UCI-ITS-WP-08-2

# Freight Transportation Contracting Under Uncertainty

UCI-ITS-WP-08-2

**Mei-Ting Tsai**[1]
**Jean-Daniel Saphores**[2]
**Amelia Regan**[3]

[1]Department of Civil Engineering and
Institute of Transportation Studies
University of California, Irvine; Irvine, CA 92697, U.S.A.
meitingt@uci.edu

[2]Department of Civil Engineering and
Economics Department
University of California, Irvine; Irvine, CA 92697, U.S.A.
saphores@uci.edu

[3]Department of Computer Science and
Institute of Transportation Studies
University of California, Irvine; Irvine, CA 92697, U.S.A.
aregan@uci.edu

**2008**

**Institute of Transportation Studies**
**University of California, Irvine**
**Irvine, CA 92697-3600, U.S.A.**
**http://www.its.uci.edu**

# Freight Transportation Contracting Under Uncertainty

**Mei-Ting Tsai**
Ph.D. Candidate
Department of Civil & Environmental Engineering
University of California, Irvine
Irvine, CA 92697
TEL: (949) 824-5989
FAX: (949) 824-8385
E-MAIL: meitingt@uci.edu

**Jean-Daniel Saphores**
Corresponding author, Associate Professor
Department of Civil & Environmental Engineering
and Economics Department
University of California, Irvine
Irvine, CA 92697
TEL: (949) 824-7334
FAX: (949) 824-8385
E-MAIL: saphores@uci.edu

**Amelia Regan**
Associate Professor
Department of Computer Science and
Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697
TEL: (949) 824-1871
FAX: (949) 824-8385
E-MAIL: aregan@uci.edu

Word Count: 3,962 + 750 (3 figures) + 1250 (5 tables) = 5,962 words.

**Abstract**

Uncertainties in transportation capacity and costs pose a significant challenge for both shippers and carriers in the trucking industry. 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 paper. 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 paper 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, 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 slightly the estimation of necessary parameters, which we obtain via two independent methods (variogram analysis and maximum likelihood), before developing a truckload options pricing formula. A numerical example based on real data shows that truckload options would be quite valuable to the trucking industry.

## INTRODUCTION

Trucking is the dominant mode of freight transportation today, and, according to a recent forecast by the American Trucking Association, its share of the nation's freight pool will increase: it is forecasted to reach 70% by 2018, up from 69% in 2006 (*1*).

The trucking industry is divided into two sectors: private carriage and for-hire. Figure 1 presents the structure of the trucking industry. The value of services provided by private carriage was approximately 45% of the trucking market in 2006 (*2*). Since private carriage refers to trucks and drivers owned and operated by shippers, this sector is not included in the trucking contracting market. We therefore focus on the for-hire sector, which accounted for approximately 55% of the market, of which 87% came from truckload (TL) and 13% from less-than-truckload (LTL) services. In order to procure for-hire services, shippers either write long-term contracts with carriers, usually for one or two years, or outsource to common carriers that mostly operate in spot markets.

A spot market is where shipments are handled on a one time load-by-load basis. It is used by almost all shippers and carriers to some extent. Spot market contracts are relatively short term contracts that serve unfilled 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. Spot markets, or in online marketplaces, are increasingly being used to match shipper demand and carrier capacity, because of the ability to generate market prices in real-time. Hence, a spot market is the best means to procure truckload services for unexpected and urgent delivery.

However, a truckload service price in the spot market is typically much higher than the long-term contract price. In addition, the availability of truckload services, in terms of time and volume, is not guaranteed to satisfy unexpected and urgent needs. Dealing with orders that require rapid, accurate, and reliable delivery challenges shippers at a time when the volume for this type of orders has significantly increased due to the adoption of demand responsive logistics. While shippers are concerned with guaranteed truckload services to satisfy uncertain demand, they increasingly depend on spot market procurement, which results in higher transportation costs.

