0.276	0.000	17.89
	Jun 98	2.281	1.451	0.687	0.336	
Apr 1998	Jun 98	2.345	1.357	0.465	0.010	18.15
	Sep 98	2.546	1.628	0.788	0.336	
Jan 1999	Mar 99	0.373	0.000	0.000	0.000	16.06
	Jun 99	0.632	0.249	0.000	0.000	

Panel B: Lincoln, Nebraska to Corpus Christi, Texas

	Option Maturity Date	Exercise Price of Call Option				Spot Price of Underlying ($/ton)
		15	16	17	18	
Jul 1997	Sep 97	1.789	0.825	0.158	0.000	16.603
	Dec 97	1.980	1.096	0.424	0.021	
Jan 1998	Mar 98	2.744	1.756	0.807	0.165	17.560
	Jun 98	2.929	1.960	1.127	0.496	
Apr 1998	Jun 98	0.000	0.000	0.000	0.000	13.929
	Sep 98	0.168	0.000	0.000	0.000	
Jan 1999	Mar 99	0.000	0.000	0.000	0.000	13.832
	Jun 99	0.104	0.000	0.000	0.000	

Source: Law et al. (2003).

2.2.3 Options in the Logistics Industry

Tibben-Lembke and Rogers (2006) present a conceptual model for using transportation options. "If shippers are uncertain about this ability to get access to transportation capacity in the future, or if they would like to lock in transportation prices for the future, they might be interested in purchasing call options. With a truckload (TL) call option, if the shipper decides against exercising the option, the carrier does not send the truck." On the other hand, "if carriers are not certain about being able to get access to shipments in the future, or want to try to lock in future business at guaranteed prices, they may be interested in purchasing put options, which gives them the right to haul a load on a particular date. Put options would require the shipper to have a reliable supply of loads to be carried."

Before writing a call or a put, the option contract must specify the quantity to be shipped; pickup and delivery dates; pickup and delivery time window length; advance notice requirements if the option is to be exercised ("drop dead dates"); origin and destination of the shipment; penalty for failure to complete the contract as promised; price of the shipment; and price of the option.

They believe transportation options are good for shippers, carriers and third-party logistics (3PLs, who provide multiple logistics services for use by customers, CSCMP, 2006), even though there are a few flaws. The positive and negative impacts are summarized in Table 2.6. However, a lot of work is needed before transportation options become a reality. For example, a supervision organizations need to be set up, the structure of the options needs to be defined, as well as details of a contract (e.g., pickup and delivery windows or advanced notice the shipper must give prior to the ship date). Last but not least, more work is needed to price them so they provide benefits to both parties.

Table 2.6 Positive and Negative Impacts of Transportation Options

	Call options	Put options
Impact on shipper	+ Flexibility	+ Cash from option
	+ Known, lower price	− Higher transportation cost
	+ Guaranteed access to transportation capacity	+ Potential net cost reduction
	− Cost of option	
Impact on carrier	+ Cash flow	+ Risk management
	+ Plan future schedules	+ Guaranteed access to shipments
	− Lower transportation revenue	+ Known, higher prices
	+ Potential net revenue increase	− Cost of option
Benefits to 3PL	+ Combine across multiple consignees	+ Combine across multiple carriers

Source: Tibben-Lembke et al. (2006)

2.3 Summary

2.3.1 Trucking Spot Markets Overview

For completeness let us now review the current state of truckload spot markets. In the trucking industry, three types of trading occur between shippers and carriers. These involve private carriage, contract carriage, and common carriage. (Hubbard, 2003) Private carriage refers to the trucks and drivers owned and operated by shippers. Contract carriage and common carriage are procured from for-hire carriers. Mostly, common carriers operate in spot markets.

A spot market is where shipments are handled on a one time load-by-load basis. It can be considered a ubiquitous market where prices are determined by market forces (Nandiraju, 2006). It is used by almost all shippers and carriers to some extent. Spot market contracts are relatively short term contracts to serve unfilled demands or urgent demands. They have short lead times, volatile market prices and typically no prior contractual agreements. Typically shippers and carriers participate in spot markets on a "per job" basis. Procuring and selling truckload services in the spot markets, or say online marketplaces, is increasingly common to match shipper demand and carrier capacity, because of the flexibility and convenience of this approach.

During the past several years, these spot markets have experienced a transition. Thank to advances in information technologies, spot markets have moved online; they traditionally relied on phone, fax and/or truck stop posting (Song and Regan, 2001). These electronic marketplaces provide freight matching, fleet management, inventory management, tracking and tracing services. However, the number of these companies once was so large (estimated over 600 in 2001), that the market has become highly competitive. In addition, the "dotcom boom" forced out some companies and motivated others to merge or to form strategic alliances.

Today, the shift from a traditional marketplace to an online marketplace appears mostly complete. The reorganization within or among companies has also become stable, while the services provided keep improving to meet customers' various needs. Several examples of spot market services providers are TransCore, Getloaded, NetTrans, Internet

Truck Stop, PostEverywhere. They provide online freight matching services, as well as E-logistics. Transcore is probably the largest freight matching corporate in US. In 2000, some of these companies were very large. TransCore, for example acquired four leading transportation services companies: American Traffic Systems (ATS), Amtech Transportation Systems, DAT Services (including its international EuroDAT operations), and Viastar Services. In 2006, TransCore introduced a new freight matching online marketplace, 3Sixty, which is powered by the DAT network. DAT was perhaps the most successful of the pre e-commerce spot markets. On the contrary, Getloaded.com is a small company with only 36 employees. However, it handles over 140,000 loads a day and its members include more than 27,000 trucking companies with upwards of 500,000 trucks (getloaded.com, 2007).

2.3.2 Potential of Trucking Option Contracts

As in the maritime industry, the demand for derivatives contracts for hedging uncertainty in trucking has appeared. Unlike the maritime industry, however, the trucking industry needs derivatives not only for hedging price uncertainty but also for capacity uncertainty. In other words, the current financial-settlement derivatives used in the maritime industry are not sufficient for hedging demand uncertainty in the trucking industry because those derivatives are operated separately from the physical shipping markets. As a result, the price risk may be fixed but the capacity for delivering cargos is not guaranteed.

The trucking option contracts we propose include call and put options, which are defined as option contracts in the previous section. The underlying asset for either type of option is a truckload service. We investigate the potential use of trucking options for shippers and carriers separately.

2.3.2.1 The Shippers' Perspective

A shipper who is uncertain about its demand for truckload services and who believes that rates may increase in the near future may buy call options (if their price is reasonable), because they would provide her with a guaranteed number of truckloads at a predetermined price. For example, if demand occurs at some point in the future and the spot price is higher than the predetermined price, then she would exercise her options to procure guaranteed capacity at a price lower than the spot market price. In that case, holding a call option would benefit her. On the other hand, if demand occurs but the spot price is lower than the predetermined price, then she would not exercise her options if she can get enough truckloads from that spot market.

Therefore, trucking call options provide the shipper with flexibility in capacity procurement. The minimum value of a call option is zero while the maximum differs from shipper to shipper, as it depends on the degree of uncertainty a shipper faces.

2.3.2.2 The Carriers' Perspective

A carrier who is concerned about fleet availability and decreasing rates may buy put options to secure guaranteed freight for delivery at a predetermined price and time. This option will be exercised depending on future spot market prices. For example, if at some time in the future the spot price is lower than the predetermined price, then he would exercise his options and procure the guaranteed freight for delivery at a price higher than the spot market price. The value of these put options is the difference between the predetermined price and the spot price. If there are idle fleets but the spot price at a future time is higher than the predetermined price, then he might not exercise the contract if he can get enough freight to move from the spot market.

2.3.3 Necessary Conditions for the Emergence of a TL Options Market

Based on the experience accumulated in the maritime derivatives markets and on current practice in the trucking industry, let us now look at some conditions necessary for making trucking options attractive and feasible.

2.3.3.1 Uncertainty

Let us first examine truckload price uncertainty (without uncertainty, options would have no value). As shown in Figure 1.3, the degree of volatility of the monthly percentage change in average truckload rates has increased significantly since the end of 2004. Besides, rate volatility is expected to continue and possibly even increase because of unstable oil prices resulting from steady world oil demand growth, and geopolitical instability. Moreover, increasing and uncertain labor costs also contribute to volatility since the shortage of drivers remains unresolved.

Let us now consider capacity uncertainty. In the trucking industry, the overall demand for truckloads is strong. The shippers' uncertain demand for trucking capacity, in terms of time and volume, has also significantly increased because of the adoption of demand responsive logistics by various industries. The case of Intel described in Section 1.1 is just one of many examples. In addition, the supply of trucking capacity tends to be limited as carriers hesitate to increase capacity because they find it difficult to hire drivers at prevailing wages and because of regulatory changes concerning hours of service and engine emissions (Kirkeby, 2007). Coupled with strong demand and tight supply, it is harder for shippers to procure sufficient trucking capacity to satisfy their needs.

2.3.3.2 Hedging Effectiveness

The maritime derivatives BIFFEX ceased to trade mainly because of low hedging effectiveness. The underlying index which is derived from the prices of a basket of routes could not hedge well for individual route. Therefore, the underlying asset of trucking options must sufficiently measure the specific movement that buyers are interested in. One truckload for a specific lane is a good choice.

2.3.3.3 Liquidity

A successful derivatives market must be liquid, which means that a seller should always be able to find a buyer without much difficulty (Hull, 2006). Lack of liquidity is another reason for BIFFEX's failure. In order to secure liquidity for trucking options, the freight flow of lanes and the seasonality effect should be considered. Trucking options would be more attractive on lanes with high freight flow during the peak season, namely Los Angeles (LA) – Dallas, Laredo – Chicago, and so on (BTS, 2006) .

2.3.3.4 Organization

To oversee truckload options trading, a specialized institution is essential. This institution could be formally established at an existing financial or commodity trading exchange, such as the New York Mercantile Exchange. Alternatively, as a starting point, it could be one of the current successful transportation marketplaces. To set up such a trading platform, one can refer to the experience of financial markets. In addition, a trading place for truckloads will need to design its products to guarantee hedging effectiveness and market liquidity. It is also essential that it publishes spot prices for truckloads on all routes where truckload options are available. To guarantee its accountability, it should agree to regular audits by independent third parties (such as a reputable accounting firm) which are known as clearinghouses. The main task of clearinghouses is to track all transactions and calculate the position for the participants (Hull, 2006). Small firms who may not have either the sophistication or the personnel needed to participate in complicated contracts could trade options in the marketplaces through a large third party logistics company.

2.3.3.5 Pricing

Pricing options is also a key issue for derivatives. A great amount of literature is devoted to pricing options in financial markets. We address the pricing issue in more detail in the following chapters.

CHAPTER 3 STOCHASTIC MODELING OF TRUCKLOAD PRICE PROCESSES

The basic idea of valuing options is to find the discounted value of the expected payoff of the contracts. In other words, the price of options is the present value such that the expectation of future payoff equal to zero, which is known as free-arbitrage pricing. Specifically, the value of options is given by

$$P_t = E[e^{-r(T-t)}\Phi(Y_T)|F_t] \tag{3.1}$$

where $\Phi(Y_T)$ is the payoff function; Y_T is the TL spot rate; r is the interest rate; t and T denote the present and maturity, respectively; F_t is the information filtration at time t which indicates the market information currently collected. Obviously, in order to derive the price of options, we need to define two functions: the TL spot rate function Y_t, and the payoff function $\Phi(Y_T)$.

This chapter focuses on modeling truckload prices; that is to investigate the TL spot rate function Y_t. As literature reviewed in Chapter 2, the Black-Scholes pricing model and the binomial option pricing model assume the underlying asset prices follow Geometric Brownian Motion (GBM). The disturbance term is independent, identically and normally distributed. However, those assumptions are questionable based on theory empirical evidence. Hence, to exhibit the particular properties and characteristics of TL prices which are described in Section 3.1, we model the truckload price process as a mean-reverting process in Section 3.2. Accordingly, we then estimate the parameters of the truckload price model in Section 3.3.

3.1 Truckload Prices

According to the industry estimate, approximately 10 to 20% of all transportation services are procured from spot markets (Tibben-Lembke and Rogers, 2006; Caplice, 2007). Most of the services are purchased through electronic markets. We have studied electronic marketplace providers by surveying the members of Transportation Intermediaries Associations (TIA) and conducting searches in Google. We found that those marketplaces provide freight match services which allow shippers to post loads and carriers to post available fleets. However, only some of them provide rates for reference. Note that the provided rates are not the realized transportation costs; they are used for giving shippers and carriers an idea of recent rates. The reference rates come in the form of maximum, minimum and average rates for point-to-point shipping lanes and are updated bi-weekly or monthly.

Obtaining reliable data for this type of research is not a simple task. To date no published papers on optimal contracting in the trucking industry (for example the many papers on the use of variants of combinatorial auctions) are based on real data from the industry. The prices of delivery services are very secretive in trucking industry, especially daily data for specific lanes. However, based on the practical spot market operation, we model truckload (TL) prices as an unobservable process bounded between maximum rate and minimum rate.

Figure 3.1 presents the simulated path of TL prices. Given the average, maximum and minimum prices for a certain period of time, say one month, the TL price could go everywhere in between. Within this range, fluctuations in truckload prices have various causes. First, they can result from changes in demand for shipping over a given lane, which is linked to regional economic activity. Second, they may depend on the number of empty containers bound for a destination ('deadhead' moves), which are linked to trade imbalances. Third, the shipping price may indirectly depend on the price of oil, which has been rising sharply in the last few months. To model these random fluctuations, we therefore propose to model the truckload spot price on a given route as a stochastic process.

3.2 Stochastic Model for Truckload Prices

As argued by Dixit and Pindyck (1994), we can expect current prices to be related to long-run marginal costs. While prices move up and down in the short-run, they will eventually revert back to long run marginal costs in a competitive market. Let us examine this argument in terms of demand and supply of truckload capacities. As long as the price increases, more and more investment in truckload capacity will take place. As a result, the price will at some point start to fall. Conversely, if the price continuously decreases, the demand for truckload will increase and eventually the equilibrium of demand and supply will be reached. Therefore, it is reasonable to consider modeling TL price dynamics with mean reverting processes. Following this argument, we assume that the spot prices follow a mean-reverting process such as the Ornstein-Uhlenbeck process (Karlin and Taylor, 1981).

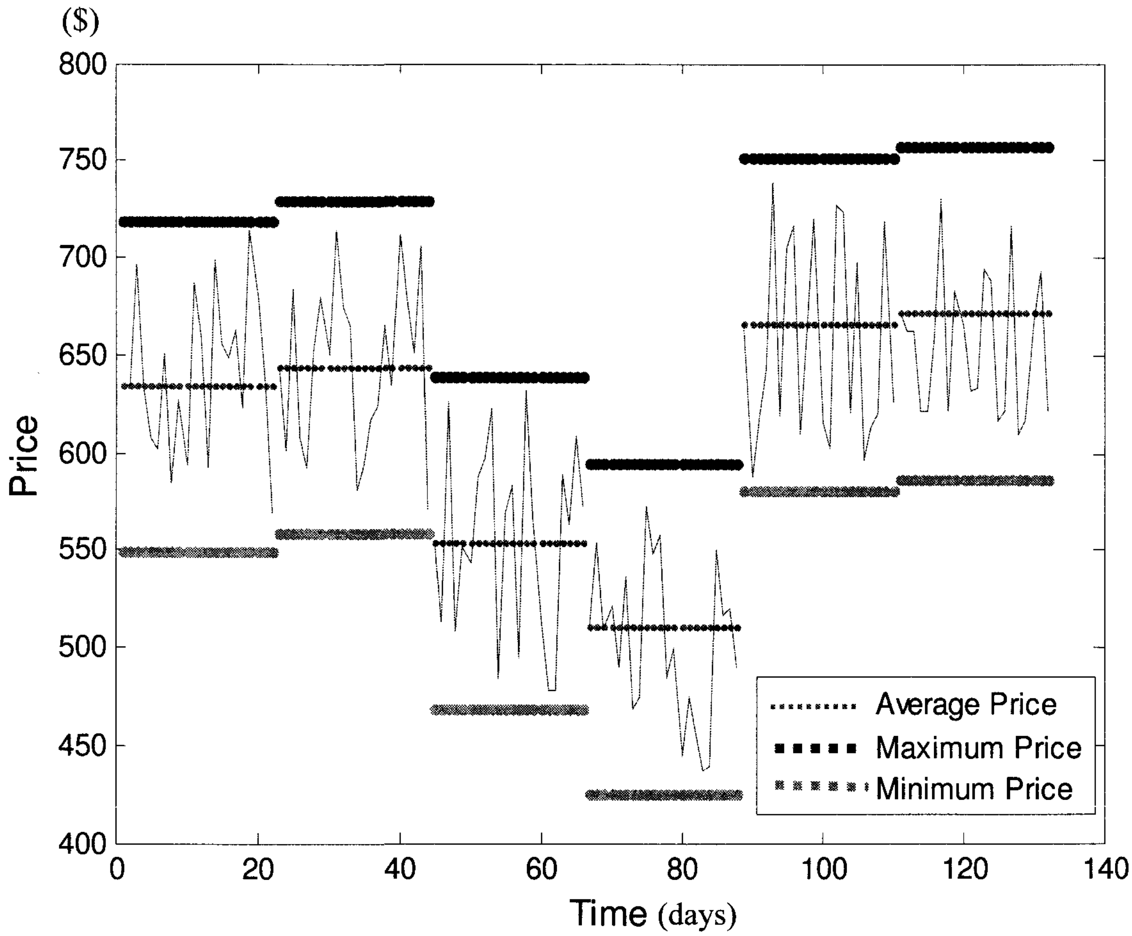


Figure 3.1 Simulated Path of Truckload Prices

3.2.1 Mean-Reverting Ornstein-Uhlenbeck Process

One of the simplest mean-reverting processes is the Ornstein-Uhlenbeck (O-U) process.