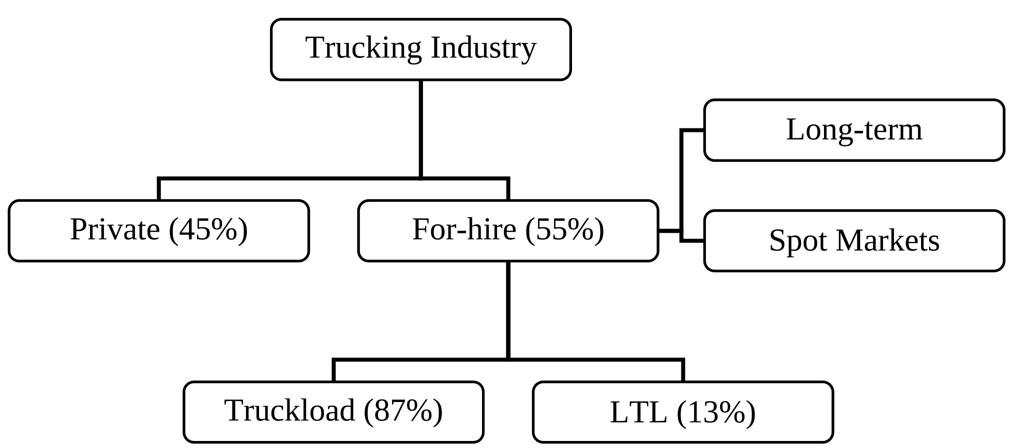


**FIGURE 1 Structure of the Trucking Industry**

Therefore, the problem of interest is how to deal with the demand and the supply uncertainties for truckload services via contracting means. 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 paper. A truckload call (put) option gives the holder the right to buy (sell) the right to transport a truckload between two points, at a predetermined delivery price, on or before a predetermined date. The predetermined price is referred to as the strike or exercise price; the predetermined date is known as the expiration or maturity date. A basic option can either be American or European. An American option can be exercised anytime up to its expiration date whereas a European option can only be exercised on the expiration date. Since it offers more flexibility, an American option is more valuable.

Using options to hedge uncertainties has begun to attract attention. After examining electronic markets for truckload transportation, Caplice (*3*) points out that current technical advances should allow the expansion of spot rates and permit the creation of more flexible contracts such as those based on Real Options. Tibben-Lembke and Rogers (*4*) generally present a framework for using options in logistics for a variety of transportation modes. They conclude that the key to making options attractive is the ability to price them. This conclusion was also reached by Tsai, Regan and Saphores (*5*) in the context of truckload options.

An issue of particular importance here, compared to established spot markets for various commodities, is that spot prices for trucking services are not public. When a quote is requested, some electronic marketplaces provide some data with a note asking to contact their representative for the final price (this is the case for freightquote.com or freightcenter.com, for example). Other sites provide their members with reference rates to strengthen their negotiation power (e.g., see truckloadrate.com or truckstop.com). However, none of the published papers we found explicitly develops pricing models, so this paper aims to develop truckload options pricing formulas to show the usefulness of options to the trucking industry.

The rest of this paper is organized as follows. First, we model the truckload price as a stochastic process based on statistics of the trucking spot market. We then develop a simple pricing formula for options on truckload services before providing a numerical example for selected lanes. The final section summarizes our conclusions.

## TRUCKLOAD PRICING MODEL

Currently, there is no single organized trucking spot market. Instead, several websites offer freight matching services which allow the shippers to post loads and the carriers to post available shipping capacity. Some of these websites also provide statistics on the minimum, the average, and the maximum prices realized for a given lane over a given period (typically one month). This gives shippers and carriers an idea of recent prices, although these are not realized contract prices.

Our first task to model truckload prices is therefore to estimate a reasonable model that is compatible with the given values of the minimum, average, and maximum prices for all transactions concluded during a set period (typically one month). 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 fluxes. Third, 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.

As argued by Dixit and Pindyck (*6*), 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 shipping prices are expected to increase, more investment in truckload capacity will take place. At some point, if truckload shipping capacity increases enough, it will be more than enough to meet demand and prices will start falling. Conversely, if shipping prices continuously decrease, the demand for truckload shipping will likely start increasing at some point and restore the equilibrium between demand and supply. It is therefore reasonable to consider modeling truckload price dynamics using a mean reverting process, which is commonly used in the time series analysis (*7*). To get started, we choose the simplest mean-reverting process, which is known as the Ornstein-Uhlenbeck (O-U) process (*8*); it is given by:

$$dY_t = \alpha(\mu - Y_t)dt + \sigma d\mathrm{B}_t, \qquad (1)$$

where $\{Y_t : t \geq 0\}$ is the truckload price at time t; $\alpha > 0$ is the rate of reversion; $\mu$ is the level to which $Y_t$ tends to return to; $\sigma$ is the volatility parameter; and $dB_t$ is an increment of a standard Brownian motion. Equivalently, $Y_t$ is given by

$$Y_t = \mu + (Y_0 - \mu)e^{-\alpha t} + \sigma \int_0^t e^{-\alpha(t-s)} d\mathrm{B}_s. \qquad (2)$$

It can then be shown that the distribution of $Y_t$ is $N(\mu + (Y_0 - \mu)e^{-\alpha t}, \frac{\sigma^2}{2\alpha}(1 - e^{-2\alpha t}))$. Figure 2 shows a simulated path for truckload prices given statistics about the monthly minimum, average, and maximum prices provided by (*9*).