Definition A stochastic process $\{X_t : t \geq 0\}$ is an Ornstein-Uhlenbeck process if it is Gaussian, stationary, Markov, and continuous in probability and satisfies the following stochastic differential equation (Breiman, 1992; Dixit and Pindyck, 1994):

$$dX_t = \alpha(\mu - X_t)dt + \sigma d\mathrm{B}_t \tag{3.2}$$

where $\{\mathrm{B}_t : t \geq 0\}$ is standard Brownian motion; α is the rate of reversion; μ is the level that X_t tends to return to; σ is the volatility parameter; and α, μ, σ are constants.

The explicit solution of Equation (3.2) is given by

$$X_t = \mu + (X_0 - \mu)e^{-\alpha t} + \sigma \int_0^t e^{-\alpha(t-s)} d\mathrm{B}_s \tag{3.3}$$

Therefore, X_t is Gaussian with expected value and variance:

$$E[X_t \mid X_0] = \mu + (X_0 - \mu)e^{-\alpha t} \tag{3.4}$$

$$Var[X_t \mid X_0] = \frac{\sigma^2}{2\alpha}(1 - e^{-2\alpha t}) \tag{3.5}$$

Considering the limit $t \to \infty$ which means over a long time horizon, the expected value and the variance tend to be:

$$\lim_{t \to \infty} E[X_t \mid X_0] = \mu \tag{3.6}$$

$$\lim_{t \to \infty} Var[X_t \mid X_0] = \frac{\sigma^2}{2\alpha} \tag{3.7}$$

In financial modeling, Vasicek (1977) first introduced the O-U process to model the evolution of interest rates. The main idea is that interest rates are less likely to go infinitely positive or negative as with the geometric Brownian motion (GBM). Instead, interest rates fluctuate within a certain positive range. Hence, the O-U process is more appropriate than the GBM for describing interest rate dynamics. This concept of mean reversion also holds for commodity prices. In practice, most commodity prices tend to return back to a certain level from either a growing or a declining price over time. This level is the marginal cost to produce. This explains why a mean-reverting model or the O-U model is popular in commodity price modeling (see, for example, Geman and Nguyen (2005) on agricultural commodities; and Pindyck (2000) on energy commodities).

However, the main drawback of modeling with an O-U process is that the process theoretically allows interest rates or commodity prices take negative value which is unreasonable in practice. This disadvantage can be fixed by: (1) switching to Cox-Ingersoll-Ross model; (2) modeling the logarithm of the variable of interest rather than the variable itself; or (3) incorporating a reflecting boundary that prevents the variable of interest from becoming negative.

3.2.2 Truckload Pricing Model

We argue that truckload prices follow a mean-reverting process just as most commodity prices behave. To support this argument, we first examine the cost structure of trucking services. Then a specific truckload price model is proposed.

3.2.2.1 Cost Structure of Trucking

The cost structure of general freight trucking comprises three parts: fixed costs, variable costs, and profit. Fixed costs include equipment cost, license, taxes, insurance, management and overhead; while variable costs are fuel, labor, tires, maintenance and repair (Berwick and Farooq, 2003). The cost structures of local and long-distance freight trucking are shown in Figure 3.2 (IBIS World, 2007).

3.2.2.1.1 Fixed costs

1. Equipment cost

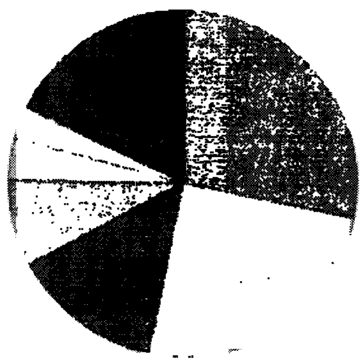
The share of equipment cost is around 5 % of total costs. It includes either lease expense or depreciation depending on truck ownership. Moreover, depreciation can be different because of the estimation of the useful life of trucks.

2. Management and overhead costs

Management and overhead costs are approximately 14 % of total costs.

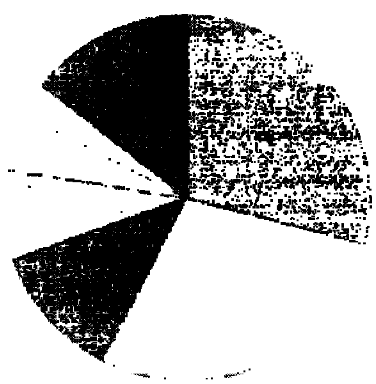
3. Other costs

Other costs, which include the costs of a license, taxes, and insurance, represent approximately 12 % of total costs.



Item	Cost %
Wages	28.2%*
Fuel	25.0%*
Administration & Overheads	14.0%*
Maintenance	8.0%*
Depreciation	4.0%*
Tires	3.0%*
Other	11.8%*
Profit	**6.0%***

Panel (a) Local Trucking



Item	Cost %
Fuel	29.0%*
Wages	28.5%*
Administration & Overheads	12.0%*
Maintenance	8.0%*
Depreciation	5.0%*
Tires	3.0%*
Other	11.5%*
Profit	**3.0%***

Panel (b) Long-Distance Trucking

Figure 3.2 Cost Structure of General Freight Trucking
Source: IBISWorld Inc. (2007)

3.2.2.1.2 Variable costs

1. Fuel costs

The share of fuel costs is approximately 25 % and 30% of total costs of local trucking and long-distance trucking, respectively. These percentages are expected to continue increasing because of steady world oil demand growth, and the risks of geopolitical instability. Fuel costs are usually calculated separately by empty and loaded trucks. They are also adjusted for speed.

2. Labor costs

Labor costs are another significant share, around 29 %, of total costs. They are expected to increase since the shortage of drivers remains unresolved.

3. Tire costs

Tire costs are around 3 % of total costs. The cost per tire is cataloged into tractor tires and trailer tires for both loaded and empty.

4. Maintenance and repair costs

Maintenance and repair costs represent around 8 % of total costs. The costs vary in terms of truck models, loaded and empty.

3.2.2.1.3 Profit margin

According to IBIS World (2007) estimate, the profit margin for local trucking is higher than for long-distance trucking (6 % and 3 % respectively). The difference in profit margins is largely due to the fact that long-distance trucking competes with rail.

3.2.2.2 Truckload Price Model

From the cost structure of trucking, we can see wages and fuel are the two main components and together they represent more than 50 % of total costs. In addition, from the percentage change in monthly truckload prices (see Figure 1.3), it is reasonable to assume that the truckload prices generally follow a mean-reverting process. Therefore, we model the truckload prices as an O-U process, which is given as Equation (3.8).

$$dY_t = \alpha(\mu - Y_t)dt + \sigma d\mathrm{B}_t \tag{3.8}$$

$\{Y_t : t \geq 0\}$: the truckload price at time t

α : the rate of reversion

μ : the level that Y_t tends to return to

σ : the volatility parameter

$\{\mathrm{B}_t : t \geq 0\}$: standard Brownian motion

α , μ , σ are constants that need to be estimated.

To derive an explicit solution for Equation (3.8), we first consider the term $de^{\alpha t} Y_t$. Using Ito's lemma, we have

$$d(e^{\alpha t} Y_t) = \alpha e^{\alpha t} Y_t dt + e^{\alpha t} dY_t .$$

Inserting Equation (3.8), we have

$$d(e^{\alpha t} Y_t) = \alpha e^{\alpha t} Y_t dt + e^{\alpha t} [\alpha(\mu - Y_t)dt + \sigma d\mathrm{B}_t]$$

$= e^{\alpha t}(\alpha\mu dt + \sigma d\mathrm{B}_t)$. Hence,

$$e^{\alpha t}Y_t = Y_0 + \int_0^t e^{\alpha s}\alpha\mu ds + \int_0^t e^{\alpha s}\sigma d\mathrm{B}_s$$

$$Y_t = e^{-\alpha t}Y_0 + \int_0^t e^{-\alpha(t-s)}\alpha\mu ds + \int_0^t e^{-\alpha(t-s)}\sigma d\mathrm{B}_s .$$

Finally, the explicit expression of Y_t is derived as

$$Y_t = \mu + (Y_0 - \mu)e^{-\alpha t} + \sigma\int_0^t e^{-\alpha(t-s)}d\mathrm{B}_s . \tag{3.9}$$

Since $\{\mathrm{B}_t : t \geq 0\}$ is standard Brownian motion, Y_t is $N(\mu + (Y_0 - \mu)e^{-\alpha t}, \frac{\sigma^2}{2\alpha}(1 - e^{-2\alpha t}))$ distributed.

3.3 Data

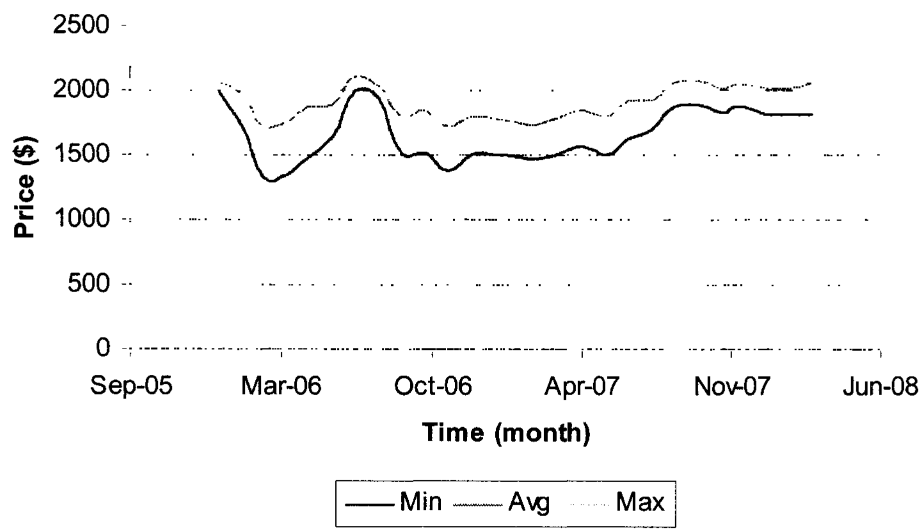
Recall the truckload price process in Equation (3.8). There three parameters need to be estimated: the rate of mean reversion, the long-term mean of the TL price, and the volatility of the TL price.

The data used for estimating parameters are manually obtained by accessing a trucking electronic marketplace named truckloadrate.com. This database provides the maximum, the minimum and the average of TL prices for specific origin-destination pair every month back to 2006. The number of observations is small as only 31 points were collected for this work. As mentioned previously, this type of data is extremely difficult to obtain and those monthly TL prices for specific origin-destination pairs are the most specific data available.

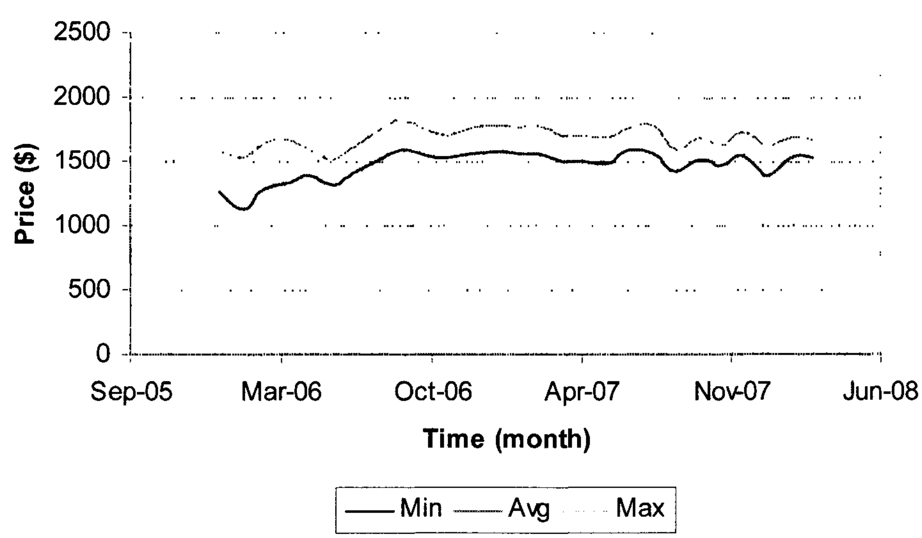
According to the Commodity Flow Survey constructed by Bureau of Transportation Statistics (2002), commodities moved by for-hire trucks from California to Texas have the highest value ($-mile). As a starting point for our numerical illustration, we choose the lane of Los Angels, CA to Dallas, TX (denoted by LADA) which represents the movements from a container port to an inland city. In addition, commodities moved by for-hire trucks from Texas to Illinois are in the top 15 for value. We choose the lane going from Laredo, TX to Chicago, IL (denoted by LRCH) because it represents the movements from a land border to an inland city. Another reason is that LRCH has a similar traveling distance as LADA (approximately 1400 miles). Figure 3.3 shows the truckload prices for the lanes of LADA and LRCH over the past two years.

3.4 Parameter Estimation

Unlike financial markets where high frequency data are available, spot prices for trucking services are not public and we can only observe some monthly statistics: average, maximum, and minimum. This complicates the estimation of necessary parameters in Equation (3.8). To this end, we adopt two independent methods (variogram analysis and maximum likelihood), and use the statistics separately as well as jointly to obtain the estimates.



(a) Prices for the LADA lane



(b) Prices for the LRCH lane

Figure 3.3 Truckload Prices (Jan. 2006 ~ March 2008)
Source: truckloadrate.com (2008)

3.4.1 Variogram Analysis

Since the spot truckload price is not observed directly, estimating α and σ is complicated. This task will be implemented by using the average prices and the variogram analysis which is a powerful tool for estimating the parameters of mean-reverting models (Fouque et al., 2000).

3.4.1.1 Estimator of the Long-term Mean of Truckload Price μ

Let $\widetilde{Y}_n$ denote the average price during the time period n, then we have

$$\widetilde{Y}_n = \frac{1}{\Delta T} \int_{(n-1)\Delta T}^{n\Delta T} Y_s ds \; ; \; n = 1, 2, \ldots, \mathrm{N} \tag{3.10}$$

where ΔT is the time period between successive observations (i.e. one month in our case) and N is the number of time periods.

Result 3.1 $\hat{\mu} = \frac{1}{N}\sum_{n=1}^{N} \widetilde{Y}_n$ is an unbiased estimator of μ defined by Equation (3.8).

Proof. In the above, $\widetilde{Y}_n$ defined in Equation (3.10). Equivalently, we want to prove that $E[\hat{\mu}] = \mu$.

$$E[\hat{\mu}] = E[\frac{1}{N}\sum_{n=1}^{N} \widetilde{Y}_n] = \frac{1}{N\Delta T} E[\int_0^{N\Delta T} Y_s ds]$$

$$= \frac{1}{N\Delta T} \int_0^{N\Delta T} [\mu + (Y_0 - \mu)e^{-\alpha s}] ds$$

$$= \frac{1}{N\Delta T}[\mu s - \frac{1}{\alpha}(Y_0 - \mu)e^{-\alpha s}\Big|_0^{N\Delta T}]$$

$$= \mu + \frac{1}{\alpha N\Delta T}(Y_0 - \mu)(1 - e^{-\alpha N\Delta T})$$

So when we take the limit $N\Delta T \to \infty$, we get that $E[\hat{\mu}] = \mu$. Therefore, $\hat{\mu}$ is an unbiased estimator of μ. ■

3.4.1.2 Estimators of α and σ

The variogram, also known as structure function, of a process $\{x\}$ is used to analyze how 'far' the process escapes from itself between times t and $t+l$. It is defined by (Bouchaud and Potters, 2003):

$$V(l) \equiv E\left[(x_{n+l} - x_n)^2\right] \tag{3.11}$$

It can be written in a discrete manner as:

$$V(l) = \frac{1}{(N-l)}\sum_{n=1}^{N-l}(x_{n+l} - x_n)^2 \tag{3.12}$$

where l is called the lag and N is the number of observations.

Result 3.2 The variogram $V_l = \frac{1}{N-l}\sum_{n=1}^{N-l}(\widetilde{Y}_{n+l} - \widetilde{Y}_n)^2$ is an unbiased estimator of $V_l^* = 2v^2(1 - e^{-\alpha l})$ with v^2 being the variance of $\widetilde{Y}$.

Proof. Equivalently, we want to prove that $E[V_l] = V_l^* = 2v^2(1 - e^{-\alpha l})$.

$$E[V_l] = E[\frac{1}{N-l}\sum_{n=1}^{N-l}(\widetilde{Y}_{n+l} - \widetilde{Y}_n)^2]$$

Assuming that the price Y_t has an invariant distribution, the above equation can be rewritten as

$$E[V_l] = E[(\widetilde{Y}_l - \widetilde{Y}_0)^2]$$

$$= \mathrm{E}[\widetilde{Y}_l^2 - 2\widetilde{Y}_l\widetilde{Y}_0 + \widetilde{Y}_0^2]$$

$$= E(\widetilde{Y}_l^2) + E(\widetilde{Y}_0^2) - 2E(\widetilde{Y}_l\widetilde{Y}_0)$$

$$= 2\{v^2 - [E(\widetilde{Y})]^2 - Cov(\widetilde{Y}_l\widetilde{Y}_0) + [E(\widetilde{Y})]^2\}$$

$$= 2v^2(1 - e^{-\alpha l}) = V_l^*$$

This completes the proof. ■

Recall that Y_t is normally distributed with variance $\sigma^2/2\alpha$ (if invariance holds), so $\widetilde{Y}_n$ is also normally distributed with variance $\sigma^2/2\alpha$. The parameters α and σ are now related to the variogram, which is $v^2 = \sigma^2/2\alpha$, so that their estimation can be obtained by fitting a variogram model.

To fit the variogram model, a weighted least squares method is adopted. Specifically, we want to choose the parameters that minimize (Cressie, 1985)

$$\sum_{l=1}^{N-l}(N-l)(\frac{V_l^*}{V_l}-1)^2.$$

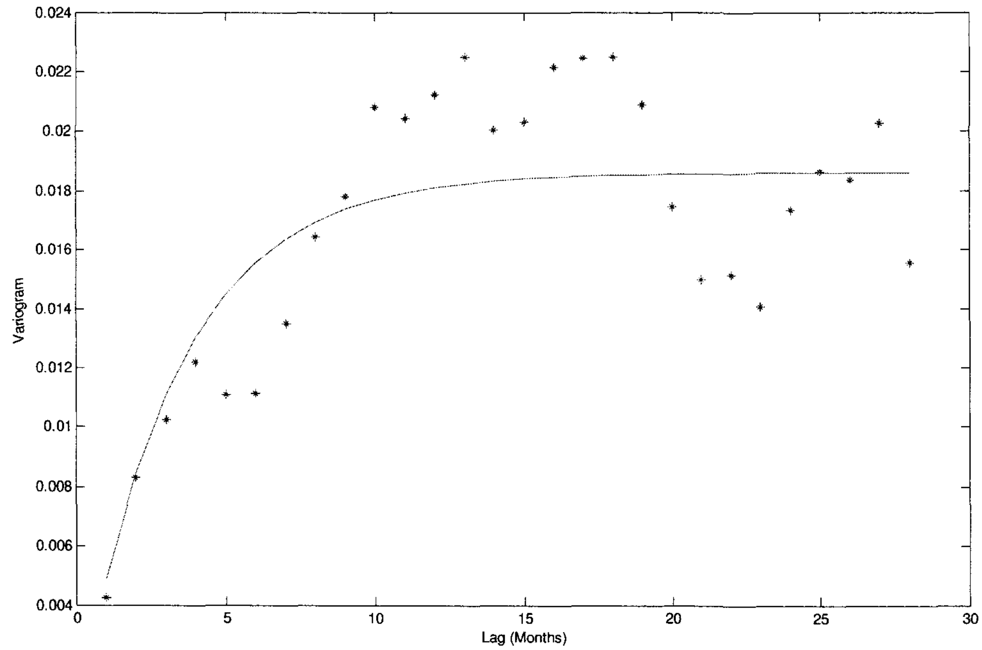
This expression takes into account the effect of lag length; variogram with small lags will gain more weights than those with large lags.

3.4.1.3 Results

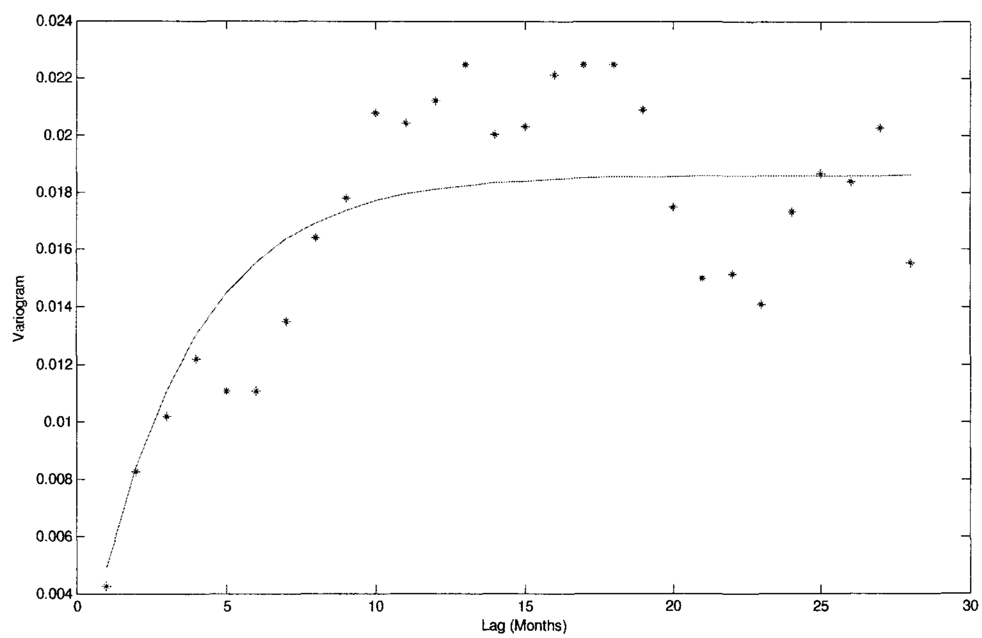
After coding this problem in MATLAB and solving for the unknown parameters, the empirical variograms and the fitted curve for LADA and LRCH truckload prices are shown in Figure 3.4. Results are summarized in Table 3.1 and the simulated variograms are shown in Figure 3.5.

Table 3.1 Results of Parameter Estimation Using Average Prices: Variogram

Lane	μ (\$/mile)	α (day^{-1})	v^2 (\$^{2}/mile^2)	σ (\$/(mile*day$^{0.5}$))
LADA	1.3239	0.3016	0.0093	0.0748
LRCH	1.2055	0.4196	0.0032	0.0520

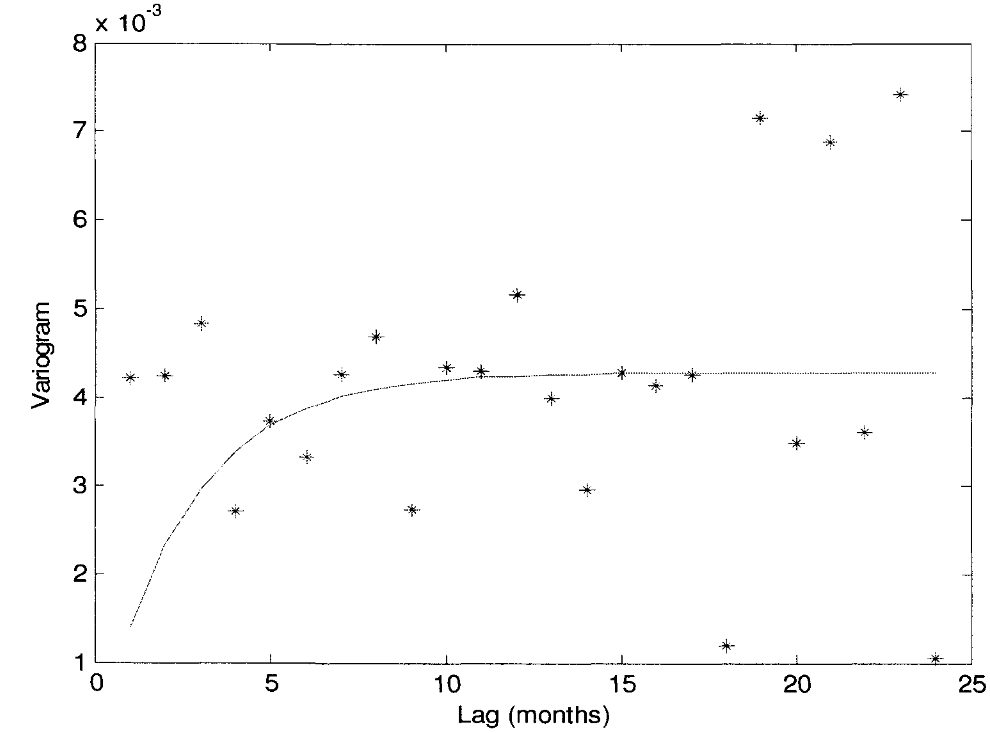


(a) LADA Lane

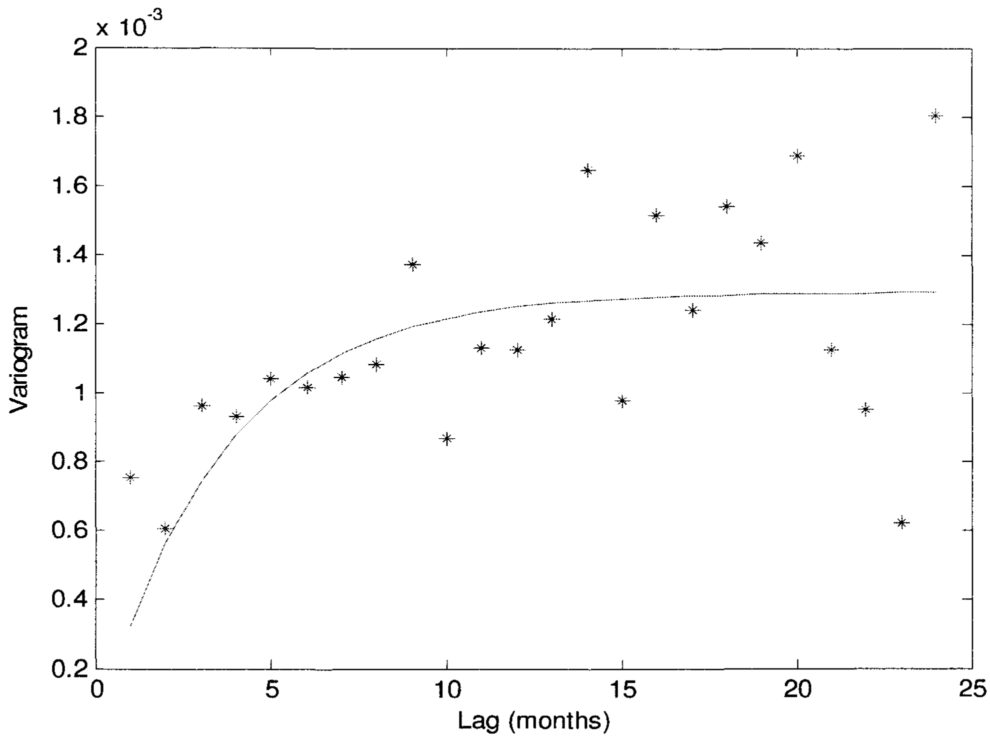


(b) LRCH Lane

Figure 3.4 Empirical and Fitted Variograms for LADA and LRCH



(a) LADA Lane



(b) LRCH Lane

Figure 3.5 Simulated and Fitted Variograms for LADA and LRCH

3.4.2 Maximum Likelihood Estimation (MLE)

3.4.2.1 Using Average Price Data

Again the average price for the nth time period is defined by

$$\widetilde{Y}_n = 1/\Delta T \cdot \int_{(n-1)\Delta T}^{n\Delta T} Y_s ds \text{; n = 1, \ldots, N.}$$

We first derive the recursive relation between $\widetilde{Y}_n$ and $\widetilde{Y}_{n-1}$, then develop the conditional probability density function of $\widetilde{Y}_n$.

Result 3.3 $\widetilde{Y}_n$ is normally distributed with a conditional mean and a conditional variance given by:

$$E[\widetilde{Y}_n \mid \widetilde{Y}_{n-1}] = \mu + (E[\widetilde{Y}_{n-1}] - \mu)e^{-\alpha\Delta T},$$

$$Var[\widetilde{Y}_n \mid \widetilde{Y}_{n-1}] = e^{-2\alpha\Delta T} Var[\widetilde{Y}_{n-1}] + \frac{\sigma^2}{2\alpha}(1 - e^{-2\alpha\Delta T}).$$

Proof. Recall that the truckload price, denoted by Y_t, is normally distributed with mean and variance given respectively by:

$$E[Y_t \mid Y_0 = y] = \mu + (y - \mu)e^{-\alpha t};$$

$$Var[Y_t] = \frac{\sigma^2}{2\alpha}(1 - e^{-2\alpha t}).$$

Then we have

$$E[\widetilde{Y}_n] = E[\frac{1}{\Delta T}\int_{(n-1)\Delta T}^{n\Delta T} Y_s ds]$$

$$= \frac{1}{\Delta T}\int_{(n-1)\Delta T}^{n\Delta T} [\mu + (y-\mu)e^{-\alpha s}]ds$$

$$= \frac{1}{\Delta T}[\mu s - \frac{1}{\alpha}(y-\mu)e^{-\alpha s}\Big|_{(n-1)\Delta T}^{n\Delta T}]$$

$$= \mu + \frac{1}{\alpha \Delta T}(y-\mu)(e^{-\alpha n \Delta T} - e^{-\alpha(n-1)\Delta T})$$

$$= [\mu + \frac{1}{\alpha \Delta T}(y-\mu)(e^{-\alpha(n-1)\Delta T} - e^{-\alpha(n-2)\Delta T})](e^{-\alpha \Delta T}) + \mu(1-e^{-\alpha \Delta T})$$

$$E[\widetilde{Y}_n \mid \widetilde{Y}_{n-1}] = e^{-\alpha \Delta T} E[\widetilde{Y}_{n-1}] + \mu(1-e^{-\alpha \Delta T}) = \mu + (E[\widetilde{Y}_{n-1}] - \mu)e^{-\alpha \Delta T}.$$

Similarly, we derive the result of $Var[\widetilde{Y}_n \mid \widetilde{Y}_{n-1}] = e^{-2\alpha \Delta T} Var[\widetilde{Y}_{n-1}] + \frac{\sigma^2}{2\alpha}(1-e^{-2\alpha \Delta T})$.

This completes the proof. ■

By Result 3.3, we can further write:

$$\widetilde{Y}_n = e^{-\alpha \Delta T}\widetilde{Y}_{n-1} + \mu(1-e^{-\alpha \Delta T}) + \frac{\sigma^2}{2\alpha}(1-e^{-2\alpha \Delta T}) \cdot N(0,1); \tag{3.13}$$

where $N(0,1)$ represents the standard normal distribution.

Result 3.3 shows that the discretization of the averaged O-U process is in line with that of the general O-U process except the temporal correlation. Therefore, we can find the conditional probability density function of the averaged O-U process by following a general O-U case (see for example, Duan (1994)). The conditional probability density function of $\widetilde{Y}_n$ is given by

$$f(\widetilde{Y}_n|\widetilde{Y}_{n-1};\mu,\alpha,\hat{\sigma})=\frac{1}{\sqrt{2\pi\hat{\sigma}^2}}\exp\{-\frac{[\widetilde{Y}_n-e^{-\alpha\Delta T}\widetilde{Y}_{n-1}-\mu(1-e^{-\alpha\Delta T})]^2}{2\hat{\sigma}^2}\} \tag{3.14}$$

where $\hat{\sigma}^2=\dfrac{\sigma^2}{2\alpha}(1-e^{-2\alpha\Delta T})$.