**Parameter Estimation**

Given the truckload price model at time t, three parameters need to be estimated: the rate of mean reversion ($\alpha$), the long-term mean of the truckload price ($\mu$), and the volatility of the truckload price ($\sigma$). An important difference compared to spot prices for stocks and commodities is that we do not observe truckload spot prices directly; we just observe some monthly statistics. By contrast, high frequency data are available in conventional financial and commodity markets. In this paper, we derive our three parameters from average prices, which can be written as:

$$\tilde{Y}_n = \frac{1}{\Delta T} \int_{(n-1)\Delta T}^{n\Delta T} Y_s ds; \; n = 1, 2, \ldots, \mathrm{N} \qquad (3)$$

where $\Delta T$ is the time period between successive observations (i.e. one month in our case) and N is the number of observations. To gain confidence in the estimated values of our parameters, given that our sample is small, we apply two estimation methods: variogram analysis and maximum likelihood.

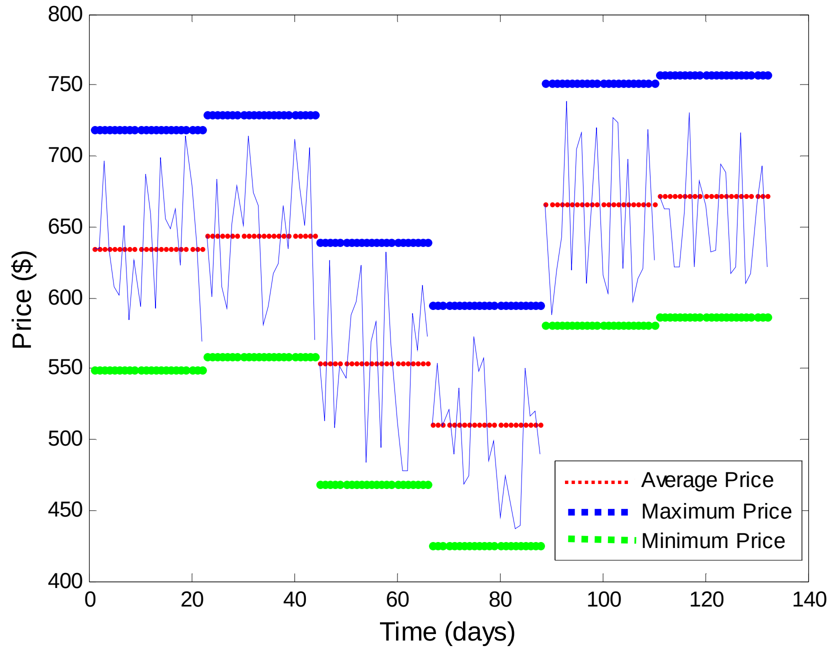


**FIGURE 2 Simulated Path of Truckload Price**

*Variogram Analysis*

The variogram analysis is a powerful tool for estimating the parameters of mean-reverting models (*10*). The variogram, also known as structure function, of a process $\{x_t\}$ is used to analyze how 'far' the process escapes from itself between times $t$ and $t+l$ (*11*). It can be written in a discrete manner as:

$$V(l)=\frac{1}{(N-l)}\sum_{n=1}^{N-l}(x_{n+l}-x_n)^2. \tag{4}$$

In the above, $l$ is called the lag and $N$ is the number of observations. It can be shown that the variogram of $\tilde{Y}$ is an unbiased estimator of $V_l^*=2v^2(1-e^{-\alpha l})$ where $v^2$ denotes the variance of $\tilde{Y}$. Recall that $Y_t$ is normally distributed with variance $\sigma^2/2\alpha$ (if invariance holds), so $\tilde{Y}_n$ is also normally distributed with variance $\sigma^2/2\alpha$. The parameters $\alpha$ and $\sigma$ are now related to the variogram, through $v^2=\sigma^2/2\alpha$, so that they can be estimated by fitting a variogram model. To this end, a weighted least squares method is adopted. Specifically, we look for the parameters that minimize $\sum_{l=1}^{N-l}(N-l)(\frac{V_l^*}{V_l}-1)^2$. This expression takes into account the effect of lag length; variograms with small lags have more weights than those with large lags (*12*). In addition, it can be shown that $\hat{\mu}=\frac{1}{N}\sum_{n=1}^{N}\tilde{Y}_n$ is an unbiased estimator of $\mu$. This approach enables us to find estimates of $\alpha$, $\mu$, and $\sigma$.