Then the likelihood function is

$$L(\mu,\alpha,\hat{\sigma})=\prod_{n=1}^{N} f(\widetilde{Y}_n|\widetilde{Y}_{n-1};\mu,\alpha,\hat{\sigma}).$$

Taking the logarithm of the likelihood function, we have the log-likelihood function

$$L^*(\mu,\alpha,\hat{\sigma})=\sum_{n=1}^{N}\ln f(\widetilde{Y}_n|\widetilde{Y}_{n-1};\mu,\alpha,\hat{\sigma})$$

$$=-\frac{N}{2}\ln(2\pi)-N\ln(\hat{\sigma})-\sum_{n=1}^{N}\frac{[\widetilde{Y}_n-e^{-\alpha\Delta T}\widetilde{Y}_{n-1}-\mu(1-e^{-\alpha\Delta T})]^2}{2\hat{\sigma}^2} \tag{3.15}$$

To maximize L^*, we differentiate L^* with respect to μ, α and $\hat{\sigma}$ individually, and set each of the derivative equal zero.

$$\frac{\partial L^*(\mu,\alpha,\hat{\sigma})}{\partial\mu}=\frac{1}{\hat{\sigma}^2}\sum_{n=1}^{N}[\widetilde{Y}_n-e^{-\alpha\Delta T}\widetilde{Y}_{n-1}-\mu(1-e^{-\alpha\Delta T})](1-e^{-\alpha\Delta T})=0$$

$$\Rightarrow \qquad \mu=\frac{1}{N(1-e^{-\alpha\Delta T})}\sum_{n=1}^{N}(\widetilde{Y}_n-e^{-\alpha\Delta T}\widetilde{Y}_{n-1}) \tag{3.16}$$

$$\frac{\partial L^*(\mu,\alpha,\hat{\sigma})}{\partial \alpha} = \frac{\Delta T \cdot e^{-\alpha\Delta T}}{\hat{\sigma}^2}\sum_{n=1}^{N}[\widetilde{Y}_n - e^{-\alpha\Delta T}\widetilde{Y}_{n-1} - \mu(1-e^{-\alpha\Delta T})](\widetilde{Y}_{n-1} - \mu) = 0$$

$$\Rightarrow \qquad \alpha = -\frac{1}{\Delta T}\ln\frac{\sum_{n=1}^{N}(\widetilde{Y}_n - \mu)(\widetilde{Y}_{n-1} - \mu)}{\sum_{n=1}^{N}(\widetilde{Y}_{n-1} - \mu)^2} \tag{3.17}$$

$$\frac{\partial L^*(\mu,\alpha,\hat{\sigma})}{\partial \hat{\sigma}} = -\frac{N}{\hat{\sigma}} + \sum_{n=1}^{N}\frac{[\widetilde{Y}_n - e^{-\alpha\Delta T}\widetilde{Y}_{n-1} - \mu(1-e^{-\alpha\Delta T})]^2}{\hat{\sigma}^3} = 0$$

$$\Rightarrow \qquad \hat{\sigma}^2 = \frac{1}{N}\sum_{n=1}^{N}[\widetilde{Y}_n - e^{-\alpha\Delta T}\widetilde{Y}_{n-1} - \mu(1-e^{-\alpha\Delta T})]^2 \tag{3.18}$$

By plugging (3.17) into (3.16), μ can be obtained by:

$$\mu = \frac{\sum_{n=1}^{N}\widetilde{Y}_n - \sum_{n=1}^{N}\widetilde{Y}_{n-1}^2 - \sum_{n=1}^{N}\widetilde{Y}_{n-1}\sum_{n=1}^{N}\widetilde{Y}_n\widetilde{Y}_{n-1}}{N(\sum_{n=1}^{N}\widetilde{Y}_{n-1}^2 - \sum_{n=1}^{N}\widetilde{Y}_n\widetilde{Y}_{n-1}) - (\sum_{n=1}^{N}\widetilde{Y}_{n-1})^2 + \sum_{n=1}^{N}\widetilde{Y}_n\sum_{n=1}^{N}\widetilde{Y}_{n-1}} \tag{3.19}$$

Accordingly, α, $\hat{\sigma}$ and σ can be found from Equations (3.20) to (3.22).

$$\alpha = -\frac{1}{\Delta T}\cdot\ln\left[\frac{\sum_{n=1}^{N}\widetilde{Y}_n\widetilde{Y}_{n-1} - \mu(\sum_{n=1}^{N}\widetilde{Y}_n + \sum_{n=1}^{N}\widetilde{Y}_{n-1}) + N\mu^2}{\sum_{n=1}^{N}\widetilde{Y}_{n-1}^2 - 2\mu\sum_{n=1}^{N}\widetilde{Y}_{n-1} + N\mu^2}\right] \tag{3.20}$$

$$\hat{\sigma}^2 = \frac{1}{N}[\sum_{n=1}^{N}\widetilde{Y}_n^2 + \beta^2\sum_{n=1}^{N}\widetilde{Y}_{n-1}^2 + N\mu^2(1-\beta)^2 - 2\beta\sum_{n=1}^{N}\widetilde{Y}_n\widetilde{Y}_{n-1} - 2\mu(1-\beta)(\sum_{n=1}^{N}\widetilde{Y}_n - \beta\sum_{n=1}^{N}\widetilde{Y}_{n-1})] \tag{3.21}$$

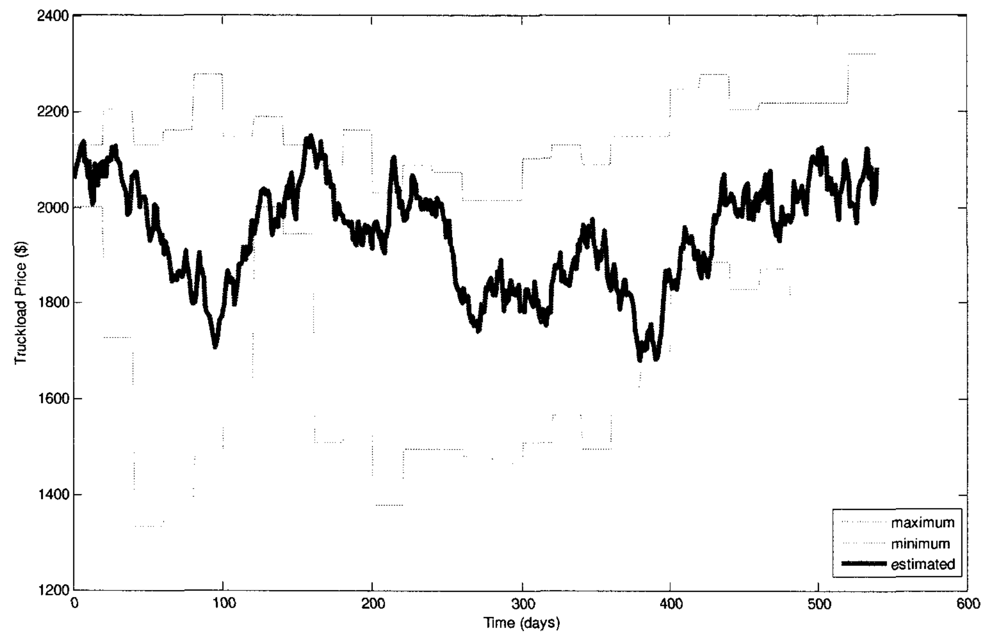
$$\sigma^2 = \frac{2\alpha\hat{\sigma}^2}{1-\beta^2} \qquad (3.22)$$

where $\beta = e^{-\alpha\Delta T}$.

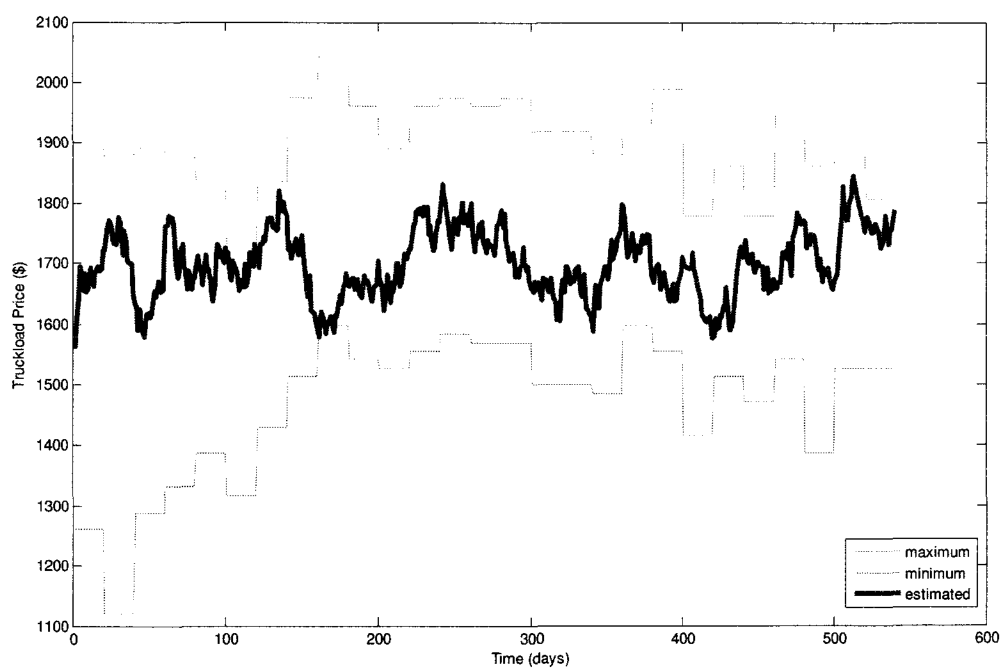
The results of parameter estimation using the average prices are shown in Table 3.2. Based on these estimates, Figure 3.6 presents the sample paths of the truckload prices for LADA and LRCH, respectively. Compared to the obtained maximum and minimum data, both sample paths are mostly within the corresponded ranges.

Table 3.2 Results of Parameter Estimation Using Average Prices: MLE

Lane	μ (\$/mile)	α (day^{-1})	σ (\$/(mile*day$^{0.5}$))
LADA	1.3190	0.3418	0.0707
LRCH	1.2112	0.7136	0.0624



(a) LADA Lane



(b) LRCH Lane

Figure 3.6 Sample Paths of Truckload Prices for LADA and LRCH

3.4.2.2 Using Maximum and Minimum Prices Data

In this section, we use the maximum and minimum prices to estimate the parameters in Equation (3.8). Thus, we are interested in the distributions of these two extreme values.

3.4.2.2.1 Introduction to maxima and minima of the stationary normal process

Extreme value distributions are usually obtained in limiting manners. We first consider the maxima, and then the minima can be treated in a similar way.

The classical extreme value theory (Leadbetter et. al, 1983, Resnick, 1987, Embrechts et. al, 1997) indicates that if $\{x_n, n \geq 1\}$ is an i.i.d. sequence of random variables with common distribution $F(x)$, its standardized extreme distribution $G(x)$ belongs to one of the following:

Gumbel $\quad G(x) = \Lambda(x) = \exp\{-e^{-x}\}, \; x \in R.$

Frechet $\quad G(x) = \Phi_\alpha(x) = \begin{cases} 0 & x < 0 \\ \exp\{-x^{-\alpha}\}, & x \geq 0 \end{cases} \qquad \alpha > 0$

Weibull $\quad G(x) = \Psi_\alpha(x) = \begin{cases} 1 & x \leq 0 \\ \exp\{-(-x)^{-\alpha}\}, & x > 0 \end{cases} \qquad \alpha > 0$

where $\quad a^{-1}(M - b) \xrightarrow{d} G(x), \; a > 0, \; b \in R$ are norming constants.

Also, it has been proved that if $F(x)$ is a normal distribution, then $G(x)$ is a Gumbel distribution. For a stationary Normal process, this remarkable result was initially studied by Pickands (1969), and extended by Berman (1971), Qualls and Watanabe (1972), and Lindgren et al. (1975). Assume that $F(t)$ is a standard stationary normal process with covariance function $\gamma(t)$ which satisfies:

$$\gamma(t) = 1 - C|\tau|^{\delta} + o(|\tau|^{\delta}) \text{ as } \tau \to 0,$$

where δ is a constant, $0 < \delta \le 2$, and C is a positive constant. Then, with the condition $\gamma(t)\log t \to 0$ as $t \to \infty$, the maximum $M(T) = \sup\{Y(t); 0 \le t \le T\}$ has the distribution (when $T\to\infty$):

$$F\{a_T^{-1}(M(T) - b_T) \le x\} \to \exp(-e^{-x}), \tag{3.23}$$

where $a_T = (2\log T)^{-1/2}$;

$$b_T = (2\log T)^{1/2} + \frac{1}{(2\log T)^{1/2}} \cdot \left\{ \frac{2-\delta}{2\delta} \log\log T + \log(C^{1/\delta} H_\delta (2\pi)^{-1/2} 2^{(2-\delta)/2\delta}) \right\};$$

H_δ is a certain positive constant with $H_1 = 1$ and $H_2 = \pi^{-1/2}$.

For a standard O-U process, the covariance is given by

$$\gamma(t) = \exp(-C|\tau|),$$

i.e. $\delta = 1$ and $H_1 = 1$. Hence, the distribution of maxima for a standard O-U process is:

$$F\{a_T^{-1}(M(T)-b_T)\le x\}\to \exp(-e^{-x}), \tag{3.24}$$

where $a_T=(2\log T)^{-1/2}$, and

$$b_T=(2\log T)^{1/2}+\frac{1}{(2\log T)^{1/2}}\cdot\left\{\frac{1}{2}\log\log T+\log(\frac{C}{\sqrt{\pi}})\right\}.$$

Regarding the distribution of minima which is defined by $m(T)=\inf\{Y(t);0\le t\le T\}$, it is the same as the distribution of $-M(T)$.

3.4.2.2.2 Maxima and minima of the truckload price model

The maximum price can be written as:

$$M_n = Max\{Y_s;(n-1)\Delta T\le s\le n\Delta T\},\ n=1, 2, \ldots, \mathrm{N}.$$

Recall the truckload price model in Equation (3.8), when $t\to\infty$, Y_t has a stationary normal distribution $N(\mu,\frac{\sigma^2}{2\alpha})$ and covariance

$$Cov(Y_s,Y_t)=\frac{\sigma^2}{2\alpha}\exp(-\alpha|s-t|)=\frac{\sigma^2}{2\alpha}(1-\alpha|s-t|+o(|s-t|)).$$

Following Equation (3.24), therefore, the distribution function of M is

$$F\{a^{-1}(\frac{M\ -\mu}{\sigma/\sqrt{2\alpha}}-b\ )\le x\}\to\exp(-e^{-x})\text{ , or}$$

$$F\{a'^{-1}(M \quad -b' \quad) \le x\} \to \exp(-e^{-x}) \tag{3.25}$$

where $a'^{-1} = \frac{\sqrt{2\alpha}}{\sigma} a^{-1} = \frac{2\sqrt{\alpha \cdot \log(\Delta T)}}{\sigma}$, and (3.26)

$$b' = \mu + \frac{\sigma}{\sqrt{2\alpha}} b = \mu + \sigma\sqrt{\frac{\log(\Delta T)}{\alpha}} + \frac{\sigma}{4\sqrt{\alpha \cdot \log(\Delta T)}} \cdot \left\{ \log\log(\Delta T) + \log(\frac{\alpha\sigma^2}{2\pi}) \right\}. \tag{3.27}$$

Again, we use the maximum likelihood method (Kotz and Nadarajah, 2000, Cont, 2001) to estimate μ, α, and σ by plugging a'_t and b'_t into the probability density function of M_t which is given by

$$f(M) = \frac{1}{a'} e^{-\frac{M-b'}{a'}} \exp(-e^{-\frac{M-b'}{a'}}) \ . \tag{3.28}$$

Then the log-likelihood function is

$$L^*(a',b') = -N \log a' - \frac{1}{a'} \sum_{n=1}^{N} (M_n - b') - \sum_{n=1}^{N} e^{-\frac{M_n - b'}{a'}} \tag{3.29}$$

Results of parameter estimation implemented in MATLAB are shown in Table 3.3.

Table 3.3 Results of Parameter Estimation Using Maximum Prices: MLE

Lane	μ (\$/mile)	α (day^{-1})	σ (\$/(mile*day$^{0.5}$))
LADA	1.3240	0.2050	0.0880
LRCH	1.2224	0.4780	0.0697

For the minimum statistics,

$$m_n = Min\{Y_s; (n-1)\Delta T \le s \le n\Delta T\},\ n=1, 2, \ldots, N$$

can be written as $-m_n = Max\{-Y_s; (n-1)\Delta T \le s \le n\Delta T\}$. The distribution function of m is (Leadbetter et. al, 1983):

$$F\{a^{-1}(\frac{-m-\mu}{\sigma/\sqrt{2\alpha}} - b) \le -x\} \to \exp(-e^x)\ , \text{or}$$

$$F\{a'^{-1}(m+b') \le x\} \to 1-\exp(-e^x) \tag{3.30}$$

where a'_t and b'_t are defined as the same as Equations (3.26) and (3.27). Thus, we have the probability density function of m:

$$f(m) = \frac{1}{a'} e^{\frac{m-b'}{a'}} \exp(-e^{\frac{m-b'}{a'}})\ . \tag{3.31}$$

and the log-likelihood function:

$$L^*(a',b') = -N\log a' + \frac{1}{a'}\sum_{n=1}^{N}(m_n - b') - \sum_{n=1}^{N} e^{\frac{m_n - b'}{a'}} . \qquad (3.32)$$

Repeating the procedure of maximizing the log-likelihood function shown in the previous section, the estimated parameters are presented in Table 3.4.

Table 3.4 Results of Parameter Estimation Using Minimum Prices: MLE

Lane	μ (\$/mile)	α (day^{-1})	σ (\$/(mile*day$^{0.5}$))
LADA	1.4415	0.1028	0.0982
LRCH	1.1770	0.3361	0.0667

We further explore parameter estimation by using maximum and minimum together. Since the normalized maximum and minimum are asymptotically independent (Borkovec and Kluppelberg, 1998, Leadbetter et. al, 1983), the joint distribution function is given by Equation (3.33) with the same constants a' and b' as before.

$$F\{a'^{-1}(M \quad - b' \quad) \le x, a'^{-1}(m \quad + b' \quad) \le y\} \to \exp(-e^{-x})(1 - \exp(-e^{y})) \qquad (3.33)$$

When we combine their likelihood functions to estimate our model parameters, the likelihood function is:

$$L^*(a',b') = -N\log a' - \frac{1}{a'}\sum_{n=1}^{N}(M_n - b') - \sum_{n=1}^{N} e^{-\frac{M_n - b'}{a'}} - N\log a' + \frac{1}{a'}\sum_{n=1}^{N}(m_n - b') - \sum_{n=1}^{N} e^{\frac{m_n - b'}{a'}}$$

$$= -2N\log a' - \frac{1}{a'}\sum_{n=1}^{N}(M_n - m_n) - e^{-\frac{b'}{a'}}\sum_{n=1}^{N}(e^{\frac{M_n}{a'}} + e^{\frac{m_n}{a'}}). \tag{3.34}$$

Again, the parameters are obtained by MATLAB coding and are presented in Table 3.5.

Table 3.5 Results of Parameter Estimation Using Max and Min: MLE

Lane	μ (\$/mile)	α (day^{-1})	σ (\$/(mile*day$^{0.5}$))
LADA	1.3646	0.1297	0.0778
LRCH	1.2020	0.3312	0.0736

3.4.2.3 Using All Price Statistics

We then investigate what more information of parameters could get by combining the average, maximum and minimum prices altogether. Based on extreme value theory, the maximum and minimum of a stochastic process $\{X_t : t \geq 0\}$ behave like i.i.d. random variables and are not from the stationary distribution of $\{X_t\}$, but from the specific distributions described in section 3.4.2.2 (Borkovec and Klueppelberg, 1998). The maximum and the minimum of an O-U process, for example, are Gumbel distributed. Thus, the distribution of the average is independent from the maximum and the minimum [1]. Again, we combine their likelihood functions to estimate our model parameters. The likelihood function is:

[1] We thank Dr. Knut Solna for his helpful comment.

$$L^* = -\frac{N}{2}\log(2\pi) - N\log(\hat{\sigma}) - \sum_{n=1}^{N}\frac{[\widetilde{Y}_n - e^{-\alpha\Delta T}\widetilde{Y}_{n-1} - \mu(1-e^{-\alpha\Delta T})]^2}{2\hat{\sigma}^2}$$

$$-2N\log a' - \frac{1}{a'}\sum_{n=1}^{N}(M_n - m_n) - e^{-\frac{b'}{a'}}\sum_{n=1}^{N}(e^{\frac{M_n}{a'}} + e^{\frac{m_n}{a'}}),$$

where $\widetilde{Y}_n$, M_n, and m_n are the average, the maximum, and the minimum for period n, respectively. a' and b' are functions of α, μ, σ and are defined as Equations (3.26) and (3.27). The results are presented in Table 3.6.

Table 3.6 Results of Parameter Estimation Using Ave, Max and Min: MLE

Lane	μ (\$/mile)	α (day^{-1})	σ (\$/(mile*day$^{0.5}$))
LADA	1.3683	0.1612	0.0732
LRCH	1.2000	0.3623	0.0682

3.4.3 Summary of Estimates and Sensitivity Analysis

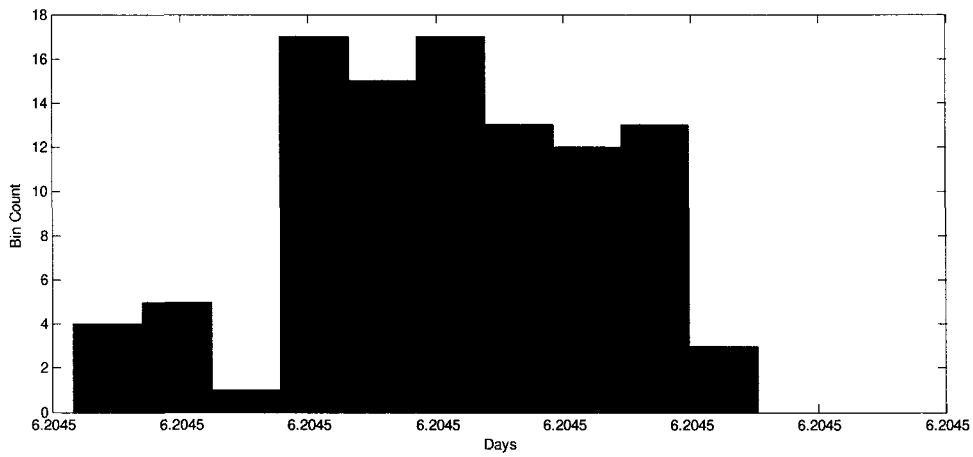
In summary, we have estimated the parameters by six alternatives with combination of two different methods and three different statistics. Table 3.7 presents all the results. We can see from the table that estimates of μ are quite stable among all the alternatives; estimates of σ are also fairly stable; the most variation is observed for α, especially for those alternatives having minimum prices involved. This could be because of some sudden changes in minima of LADA lane (see Figure 3.3) or small data size.

Therefore, we conduct a sensitivity analysis for the rate of mean reversion, α. We simulate 100 realizations of the truckload prices for 31 months based on the estimates derived from ML using all statistics jointly (the last row of each lane in Table 3.7). Then, we apply the variogram analysis and obtain estimates of α for each realization by fitting the variogram model using weighted least squares. Figure 3.7 shows the distribution of α. The simulation returns very consistent results for both LADA and LRCH: 6.2045 days (the estimate is 6.2035 days) and 2.7604 days (the estimate is 2.7601 days). We thus adopt the estimates derived from ML using all statistics jointly for option prices and the applications.

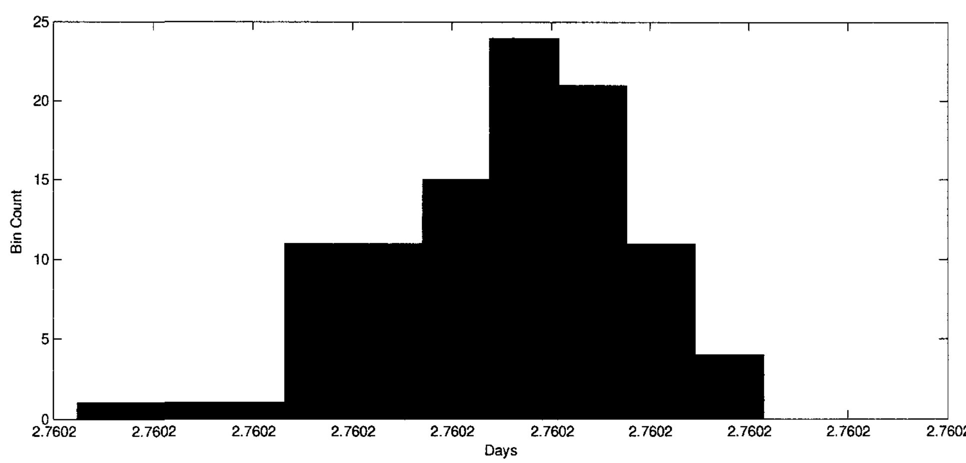
Table 3.7 Summary of Estimate Results

Lane	Statistics Adopted	Estimation Method	Parameters		
			α (day^{-1})	μ ($/mile)	σ ($/(mile*day$^{0.5}$))
LADA	Average Prices	Variogram	0.3016	1.3239	0.0748
	Average Prices	Maximum Likelihood	0.3418	1.3190	0.0707
	Maximum Prices	Maximum Likelihood	0.2050	1.3240	0.0880
	Minimum Prices	Maximum Likelihood	0.1028	1.4415	0.0982
	Max. & Min. Prices	Maximum Likelihood	0.1297	1.3646	0.0778
	Average, Max. & Min. Prices	Maximum Likelihood	0.1612	1.3683	0.0732
LRCH	Average Prices	Variogram	0.4196	1.2055	0.0520
	Average Prices	Maximum Likelihood	0.7136	1.2112	0.0624
	Maximum Prices	Maximum Likelihood	0.4780	1.2224	0.0697
	Minimum Prices	Maximum Likelihood	0.3361	1.1770	0.0667
	Max. & Min. Prices	Maximum Likelihood	0.3312	1.2020	0.0736
	Average, Max. & Min. Prices	Maximum Likelihood	0.3623	1.2000	0.0682

Notes: LADA refers to the lane from Los Angels, CA to Dallas, TX. LRCH denotes the lane from Laredo, TX to Chicago, IL.



(a) LADA lane



(b) LRCH lane

Figure 3.7 Distribution of 1/α for LADA and LRCH

CHAPTER 4 TRUCKLOAD OPTION PRICING MODEL

To develop our truckload option pricing model, we rely on option pricing theory. In general, the value of a truckload option is a function of the truckload price, Y, and of time t. Recall that the truckload price is assumed to follow an O-U process, and that the truckload option is European that can be exercised only on the expiration date.

In this chapter, we introduce the main methods used for developing the partial differential equation of options in the literature. Accordingly, the truckload option partial differential equation can be derived. Associated with the truckload price model established in Chapter 3, we derive a closed-form solution for truckload option price using a free-arbitrage pricing method.

4.1 Partial Differential Equation for Truckload Options

Two methods of deriving partial differential equation, which are particularly used in the real options literature, are dynamic programming and contingent claims. For a risk-neutral European type option, the same partial differential equation is given by these two methods.

4.1.1 Dynamic Programming Method

The dynamic programming approach is an older approach developed by Bellman and others in 1950's (Insley and Wirjanto, 2008). It is mostly adopted in management science to help make investment decisions. Some of the applications are natural resource investment problems, the optimal abandonment of a machine (Dixit and Pindyck, 1994), the optimal timing of applying a pesticide (Saphores, 2000).

Using a dynamic programming approach, the value $V(Y,t)$ of a truckload option is the expected present value with an exogenous discount rate. Then, $V(Y,t)$ can be expressed as (Dixit and Pindyck, 1994):

$$V(Y,t) = E[e^{-\rho(T-t)}\Omega(Y_T,T)] \tag{4.1}$$

where ρ is the discount rate; $\Omega(Y_T,T)$ is the payoff on the expiration date, T.

Now consider the situation with a short time interval, dt. The truckload price will have moved to $(Y+dY)$, and thus the value of the truckload option will have moved to $V(Y+dY,t+dt)$. As a result,

$$V(Y,t) = e^{-\rho \cdot dt}E[V(Y+dY,t+dt)]$$

$$= (1-\rho \cdot dt)[V(Y,t)+dV(Y,t)]. \tag{4.2}$$

And,

$$dV(Y,t) = \frac{\partial V}{\partial t}dt + \frac{\partial V}{\partial y}dy + \frac{1}{2}\frac{\partial^2 V}{\partial t^2}(dt)^2 + \frac{1}{2}\frac{\partial^2 V}{\partial y^2}(dy)^2 + + \frac{1}{2}\frac{\partial^2 V}{\partial t \partial y}(dtdy). \quad (4.3)$$

From Ito's lemma, the terms that go to zero faster than dt when $dt \to \infty$ can be ignored. Then, substitute dY from Equation (3.8) to get:

$$dV(Y,t) = \frac{\partial V}{\partial t}dt + \frac{\partial V}{\partial y}[\alpha(\mu - Y)dt + \sigma d\mathrm{B}] + \frac{1}{2}\frac{\partial^2 V}{\partial y^2}(\sigma^2 dt)$$

$$dV(Y,t) = [\frac{\partial V}{\partial t} + \alpha(\mu - Y)\frac{\partial V}{\partial y} + \frac{1}{2}\sigma^2\frac{\partial^2 V}{\partial y^2}]dt + \sigma\frac{\partial V}{\partial y}d\mathrm{B}. \quad (4.4)$$

Replacing $dV(Y,t)$ in Equation (4.2) by Equation (4.4) and choosing ρ to reflect the market risk and the risk-free interest rate (r), the risk-neutral value of a truckload option must satisfy the partial differential equation (PDE):

$$\frac{\partial V(Y,t)}{\partial t} + \frac{1}{2}\sigma^2\frac{\partial^2 V(Y,t)}{\partial y^2} + rY(t)\frac{\partial V(Y,t)}{\partial y} - rV(Y,t) = 0 \quad (4.5)$$

Therefore, Equation (4.5) is the partial differential equation for our proposed truckload options derived by dynamic programming.

4.1.2 Contingent Claims Method

The contingent claims approach is due to Black and Scholes (1973) and Merton (1973). In the finance literature, the contingent claims approach has generally dominated. Its basic concept is to eliminate risks by building a riskless portfolio.

For the truckload options, we construct a portfolio consisting of one unit of truckload option and some number of its underlying which is the spot truckload capacity. Again, truckload options are assumed to be European. The value of this portfolio, then, is given by

$$F(Y,t) = V(Y,t) + \Delta \cdot Y(t) \tag{4.6}$$

where $F(Y,t)$ is the portfolio value;

$V(Y,t)$ is the truckload option price;

$Y(t)$ is the truckload price, and

Δ is the number of truckload.

Assume this portfolio is self-financing, so the change in portfolio value only depends on the change in the asset prices. Then, the change is given by

$$dF(Y,t) = dV(Y,t) + \Delta \cdot dY(t) \tag{4.7}$$

Recall that the truckload price is modeled as an Ornstein-Uhlenbeck mean-reverting process in Equation (3.8):

$$dY(t) = \alpha(\mu - Y(t))dt + \sigma d\mathrm{B}(t).$$

By Ito's lemma, we have $dV(Y,t)$ as shown in Equation (4.4). Thus, Equation (4.7) can be written as

$$dF(Y,t) = [\frac{\partial V(Y,t)}{\partial t} + \alpha(\mu - Y(t))(\Delta + \frac{\partial V(Y,t)}{\partial y}) + \frac{1}{2}\sigma^2 \frac{\partial^2 V(Y,t)}{\partial y^2}]dt + \sigma(\Delta + \frac{\partial V(Y,t)}{\partial y})d\mathrm{B}(t) \tag{4.8}$$

To make sure this is a risk neutral investment, we set the change in this portfolio value to be the same as a portfolio with only risk-free assets. Specifically, this portfolio is required to have a return similar to a bank account with the risk-free interest rate. The change in the account value is

$$dF(Y,t) = [V(Y,t) + \Delta \cdot Y(t)] \cdot rdt \tag{4.9}$$

where r is the risk-free interest rate. Therefore, Equations (4.9) and (4.8) are equivalent, and we have

$$\begin{aligned}&[\frac{\partial V(Y,t)}{\partial t} + \alpha(\mu - Y(t))(\Delta + \frac{\partial V(Y,t)}{\partial y}) + \frac{1}{2}\sigma^2 \frac{\partial^2 V(Y,t)}{\partial y^2}]dt + \sigma(\Delta + \frac{\partial V(Y,t)}{\partial y})d\mathrm{B}(t)\\ &= [V(Y,t) + \Delta \cdot Y(t)]rdt\end{aligned}$$

To eliminate risk, we set the coefficient of the random term to zero, i.e.

$$\Delta = -\frac{\partial V(Y,t)}{\partial y}. \tag{4.10}$$

Consequently, the partial differential equation (PDE) for truckload options derived by the contingent claims approach is the same as the one derived by the dynamic programming approach (see Equation (4.5)).

4.2 Truckload Option Pricing Formula

4.2.1 Martingale Pricing Method

The PDE shown in Equation (4.11) has the same form as Black-Scholes equation, but the underlying processes are different. In the Black-Scholes model, the log return of the underlying follows a geometric Brownian motion, while the underlying itself follows mean-reverting O-U process in our model. In addition to the different processes, we model the truckload price itself, neither the log price nor the log return.

Regarding option pricing under O-U process, it is not difficult to find literature on pricing when the options are on log prices or log returns either in complete markets where the underliers are traded (see for examples, Lo and Wang, 1995; Schwartz, 1997; Haug, 2007), or in incomplete markets where the underliers are not traded (see for examples, Bjork, 2004; Hui et al., 2008). However, there are few option pricing formulas in the literature on the underliers whose price process are modeled as ours (Equation 3.8). One exception is Bjerksund and Ekern (1995), who value a European call option written on the spot freight rate of maritime shipping which is not traded. What makes our model different from Bjerksund and Ekern (1995) is that we regard truckloads as traded assets so that the capacity risk can be hedged.

To obtain an arbitrage-free option price for the truckload option, we construct an equivalent martingale measure for solving the PDE shown in Equation (4.11). Under the equivalent martingale measure denoted by P^*, the truckload price in Equation (3.8) is written as

$$dY_t = rY_t dt + \sigma d\mathrm{B}_t^* \tag{4.12}$$

where r is a constant interest rate, and

$$d\mathrm{B}_t^* = d\mathrm{B}_t + \frac{\alpha(\mu - Y_t) - rY_t}{\sigma} dt$$

is a Brownian motion under P^*.

Result 4.1 $E^*[Y_t \mid Y_0] = e^{rt} Y_0$ and $Var^*[Y_t \mid Y_0] = -\frac{\sigma^2}{2r}(1 - e^{2rt})$.

Proof. Consider $de^{-rt} Y_t = -re^{-rt} Y_t dt + e^{-rt} dY_t$

$$= (-re^{-rt} Y_t + re^{-rt} Y_t) dt + \sigma e^{-rt} d\mathrm{B}_t^*$$

$= \sigma e^{-rt} d\mathrm{B}_t^*$. (Remark: $e^{-rt} Y_t$ is a martingale under P^*.)

Then, $Y_t = e^{rt} Y_0 + \sigma e^{rt} \int_0^t e^{-rs} d\mathrm{B}_s^*$.

Therefore, $E^*[Y_t \mid Y_0] = e^{rt} Y_0$ and

$$Var^*[Y_t \mid Y_0] = -\frac{\sigma^2}{2r}(1 - e^{2rt}). \blacksquare$$

Next, we introduce the Feynman-Kac formula (Bjork, 2004). Assume that F is a solution to the boundary value problem

$$\frac{\partial F(x,t)}{\partial t} + \mu(x,t)\frac{\partial F(x,t)}{\partial x} + \frac{1}{2}\sigma^2(x,t)\frac{\partial^2 F(x,t)}{\partial x^2} - rF(x,t) = 0$$

with $F(x,T) = \Phi(x)$,

and $\int_0^t E[\sigma^2(X_s,s)\frac{\partial^2 F(X_s,s)}{\partial x^2}]ds < \infty$, then F has the representation

$$F(x,t) = e^{-r(T-t)}E[\Phi(X_T) \mid X_t]$$

where X satisfies the stochastic differential equation

$$dX_s = \mu(s,X_s)ds + \sigma(s,X_s)d\mathrm{B}_s$$

$$X_t = x.$$

According to the Feynman-Kac formula, the truckload option price can be represented as

$$V(Y,t) = e^{-r(T-t)}E[\Phi(Y_T) \mid Y_t] \tag{4.13}$$

where $\Phi(\cdot)$ is the payoff function corresponding to the truckload option contract; and T and t are the maturity of the option contract and the current time, respectively.