*Maximum Likelihood*

The discretization of $\tilde{Y}_n$ is given by (*6*, *13*)

$$\tilde{Y}_n = e^{-\alpha\Delta T}\tilde{Y}_{n-1} + \mu(1-e^{-\alpha\Delta T}) + \frac{\sigma^2}{2\alpha}(1-e^{-2\alpha\Delta T})\cdot z, \tag{5}$$

where z is a draw from a standard normal so the conditional probability density function of $\tilde{Y}_n$ is:

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

with $\hat{\sigma}^2 = \frac{\sigma^2}{2\alpha}(1-e^{-2\alpha\Delta T})$. As a result, the likelihood function is:

$$L(\mu,\alpha,\hat{\sigma}) = \prod_{n=1}^{N} f(\tilde{Y}_n \big| \tilde{Y}_{n-1};\mu,\alpha,\hat{\sigma}). \tag{6}$$

To maximize the logarithm of this likelihood function, we differentiate it with respect to $\mu$, $\alpha$ and $\hat{\sigma}$, and set each of these first order derivatives to zero. This gives us three equations with three unknowns from which we can find estimates of $\alpha$, $\mu$, and $\sigma$.

## TRUCKLOAD OPTIONS PRICING

To develop our truckload options pricing model, we use basic concepts from option pricing theory. Consider a portfolio comprised of one truckload option and some number of spot truckload capacity. Assume truckload options are of the European type and this portfolio is self-financing so that changes in the portfolio value only depend on changes in the portfolio's asset prices. Then, the value of this portfolio and its change are given by:

$$F(Y,t) = V(Y,t) + \Delta\cdot Y(t), \tag{7}$$

$$dF(Y,t) = dV(Y,t) + \Delta\cdot dY(t), \tag{8}$$

where $F(Y,t)$ is the portfolio value; $V(Y,t)$ is the truckload option price; $Y(t)$ is the truckload price, and $\Delta$ is an increment in the number of truckloads.

To value the portfolio under the assumption of risk neutrality, 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 earn as much as the amount in a bank account with a risk-free interest rate. Thus, the change in the value of this account given below is equivalent to Equation (8):

$$dF(Y,t) = [V(Y,t) + \Delta\cdot Y(t)]\cdot rdt \tag{9}$$

where r is a constant interest rate.

Let us now consider the case where the truckload price follows an O-U process. From Ito's lemma, we have:

$$dV(Y,t) = [\frac{\partial V}{\partial t} + \frac{\partial V}{\partial y} \cdot \alpha(\mu - Y) + \frac{\partial^2 V}{\partial y^2} \cdot \frac{\sigma^2}{2}]dt + \frac{\partial V}{\partial y} \cdot \sigma \cdot d\mathrm{B}. \tag{10}$$

Plugging Equations (1) and (10) into Equation (8), and using that Equations (8) and (9) are equivalent, the partial differential equation (PDE) for truckload options is given by:

$$\frac{\partial V(Y,t)}{\partial t} + \frac{1}{2}\sigma^2 \frac{\partial^2 V(Y,t)}{\partial y^2} + rY(t)\frac{\partial V(Y,t)}{\partial y} - rV(Y,t) = 0\ . \tag{11}$$

Consider now European type call options which provide the shipper with a right to procure a truckload service at a fixed ("strike") price *K*, on a given date T (the expiration date). Thus the boundary conditions to Equation (11) are

$$\begin{cases} V(T,Y) = \Phi(Y), \\ \Phi(Y_T) = \max(Y_T - K, 0), \end{cases} \tag{12}$$

where $\Phi(\cdot)$ is the payoff function. Using the Feynman-Kac formula (*14*), the truckload option price can then be represented as

$$V(Y,t) = e^{-r(T-t)}E[\Phi(Y_T) \mid Y_t] = e^{-r(T-t)}E[\max(Y_T - K, 0) \mid Y_t] \tag{13}$$

To obtain an arbitrage-free price for the truckload option, we construct an equivalent martingale measure (denoted by $P^*$) under which the truckload price in Equation (1) can be written as

$$dY_t = rY_t dt + \sigma \cdot d\mathrm{B}_t^* \tag{14}$$

where $d\mathrm{B}_t^* = d\mathrm{B}_t + \frac{\alpha(\mu - Y_t) - rY_t}{\sigma}dt$ is a Brownian motion under $P^*$. The explicit expression of $Y_t$ is then given by Equation (2) with $\mu$=0 and $\alpha$=*r*. Thus $Y_T$ can be equivalently represented as