4.2.2 Truckload Options Pricing

4.2.2.1 Truckload Call Options Pricing

Recall from Chapter 2 that the payoff of a European call option is given by

$$\Phi(Y_T) = \max(Y_T - K, 0).$$

Following Equation (4.13), the price of a truckload call option, denoted by C(Y, t), is

$$C(Y,t) = E^*[e^{-r(T-t)} \max(Y_T - K,0) \mid Y_t]$$

(4.14)

which solves the PDE (Equation 4.11) with the following boundary conditions:

$$\begin{cases} C(0,t) = 0, \\ C(Y,t) \approx Y, \quad as \ Y \to \infty, \\ C(Y_T,T) = \max(Y_T - K,0) \end{cases}$$

According to Result 4.1, Y_T can be equivalently represented as

$$Y_T = m^* + \sigma^* \cdot z^* \qquad (4.15)$$

where $m^* = E^*[Y_T \mid Y_t] = e^{r(T-t)} Y_t$;

$\sigma^{*2} = Var^*[Y_T \mid Y_t] = -\dfrac{\sigma^2}{2r}(1 - e^{2r(T-t)})$; and

z^* being a standard normal random variable under P^*.

Back to Equation (4.14), we have

$$C(Y,t) = E^*[e^{-r(T-t)} \max(Y_T - K,0) \mid Y_t]$$

$$= e^{-r(T-t)} E^*[\max(m^* + \sigma^* \cdot z^* - K,0) \mid Y_t]$$

$$= e^{-r(T-t)} [\int_{-d}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^{*2}}{2}} (m^* - K) dz^* + \sigma^* \int_{-d}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^{*2}}{2}} \cdot z^* dz^*]$$

$$= e^{-r(T-t)} [(m^* - K) N(d) + \sigma^* n(d)] \tag{4.16}$$

where K is the exercise price; $d = \frac{m^* - K}{\sigma^*}$; $N(\cdot)$ and $n(\cdot)$ represent standard normal cumulative distribution and density function, respectively.

4.2.2.2 Truckload Put Options Pricing

The truckload put option price can be obtained like the call option. The payoff of a European put option is given by

$$\Phi(Y_T) = \max(K - Y_T, 0).$$

The price of a truckload put option, denoted by P(Y, t), also solves the PDE shown in Equation (4.11) but with the boundary conditions:

$$\begin{cases} P(0,t) = K \cdot e^{-r(T-t)}, \\ P(Y,t) \approx 0, \ \ as \ Y \to \infty, \\ P(Y_T, T) = \max(K - Y_T, 0) \end{cases}$$

Following Equation (4.13), we have:

$$P(Y,t) = E^*[e^{-r(T-t)} \max(K - Y_T, 0) \mid Y_t]$$

$$= e^{-r(T-t)} E^*[\max(K - m^* - \sigma^* \cdot z^*, 0) \mid Y_t]$$

$$= e^{-r(T-t)} [\int_{-\infty}^{-d} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^{*2}}{2}} (K - m^*) dz^* - \sigma^* \int_{-\infty}^{-d} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^{*2}}{2}} \cdot z^* dz^*]$$

$$= e^{-r(T-t)} [(K - m^*) N(-d) - \sigma^* n(-d)] \qquad (4.17)$$

where K is the exercise price; $d = \frac{m^* - K}{\sigma^*}$; $N(\cdot)$ and $n(\cdot)$ represent standard normal cumulative distribution and density function, respectively.

It is easy to show that the truckload call and put options prices in Equations (4.16) and (4.17) satisfy the put-call parity which is given by Equation (4.18).

$$Y(t) + P(Y,t) - C(Y,t) = K \cdot e^{-r(T-t)}. \qquad (4.18)$$

The put-call parity is a useful means to correlate the prices of a put option and a call option by considering a portfolio consisting with buying one asset, buying one put and selling one call when they have the same strike price and the same expiration date.

Figure 4.1 presents the arbitrage-free prices for a call option and a put option within a range of strike prices and expiration dates. For a call option, the price is higher when the strike price is lower because the payoff is the difference of the strike price and the spot price on expiration date. The price of a call option is also higher when the expiration date is farther ahead, because it is more uncertain about the future market. The reverse holds for the price of a put option.

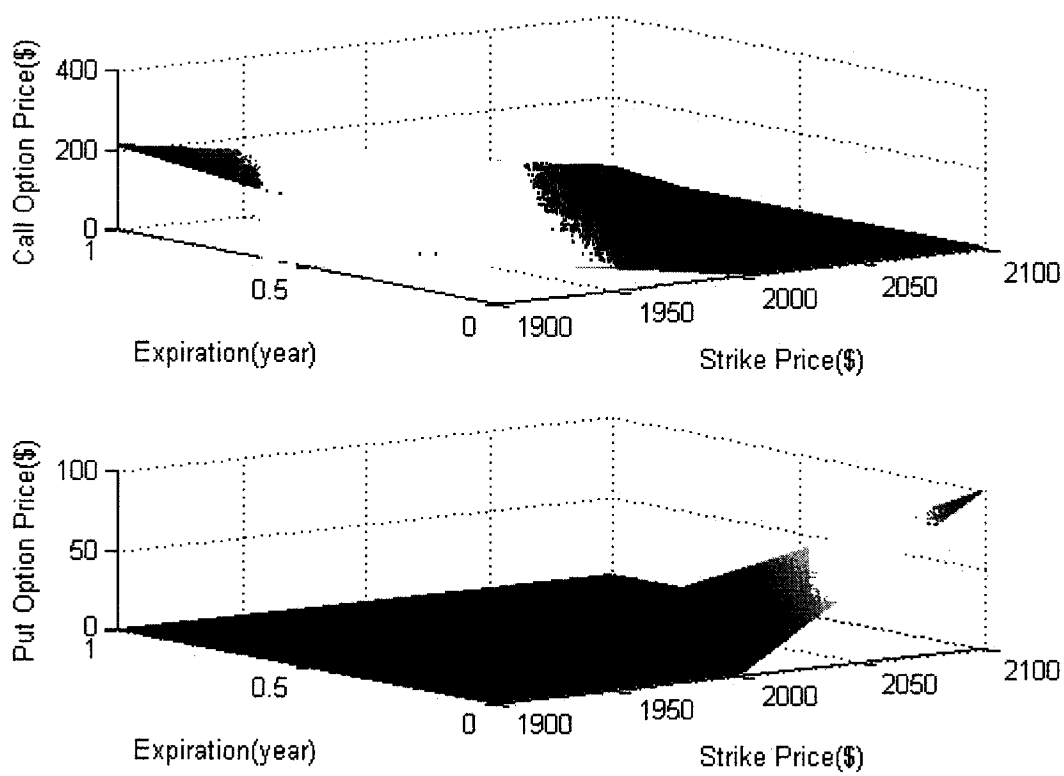


Figure 4.1 Truckload Option Prices for a Range of Strike Prices and Expiration Dates

4.3 Prices of Truckload Options

Given the pricing formula for truckload call options and put options in Equations (4.16) and (4.17), we illustrate the numerical examples for the two lanes used in Chapter 3, which are Los Angeles to Dallas (denoted by LADA) and Laredo to Chicago (denoted by LRCH).

The parameter estimates adopted here are the results obtained by MLE using all price statistics available: average, maximum, and minimum prices (see Table 3.6). Assume the current truckload prices for LADA and LRCH are $2,060 and $1,560, respectively. The strike prices for the LADA lane are set to be $1,950, $2,000, $2,050, and $2,100; for LRCH lane, the strike prices are at $1,450, $1,500, $1,550, and $1,600. Then, the prices of truckload call and put options with the setting strike prices and expiration dates (weekly based) are presented in Tables 4.1 to 4.4 and in Figures 4.2 to 4.5, correspondingly.

We can see from those Tables and Figures that for a given expiration date, the call option price increases as the strike price decreases because the option guarantees a fixed and lower price so it becomes more valuable; moreover, for a given strike price, the value of the call option increases with its expiration date: a longer time horizon allows more potential fluctuations and so it makes the option more valuable. These numerical results are consistent with the modeling results shown in Figure 4.1.

Table 4.1 Truckload Call Options Prices for the LADA Lane

Week	Strike Price			
	\$1,950	**\$2,000**	**\$2,050**	**\$2,100**
1	\$112.6	\$65.7	\$28.4	\$7.8
2	\$116.8	\$73.1	\$38.5	\$16.1
3	\$121.5	\$80.0	\$46.6	\$23.3
4	\$126.4	\$86.3	\$53.6	\$29.7
5	\$131.2	\$92.2	\$59.9	\$35.5
6	\$136.0	\$97.7	\$65.7	\$41.0
7	\$140.6	\$102.9	\$71.2	\$46.2
8	\$145.1	\$107.9	\$76.4	\$51.1
9	\$149.4	\$112.7	\$81.3	\$55.8
10	\$153.7	\$117.4	\$86.1	\$60.3
11	\$157.9	\$121.9	\$90.6	\$64.7
12	\$162.0	\$126.2	\$95.1	\$69.0

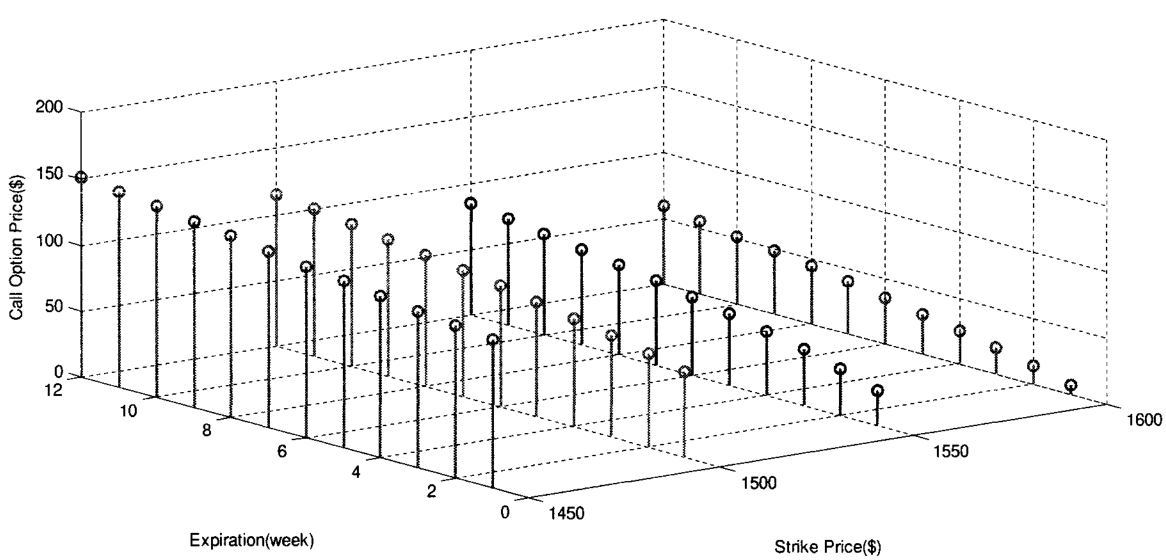


Figure 4.2 Plot of Truckload Call Options Prices for the LADA Lane

Table 4.2 Truckload Call Options Prices for the LRCH Lane

Week	Strike Price			
	$1,450	**$1,500**	**$1,550**	**$1,600**
1	$111.9	$64.3	$26.2	$6.3
2	$114.9	$70.4	$35.2	$13.4
3	$118.6	$76.2	$42.4	$19.7
4	$122.4	$81.6	$48.6	$25.2
5	$126.4	$86.6	$54.2	$30.4
6	$130.2	$91.4	$59.3	$35.1
7	$134.0	$95.8	$64.1	$39.6
8	$137.7	$100.1	$68.6	$43.9
9	$141.4	$104.3	$72.9	$48.0
10	$144.9	$108.2	$77.0	$51.9
11	$148.4	$112.1	$81.3	$55.7
12	$151.8	$115.8	$84.8	$59.4

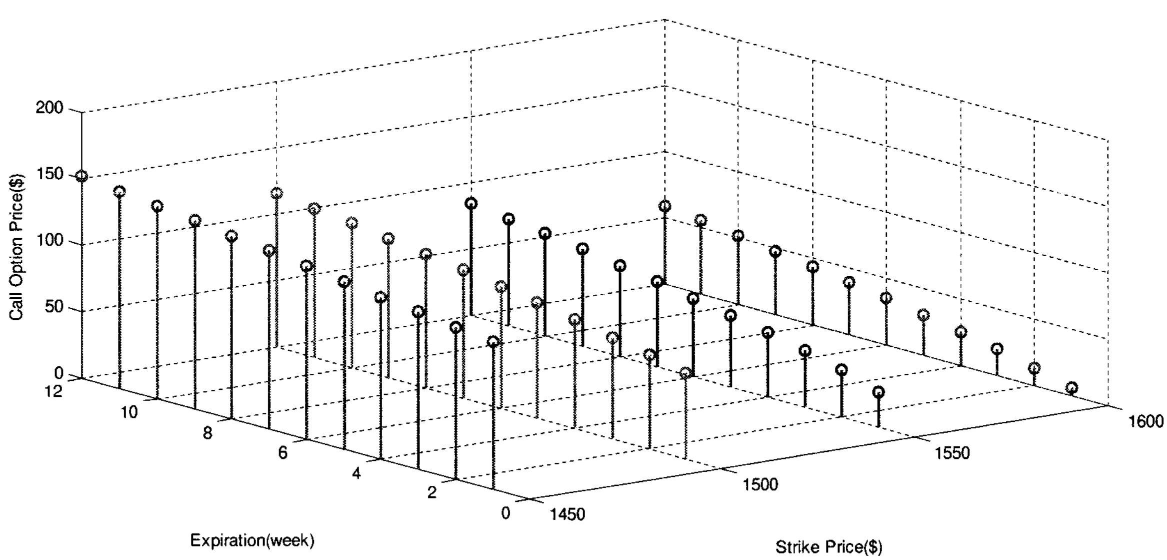


Figure 4.3 Plot of Truckload Call Options Prices for the LRCH Lane

Table 4.3 Truckload Put Options Prices for the LADA Lane

Week	Strike Price			
	$1,950	**$2,000**	**$2,050**	**$2,100**
1	$0.4	$3.4	$16.0	$45.4
2	$2.3	$8.5	$23.8	$51.3
3	$4.8	$13.1	$29.5	$56.0
4	$7.4	$17.1	$34.1	$60.0
5	$10.0	$20.7	$38.1	$63.5
6	$12.5	$23.9	$41.6	$66.5
7	$14.9	$26.8	$44.7	$69.3
8	$17.1	$29.6	$47.6	$71.8
9	$19.3	$32.1	$50.2	$74.1
10	$21.4	$34.4	$52.6	$76.3
11	$23.3	$36.6	$54.8	$78.2
12	$25.2	$38.7	$56.9	$80.1

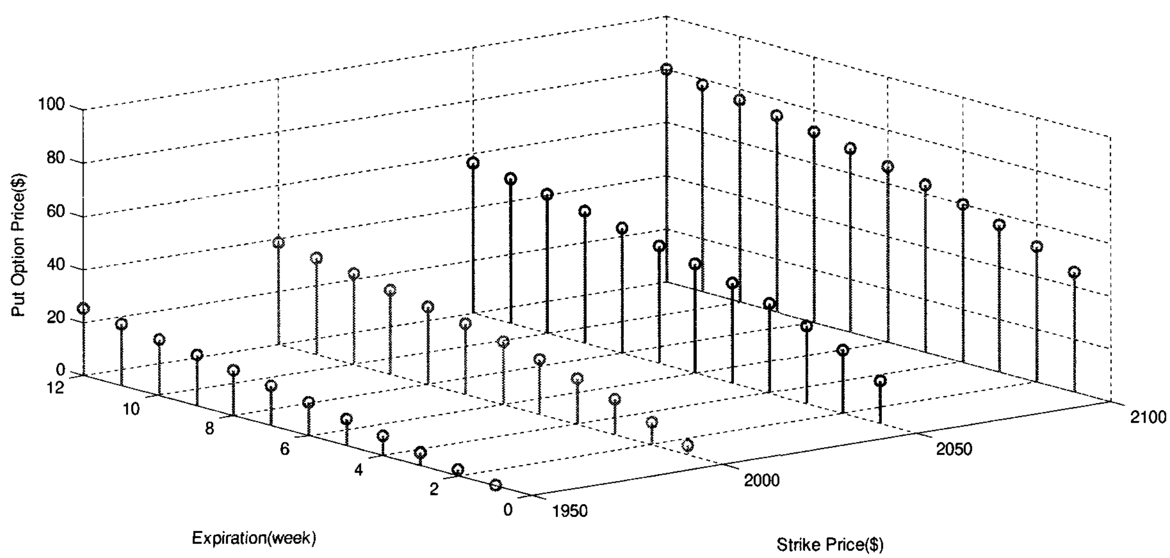


Figure 4.4 Plot of Truckload Put Options Prices for the LADA Lane

Table 4.4 Truckload Put Options Prices for the LRCH Lane

Week	Strike Price			
	$1,450	**$1,500**	**$1,550**	**$1,600**
1	$0.2	$2.5	$14.4	$44.4
2	$1.6	$6.9	$21.7	$49.7
3	$3.6	$11.0	$27.0	$54.1
4	$5.8	$14.7	$31.5	$57.9
5	$8.0	$18.0	$35.2	$61.2
6	$10.2	$21.0	$38.6	$64.1
7	$12.4	$23.8	$41.6	$66.8
8	$14.4	$26.4	$44.4	$69.2
9	$16.4	$28.8	$46.9	$71.5
10	$18.3	$31.0	$49.2	$73.6
11	$20.1	$33.1	$51.4	$75.5
12	$21.9	$35.1	$53.5	$77.4

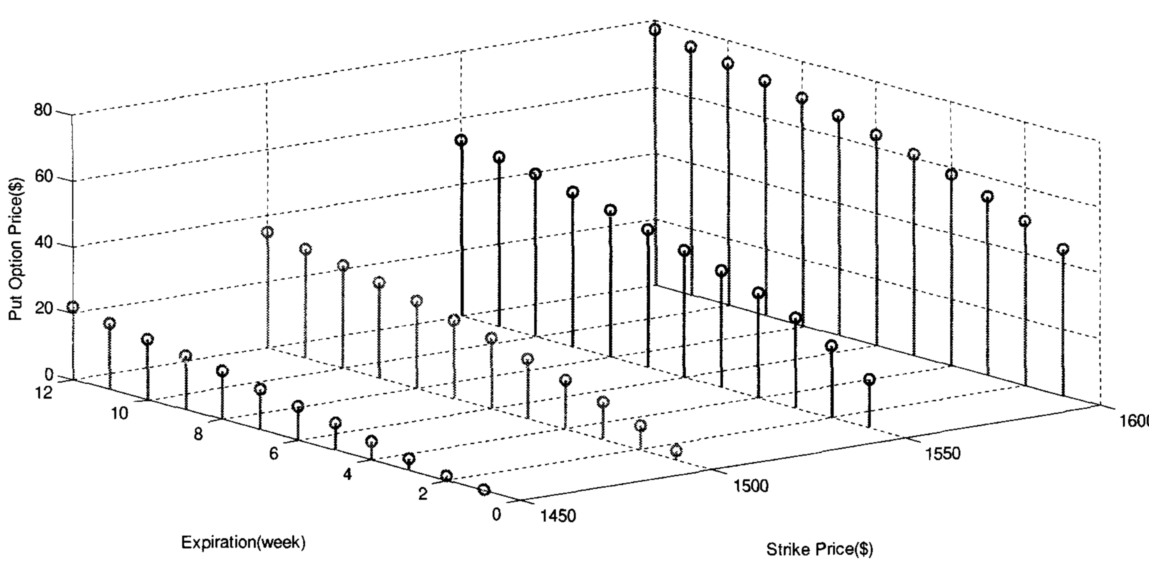


Figure 4.5 Plot of Truckload Put Options Prices for the LRCH Lane

CHAPTER 5 NUMERICAL EXAMPLES

To illustrate how truckload options work and show the benefits that truckload options bring to shippers and carriers, we develop two possible applications of truckload call and put options.

5.1 Marketplace Setting

Before going to the details of the applications, it is worthwhile describing our simulated marketplace for trading truckload options.

A simulated marketplace based on the practice of a current on-line transportation market is established. The simulated marketplace is functional as a truckload options trading platform. The truckload options section would look like Figure 5.1.

Taking the necessary conditions of the hedging effectiveness and the liquidity into consideration, the truckload options are not available for all origin-destination pairs, but only available for those lanes with high freight traffic and high transported value, which are decided by the marketplace. Each lane available for trading is called a 'product' of the marketplace. The details of the products include the route description, the trading unit, the trading time window, etc. Figure 5.2 shows the page of products, while Figure 5.3 presents the description for each specific product.

The marketplace also publishes the information on truckload spot prices, truckload call and put options prices (see Figures 5.4 ~ 5.5). There would be a clearing system that is implemented by a neutral third party. The clearinghouse supervises the transactions and ensures compliance with the exchange rules. It helps mitigate counterparty credit risk. Consequently, a fee is charged for the service. However, it is usually a small percent of the transaction amount; for example, 1.25 % for the IMAREX clearinghouse. We do not consider the fee in the following applications.

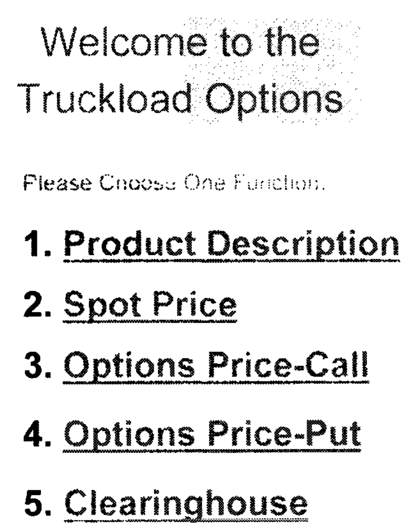


Figure 5.1 Simulated Marketplace for Truckload Options

Product Description

Los Angeles, CA to Dallas, TX

Los Angeles, CA to Las Vegas, NV

Los Angeles, CA to San Francisco, CA

Laredo, TX to Chicago, IL

Laredo, TX to Detroit, MI

Laredo, TX to New York, NY

Go back to the Main Page

Figure 5.2 List of Product Available for Trading

Product Description

Los Angeles, CA to Dallas, TX

Trading Unit
One truckload.

Trading Weeks
12 consecutive weeks.

Termination of Trading
Trading ceases on the last business day of the contract week.

Trading Symbol
LADA

Go back to the Main Page

Figure 5.3 Product Description

Options Price-Call

Trading Symbol: LADA Oct. 24, 2008

Strike Price: [illegible] **Spot Price:** 2060

Expiration	Deal	Bid	Ask	Qty	Trade
Nov. Week 1	65.7	65.7	65.7	13	Bid Ask
Nov. Week 2	73.1	72.5	73.1	14	Bid Ask
Nov. Week 3	80.0	79.5	80.5	12	Bid Ask
Nov. Week 4	86.3	86.5	86.8	20	Bid Ask
Dec. Week 1	92.2	92.5	92.8	35	Bid Ask
Dec. Week 2	97.7	98.5	99.0	40	Bid Ask
Dec. Week 3	102.9	103	103.5	40	Bid Ask
Dec. Week 4	107.9	107.9	107.9	30	Bid Ask

Go back to the Main Page

Figure 5.4 Truckload Call Options Trading Platform

Options Price-Put

Trading Symbol: LADA Oct. 24, 2008

Strike Price: [illegible] **Spot Price:** 2060

Expiration	Deal	Bid	Ask	Qty.	Trade
Nov. Week 1	45.4	45.8	46.0	43	Bid Ask
Nov. Week 2	52.0	52.0	52.0	40	Bid Ask
Nov. Week 3	56.0	56.5	57.0	31	Bid Ask
Nov. Week 4	60.0	60.2	60.5	32	Bid Ask
Dec. Week 1	63.5	63.0	63.5	23	Bid Ask
Dec. Week 2	66.5	66.0	66.2	20	Bid Ask
Dec. Week 3	69.3	68.0	69.0	26	Bid Ask
Dec. Week 4	71.8	71.0	71.5	13	Bid Ask

Go back to the Main Page

Figure 5.5 Truckload Put Options Trading Platform

5.2 Application of Truckload Call Options

5.2.1 Example Description

Suppose a shipper who does not have a long-term transportation contractor is not certain about its demand for truckload services for the next 12 weeks. The shipper is worried about the unavailability and the high cost of truckload service when a sudden delivery demand occurs. Therefore, the shipper buys truckload call options now to protect against an increase in cost as well as to ensure that he or she can obtain service if demand materializes in the near future, because a truckload call option provides a shipper with the right to procure truckload service with a certain strike price and expiration date.

The shipper could buy truckload call options with whatever strike price and whatever expiration date she wants. However, in order to understand all the possible situations and simplify the problem, we assume the shipper buys call options for each of the next 12 week, with a constant strike price now. We then analyze four situations corresponding to four different strike prices.

5.2.2 Effects on Hedging Price and Capacity Uncertainties for Shippers

To demonstrate the quantitative benefit of truckload call options, we start with three scenarios characterized by different levels of uncertainty. We assume that the demand for truckload services for a shipper follows a Poisson distribution with a weekly arrival rate λ. We set λ equal to 3, 1 and 0.2; this corresponds to the scenarios in which unexpected demand occurs according to a very likely, somewhat likely, and less likely probability, respectively. The total cost for a shipper includes the cost of call options and the cost of shipping. The shipping cost is either the strike price or the spot price, depending on which is lower on the date of need. Tables 5.1 and 5.2 present the representative benefits of purchasing truckload options for shippers and carriers for 12 consecutive weeks based on the prices in Tables 4.1 and 4.2; these benefits are then compared to the case where truckload options are not available and the transportation cost is simply the sum of spot prices.

Table 5.1 Benefits for Shippers and Carriers Using Call Options: LADA Lane

			Strike Price				Without Options
			$1,950	**$2,000**	**$2,050**	**$2,100**	
A (λ=3)	Transportation Costs		$62,100	$63,180	$64,340	$65,600	$66,800
	Benefit	Shipper	$4,700	$3,620	$2,460	$1,210	-
		Carrier	-$2,630	-$1,550	-$400	$860	-
B (λ=1)	Transportation Costs		$44,550	$45,180	$45,890	$46,660	$47,880
	Benefit	Shipper	$3,320	$2,690	$1,980	$1,210	-
		Carrier	-$1,200	-$570	$140	$910	-
C (λ=0.2)	Transportation Costs		$9,450	$9,180	$8,990	$8,900	$8,780
	Benefit	Shipper	-$670	-$400	-$210	-$120	-
		Carrier	$17,850	$17,580	$17,390	$17,300	-

Table 5.2 Benefits for Shippers and Carriers Using Call Options: LRCH Lane

Scenario			Strike Price				Without Options
			$1,450	**$1,500**	**$1,550**	**$1,600**	
A (λ=3)	Transportation Costs		$45,080	$46,110	$47,210	$48,430	$51,220
	Benefit	Shipper	$6,140	$5,120	$4,010	$2,800	-
		Carrier	-$2,620	-$1,590	-$490	$730	-
B (λ=1)	Transportation Costs		$20,430	$20,610	$20,860	$21,230	$22,090
	Benefit	Shipper	$1,660	$1,490	$1,230	$870	-
		Carrier	$3,610	$3780	$4,040	$4,400	-
C (λ=0.2)	Transportation Costs		$8,830	$8,610	$8,460	$8,430	$8,610
	Benefit	Shipper	-$230	$0	$140	$180	-
		Carrier	$12,270	$12,040	$11,900	$11,860	-

Although some situations benefit either shippers or carriers, there are win-win cases for both parties. We see that the impact of truckload options on shippers' cost of spot truckload services varies between -3.1% and 4.8% per month. We expect the actual benefit for shippers will be higher, because here we did not consider the opportunity cost of service unavailability. That is, the results did not reflect the advantage of guaranteed transportation service, which is difficult to quantify. Besides, the negative effects are only shown in the scenario where the unexpected demand is less likely to occur. This responds to the necessary condition – uncertainty. The demand uncertainty is not obvious so the benefit of truckload options is not clear. On the other hand, the effect on carriers is between -2.1% and 81.3% per month; the latter corresponds to the case where the shipper does not exercise his or her call option and the carrier sells the truckload in the spot market. One interesting observation is that the total benefit for each case is positive. That result does not depend on which party wins or loses; truckload options have positive value to the whole system. This also illustrates the value of risk management and the spirit of risk sharing which is increasingly popular in the logistics industry.

5.3 Application of Truckload Put Options

5.3.1 Example Description

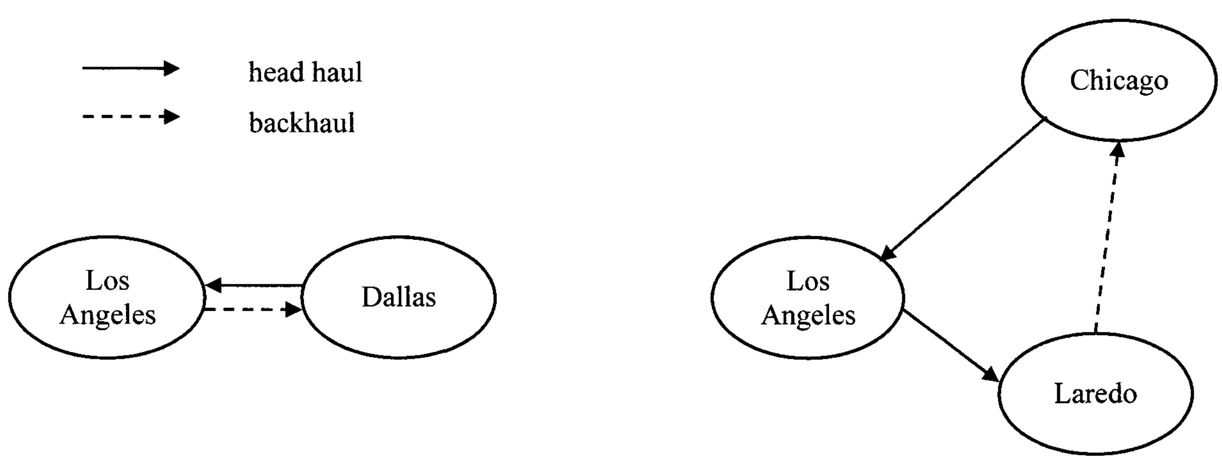
We now demonstrate how truckload put options would help carriers construct bids and strengthen power of the auction. In practice, carriers bid for long term contracts which are usually valid for one year. The contracts specify the shipping cost and the forecasted total number of (typically weekly) truckloads for certain lanes. The contract provides the shipper the right to request service at the pre-determined price and the carrier the right to carry the loads at that same price; it does not *guarantee* either the demand or the availability of capacity at a specific time. The uncertain delivery schedule makes fleet management and dispatching more difficult and also increases the probability of empty backhauls. Empty movements (also known as 'deadhead' movements) challenge carriers and increase overall costs. It is not surprising that carriers would add the partial or full backhaul cost into the price of loaded moves, if the backhaul is expected to be empty. On the other hand, carriers would reduce the price of the loaded move by 5%~8% if the movements are continuous (Caplice and Sheffi, 2006). Therefore, loaded backhauls are essential to trucking operations. To this end, carriers may buy put options which guarantee they have truckload delivery at a predetermined price on a predetermined date.

5.3.2 Effects on Compensation for 'Deadhead' Movements for Carriers

Consider three scenarios of the request for bids with numbers of annual shipments 150, 100, and 50 for the lane from Dallas to Los Angeles (see Figure 5.6 (a)). While preparing the bid, the carrier takes not only the cost and the reasonable profit of shipping loads from Dallas to Los Angeles into account, but also the cost of a backhaul. Assume the cost and the profit of loaded moves are constant and independent from those of the backhaul. Then the value of the submitted bid will be affected by whether the backhaul is loaded or not. Therefore, we focus on the contribution that truckload put options would bring to the backhaul operation. The three scenarios are roughly equivalent to the weekly average movements of 3 truckloads (λ=3), 2 truckloads (λ=2) and 1 truckload (λ=1), corresponding to the above numbers of annual shipments (assume that there are 52 weeks in a year). Table 5.3 presents the reduction in the bidding price, based on the put option prices shown in Table 4.3. Conservatively, having put options reduces the bidding price by \$620~\$650, or 18%~19%.

Since the benefit of using put options on backhaul operation is considered exogenous, i.e. independent from the loaded operation, it is easy to extend our example to the case with more nodes and links. For example, consider a request for bid for two shipping lanes: from Chicago to Los Angeles and from Los Angeles to Laredo (see Figure 5.6 (b)). A carrier may bid the two lanes together (possibly in a combinatorial auction) and would like to hedge the deadhead movements from Laredo to Chicago. Again, we show the possible reduction in the bidding price under three scenarios of annual shipments in Table 5.4. Overall, the bidding price is reduced by \$450~\$500, or 18%~20%.

The application of put options integrates the operations of a long term contract and a spot market. A carrier gains more room to decrease the bidding price for a long term contract with the right of offering truckload services in a spot market. By the same token, a shipper benefits from a lower contract price while other shippers profit from selling put options, especially for those who have large and less time-sensitive delivery needs.



(a) two nodes and one link

(b) three nodes and three links

Figure 5.6 Examples of Shipment Lanes

Table 5.3 Decrease in Bidding Price Using Truckload Put Options: LADA Lane

Scenario	Strike Price			
	$1,950	$2,000	$2,050	$2,100
A (λ=3)	$641.38 (19.35%)	$637.30 (19.22%)	$630.69 (19.03%)	$621.04 (18.73%)
B (λ=2)	$646.73 (19.51%)	$642.22 (19.37%)	$634.90 (19.15%)	$625.21 (18.86%)
C (λ=1)	$645.67 (19.48%)	$639.93 (19.30%)	$630.61 (19.02%)	$618.52 (18.66%)

Table 5.4 Decrease in Bidding Price Using Truckload Put Options: LRCH Lane

Scenario	Strike Price			
	$1,450	$1,500	$,1550	$1,600
A (λ=3)	$507.81 (20.60%)	$503.83 (20.44%)	$497.06 (20.16%)	$486.73 (19.75%)
B (λ=2)	$510.80 (20.72%)	$506.03 (20.53%)	$497.90 (20.20%)	$485.50 (19.70%)
C (λ=1)	$499.64 (20.27%)	$490.45 (19.90%)	$474.83 (19.26%)	$450.98 (18.30%)

CHAPTER 6 CONCLUSIONS AND FUTURE RESEARCH

6.1 Conclusions

Based on observations of current supply chain practices, one of the challenges facing shippers who need to have loads transported, such as suppliers, manufacturers and retailers, is that they are required to deliver cargos rapidly and accurately within a short time window, even though the orders arrive with a high degree of irregularity and uncertainty. This situation has become more and more serious, because shippers would like to delay ordering so they can reduce inventory costs and can have more time to analyze the market reaction to their products. Therefore, any ordering mechanism that can achieve this purpose is prevailing throughout the supply chain industry, namely demand-response, just-in-time, lean logistics, etc. The current procurement of transportation services is not sufficiently efficient or flexible to cope with these immediate needs. Even large retailers who have their own fleets, like Wal-Mart, also procure truckload services from spot markets to meet unexpected demands. However, spot prices are higher than the contract prices. It is not surprising that transportation costs increase significantly as unexpected demand occurs. Another issue is the availability of truckload services. It is not guaranteed that shippers could procure any quantity of truckloads for any origin-destination pairs at any time they want. The availability of truckload services is severely restricted during the peak seasons. As a result, shippers need a new contracting technique to manage the tough demand environment.

This dissertation introduces truckload options as a means of hedging uncertainty in price, demand and supply of truckload services. We start with investigating derivatives contracts applied to ocean transportation, which is the only mode of transportation where this type of contract has been applied. By reviewing the termination of BIFFEX, and surveying the current options market in the maritime industry, we conclude that the necessary conditions and potential benefits for the emergence of a market for truckload options derivatives contracts are: uncertainty, hedging effectiveness, liquidity and institutional robustness.

Uncertainty is crucial for truckload options. Without uncertainty, options would have no value. Hedging effectiveness is the ability of the contract to hedge the uncertainties of interest; while market with liquidity means that a seller is able to find a buyer without much difficulty. In order to secure liquidity for trucking options, the freight flow of various lanes and their seasonality effects should be considered. Trucking options are more attractive on lanes with high freight flows throughout the year. To fulfill truckload options trading, an institution specializing in setting the marketplace specifications and overseeing transactions will be essential. It would be responsible for setting trading rules and types of options, publishing trading prices, and clearing trades.

Next, we model the dynamics of spot truckload prices. For simplicity, we model the spot prices as a mean-reverting O-U process whose basic concept is that a variable fluctuates up and down, but tends to go back to a set level. In the mean-reverting O-U process, there are three parameters which must be estimated. They are the rate of reversion (α), the level that the variable tends to return to (μ), and the volatility parameter (σ). The data used to estimate these parameters are manually obtained by accessing a trucking electronic marketplace named truckloadrate.com. This database provides the maximum, the minimum and the average of TL prices for specific origin-destination pairs every month. Although they only provide price statistics, the data are the most appropriate that we could possibly obtain because the truckload rates are not public. However, it complicates the estimation for the parameters of a day-by-day based model. To increase the confidence in the estimating results, we apply two estimation methods (variogram analysis and maximum likelihood) and use three price statistics (average, maximum, and minimum) separately as well as jointly to estimate the three parameters of our spot price model.

Furthermore, we present how to derive the partial differential equation (PDE) for truckload option price using a dynamic programming method and a contingent claims method. Applying martingale pricing method, we solve the PDE and obtain a closed-form pricing formula for a European type option. We then use the estimates derived above to value truckload options. We also explore two applications for two selected lanes based on real data from a website that matches buyers and sellers of truckload services.

Obtaining daily data would make it unnecessary to estimate parameters based on the min, the max, and the average; it would also likely yield more precise estimates of the OU parameters and it would enable considering other models (including a model whose log follows an OU, which is likely more realistic).

An exploration of shippers buying and carrier selling truckload call options follows. The numerical results of scenarios based on different levels of uncertainty shows that while not all parties always win, there do exist win-win solutions for both parties. The negative effects for shippers are seen only in the scenario where the unexpected demand is less likely to occur. This corresponds to the necessary condition – uncertainty. The demand uncertainty is not obvious so the benefit of truckload options is not clear. The most interesting observation is that the overall benefit of truckload call options to the system (that is to shippers and carriers combined) appears to be positive. This illustrates the value of risk management and the spirit of risk sharing which is increasingly popular in the logistics industries.

Another application of options concerns a carrier buying and a shipper selling truckload put options. Truckload put options contribute to reducing bidding prices, which implies that the application of put options benefit carriers as well as shippers. According to our numerical results, the price of a shipment could decrease by up to 20%, which compares favorably to a 5% to 8% decrease using current contracting methods (Caplice, 2007). This decrease results from an increase in carrier loaded backhaul opportunities.

In summary, this dissertation presents a method to create value through more flexible procurement contracts, which could benefit the trucking industry as a whole -- particularly in an uncertain business environment. We carefully investigate a truckload rate model and a truckload options pricing model. In addition, we explore parameter estimation for a continuous stochastic model using discrete statistics. Finally, we illustrate numerical trading examples and set up a picture of truckload option trading becoming a reality. We believe that truckload options have the potential of stimulating the entire trucking and logistics industries.

6.2 Future Research Suggestions

This research is the first attempt to develop options contracts for procuring truck transportation services. As expected, there are still some aspects worth more efforts.

First, future research could focus more on hedging effectiveness, market liquidity and smart regulations, which are the necessary conditions for the success of our proposed options. These issues can be addressed in the light of financial options. However, it would need options trading data to develop appropriate measurements for hedging effectiveness and market liquidity. This could be a challenge when the truckload options market has not realized.

Second, non-quantitative and side benefits of truckload options can be integrated in the benefit analysis. We expect truckload options to be even more valuable. Some of these benefits include guaranteed truckload services, decreased storage costs for shippers and so on.

Third, dynamic trading strategies would further increase the benefits of having truckload options, as they would provide even more flexibility. In our applications, we assume that shippers and carriers buy and sell options for each of the coming twelve weeks at the first day. This assumption can be relaxed; shippers and carriers could buy or sell options whenever they need to. An optimal result can be reached if trading strategies are applied appropriately.

Finally, different truckload price models and different type of truckload options can be studied. In our research, we model the truckload prices as a mean-reverting O-U process with a constant variance. The future study can extend this to a model with stochastic volatility or/and with a jump process. In addition to the European type of options, American and Asian options can also be considered.

REFERENCES

Ambrogi, S. (2007) Update 1-Dry Freight Futures Trade Hits Record in Q2-Baltic. Reuters News, London.

ATA. (2006) U.S. Freight Transportation Forecast to 2017. American Trucking Associations, Alexandria, VA.

Baltic Exchange Homepage. www.balticexchange.com. Accessed July, 2007.

Berman, S.M. (1971) Maxima and High Level Excursions of Stationary Gaussian Processes. Transactions of the American Mathematical Society 160, 65-85.

Berwick, M., Farooq, M. (2003) Truck Costing Model for Transportation Managers.

Bjerksund, P., Ekern S. (1995) Contingent Claims Evaluation of Mean-Reverting Cash Flows in Shipping. Real Options in Capital Investment: Models, Strategies, and Applications, Chapter 12, Praeger, Westport, CT.

Bjork, T. (2004) Arbitrage Theory in Continuous Time, 2nd Edition. Oxford University Press, New York.

Black, F. (1976) The Pricing of Commodity Contracts. Journal of Financial Economics 3, 167-179.

Black, F., Scholes, M. (1973) The Pricing of Options and Corporate Liabilities. The journal of Political Economy 81 (3), 637-654.

Borkovec, M., Klueppelberg, C. (1998) Extremal Behavior of Diffusion Models in

Finance. Extremes 1 (1), 47-80.

Bouchaud, J.P., Potters M. (2003) Theory of Financial Risk and Derivative Pricing. Chapter 4, 2nd edition, Cambridge University Press, Cambridge, U.K.

Breiman, L. (1992) Probability. Chapter 16, Society for Industrial and Applied Mathematics, Philadelphia, PA.

Bureau of Transportation Statistics. (2006) Freight in America. U.S. Department of Transportation.

Bureau of Transportation Statistics. (2002) Commodity Flow Survey. U.S. Department of Transportation.

Caplice, C. (2007). Electronic Markets for Truckload Transportation. Production and Operations Management 16 (4), 423-436.

Caplice, C., Sheffi, Y. (2006) Combinatorial auctions for truckload transportation. In: Cramton, P., Shoham, Y., Steinberg, R. (Eds), Combinatorial Auctions, MIT Press, Chapter 21.

Campbell, J.Y., Lo, A.W., MacKinlay, A.C. (1997) The Econometrics of Financial Markets. Princeton University Press, Princeton, NJ.

Center for Transportation and Logistics. (2004) Looking for Options. MIT SUPPLY CHAIN FRONTIERS (1). Cambridge, MA.

Cont, R. (2001) Empirical Properties of Asset Returns: Stylized Facts and Statistical Issues. Quantitative Finance 1, 223-236.

Cont, R., Tankov, P. (2004) Financial Modelling with Jump Processes. Chapman & Hall/CRC. Boca Raton, FL.

Corsi, T.M. (2005) The Truckload Carrier Industry Segment. Trucking in the Age of Information. Ashgate Publishing Company, Burlington, VT. 21-42.

Council of Supply Chain Management Professionals (CSPCP). (2006) Glossary of Terms. http://www.cscmp.org/Website/Resources/Terms.asp.

Cox, J.C., Ross, S.A., and Rubinstein, M. (1979) Option Pricing: A Simplified Approach. Journal of Financial Economics 7, 229-263.

Cressie, N. (1985) Fitting Varioagram Models by Weighted Least Squares. Mathematical Geology 17 (5), 563-586.

Dalheim, F. (2002) Freights Derivatives Trading and 'Value-at-Risk' in Tanker and bulk shipping. Marine Money, June, 23-29.

Dixit, A.K., Pindyck, R.S. (1994) Investment under Uncertainty. Princeton University Press, NJ.

Duan, J.C. (1994) Maximum Likelihood Estimation Using Price Data of the Derivative Contract. Mathematical Finance 4 (2), 155-167.

Embrechts, P., Kluppelberg, C., Mikosch, T. (1997) Modelling Extremal Events for Insurance and Finance. Springer-Verlag, Berlin Heidelberg.

Fouque, J.P., Papanicolaou, G, Sircar, R.K. (2000) Derivatives in Financial Markets with Stochastic Volatility. Chapter 4, Cambridge University Press, Cambridge, U.K.

Fouque, J.P., Papanicolaou, G, Sircar, R.K., Solna, K. (2000) Mean Reversion of S&P 500 Volatility. Working Paper, Raleigh, NC.

Geman, H. (2005) Commodities and Commodity Derivatives. John Wiley & Sons, Ltd., West Sussex, England.

Geman, H., Nguyen, V.N. (2005) Soybean Inventory and Forward Curve Dynamics. Management Science 51 (7), 1076-1091.

Getloaded.com, LLC. (2007) Midlothian, VA. http://www.getloaded.com.

Haigh, M.S., Holt, M.T. (2002) Hedging Foreign Currency, Freight and Commodity Futures Portfolios – A Note. The Journal of Futures Markets 22 (12), 1205–1221.

Haug, E.G. (2007) The Complete Guide to Option Pricing Formulas. McGraw-Hill, New York.

Heston, S.L. (1993) A Closed-Form Solution for Options with Stochastic Volatility with Applications to Bond and Currency Options. The Review of Financial Studies 6 (2), 327-343.

Hubbard, T.N. (2003) Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking. The American Economic Review 93 (4), 1328-1353.

Hui, C.H., Lo, C.F., Yeung, V., Fung, L. (2008) Valuing Foreign Currency Options with a Mean-Reverting Process. International Journal of Finance and Economics 13, 118-134.

Hull, J.C. (2006) Options, Futures, and Other Derivatives. 6th edition, Prentice Hall, Upper Saddle River, NJ.

IBIS World (2007) General Freight Trucking: Local in the US, IBIS World Inc.

IBIS World (2007) General Freight Trucking: Long-distance in the US, IBIS World Inc.

Insley, M.C., Wirjanto, T.S. (2008) Contrasting Two Approaches in Real Options Valuation: Contingent Claims Versus Dynamic Programming. Working Paper, Ontario, Canada.

International Maritime Exchange Homepage. www.imarex.com. Accessed July, 2007.

Karlin, S., Taylor, H.M. (1981) A Second Course in Stochastic Processes. Academic Press, Inc. San Diego, CA.

Kavussanos, M. G., Nomikos N. K. (2000)Futures Hedging When the Structure of the Underlying Asset Changes: The Case of the BIFFEX Contract. The Journal of Futures Markets 20 (8), 775-801.

Kavussanos, M. G., Visvikis, I. D. (2006) Shipping Freight Derivatives: A Survey of Recent Evidence. Maritime Policy & Management 33 (3), 233-255.

Kirkeby, K. (2007) Transportation: Commercial, Industry Surveys. Standard & Poor's, New York.

Koekebakker S., Adland, R. O. (2004) Modelling Forward Freight Rate Dynamics – Empirical Evidence from Time Charter Rates. Maritime Policy and Management 31 (4), 319-335.

Koekebakker, S., Adland, R., Sødal, S. (2007) Pricing Freight Rate Options. Transportation Research Part E 43 (5), 535-548.

Kotz, S., Nadarajah, S. (2000) Extreme Value Distributions: Theory and Applications. Imperial College Press, London, U.K.

Law, S.M., MacKay, A.E., Nolan, J.F. (2003) Using Financial Options to Hedge Transportation Capacity in a Deregulated Rail Industry. Edward Elgar Publishing, Northampton, MA, 169-194.

Leadbetter, M.R., Lindgren, G., Rootzen, H. (1983) Extremes and Related Properties of Random Sequences and Processes. Springer-Verlag, New York, NY.

Lindgren, G., Mare, J.D., Rootzen, H. (1975) Weak Convergence of High Level Crossings and Maxima for One or More Gaussian Processes. The Annals of Probability 3 (6), 961-978.

Lo, A.W., Wang, J. (1995) Implementing Option Pricing Models When Asset Returns Are Predictable. The Journal of Finance 50 (1), 87-129.

Logistics Management. Reed Business Information, Highlands Ranch, CO.

Merton, R.C. (1973) Theory of Rational Option Pricing. The Bell Journal of Economics and Management Science 4 (1), 141-183.

Mittal, G (2004) Real Options Approach to Capacity Planning Under Uncertainty. Master Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Nagali, V. et. al (2005) Procurement Risk Management (PRM) at Hewlett-Packard

Company. Council of Supply Chain Management Professionals, Lombard, IL.

Nandiraju, S. (2006) Strategic Freight Transportation Contract Procurement. Ph D Dissertation, University of California, Irvine.

New York Mercantile Exchange Homepage. www.nymex.com. Accessed July, 2007.

Pickands, J. (1969) Upcrossing Probabilities for Stationary Gaussian Processes. Transactions of the American Mathematical Society 145, 51-73.

Qualls, C., Watanabe, H. (1972) Asymptotic Properties of Gaussian Processes. The Annals of Mathematical Statistics 43 (2), 580-596.

Resnick, S.I. (1987) Extreme Values, Regular Variation, and Point Processes. Springer-Verlag, New York, NY.

Saphores, J.-D. (2000) The Economic Threshold With A Stochastic Pest Population: A Real Options Approach. American Agricultural Economics Association 82, 541–555.

Saphores, J.-D. (2007) Population Uncertainty and the Timing of an Urban Transportation Infrastructure Investment, Working Paper, University of California, Irvine.

Saphores, J.-D. and Boarnet, M. G. (2006) Uncertainty and the Timing of an Urban Congestion Relief Investment - The no-land case, The Journal of Urban Economics. 59 (2), 189-208.

Schwartz, E.S. (1997) The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging. The Journal of Finance 52 (3), 923-973.

Song, J., Regan, A.C. (2001) Transition or Transformation? Emerging Freight Transportation Intermediaries. Transportation Research Record 1763, 1-5.

Song, J., Regan, A. (2005) Approximation Algorithms for the Bid Construction Problem in Combinatorial Auctions for the Procurement of Freight Transportation Contracts. Transportation Research B 39 (10), 914-933.

Tibben-Lembke, R.S., Rogers, D.S. (2006) Real Options: Applications to Logistics and Transportation. International Journal of Physical Distribution and Logistics Management 36 (4), 252-270.

Truckloadrate.com Homepage. www.truckloadrate.com. Accessed October, 2007.

Tsai, M.T., Regan, A., Saphores, J.D. (2008) Freight Transportation Derivatives Contracts: State of the Art and Future Developments. Proceedings of the 87th Annual Meeting of the Transportation Research Board, Washington D.C.

Tsai, M.T., Saphores, J.D., Regan, A. (2009) Freight Transportation Contracting under Uncertianty. Proceedings of the 88th Annual Meeting of the Transportation Research Board, Washington D.C.

Tvedt, J. (1998) Valuation of a European Futures Options in the BIFFEX Market. The Journal of Futures Markets 18 (2), 167-175.

Vaidyanathan, V., Metcalf, D., Martin, D. (2005) Using Capacity Options to Better Enable Our Factory Ramps. Intel Technology Journal 9 (3), 185-191.

Vasicek, O. (1977) An Equilibrium Characterization of the Term Structure. Journal of

Financial Economics 5, 177-188.

Washington, S. P., Karlaftis, M. G., and Mannering, F. L. (2003) Statistical and Econometric Methods for Transportation Data Analysis. CRC Press LLC. Washington D.C.

Wilmott, P., Howison, S., Dewynne, J. (1995) The Mathematics of Financial Derivatives: a Student Introduction. Cambridge University Press, Cambridge, U.K.

Wilson, R. (2006) Embracing Security as a Core Business Function. 17th Annual State of Logistics Report, Council of Supply Chain Management Professionals, Lombard, IL.