$$Y_T = m^* + \sigma^* \cdot z^* \tag{15}$$

where $m^* = E^*[Y_T \mid Y_t] = e^{r(T-t)}Y_t$; $\sigma^{*2} = Var^*[Y_T \mid Y_t] = \frac{\sigma^2}{2r}(e^{2r(T-t)} - 1)$; and $z^*$ is a standard normal random variable under $P^*$. Thus, we have the truckload option price formula as

$$V(Y,t) = e^{-r(T-t)}[(m^* - K)N(d) + \sigma^* n(d)] \tag{16}$$

where $K$ is the exercise price; $d = \frac{m^* - K}{\sigma^*}$; and $N(\cdot)$ and $n(\cdot)$ represent standard normal cumulative distribution and density function, respectively. Figure 3 presents the arbitrage-free prices for a call option within a range of strike prices and expiration dates. We can see from Figure 3 that the call option 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 is also higher when the expiration date is farther ahead, because there is more uncertainty about the future.

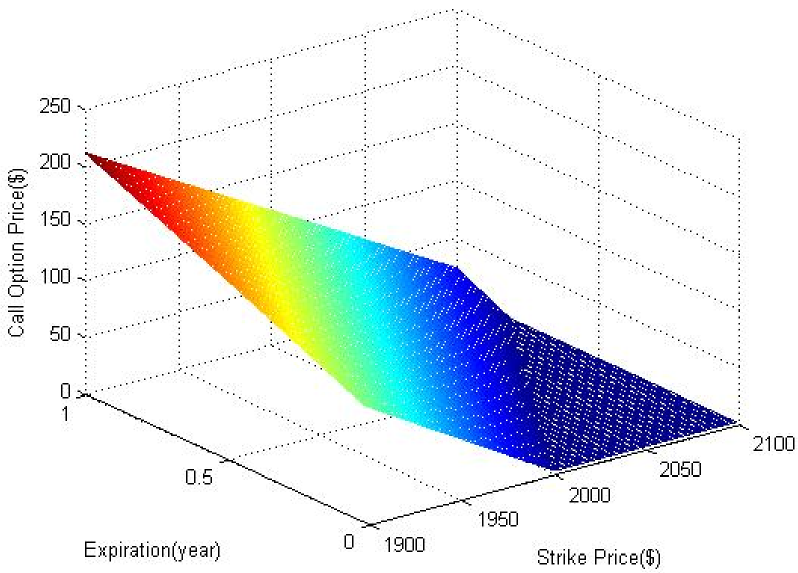


**FIGURE 3 Truckload Option Prices for a Range of Strike Prices and Expiration Dates**

## NUMERICAL EXAMPLE

To illustrate how truckload options work, let us now consider a numerical example using real data. After estimating parameters and obtaining the truckload option prices, we will explore the potential value of truckload options.

### Data

Obtaining reliable truckload spot price data can be a challenge so it is not very surprising that to-date no published papers on optimal contracting in the trucking industry are based on industry data. Probably for competitive purposes, the prices of delivery services are kept somewhat secret in the trucking industry, especially daily prices for specific lanes.

The data used for estimating our parameters were manually obtained by accessing (*9*), a trucking electronic marketplace. This database provides the maximum, the minimum and the average of truckload prices for specific origin-destination pairs every month back to 2006. The number of observations is small as only 28 points are available.

According to (*15*), the costs ($-mile) between California and Texas, and also between Texas and Illinois rank high compared to other origin-destination pairs. Therefore, we selected two lanes based on commodity values moved by for-hire carriers: 1) Los Angeles, CA, to Dallas, TX (denoted by LADA), which represents the movements from a container Port to an inland city;

and 2) Laredo, TX, to Chicago, IL (denoted by LRCH), which represents the movements from a busy inland port to a major inland city.

**Results of Parameter Estimation**

Estimates of our model parameters obtained using both variograms and maximum likelihood are shown in Table 1. We see that these estimates are quite close to each other, which suggests that our results are robust. For the rest of our numerical illustration, we adopt estimates obtained by maximum likelihood.

**TABLE 1 Results of Parameter Estimation**

| Lane | Estimation Method | $\alpha$ day$^{-1}$ | $\mu$ \$/mile | $\sigma$ \$/(mile*day$^{0.5}$) |
|---|---|---|---|---|
| LADA | Variogram | 0.3870 | 1.3122 | 0.0843 |
| | Maximum Likelihood | 0.4013 | 1.3081 | 0.0768 |
| LRCH | Variogram | 0.5367 | 1.2044 | 0.0616 |
| | Maximum Likelihood | 0.7111 | 1.2095 | 0.0663 |

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

**Price of Truckload Options**

Assume that current truckload prices for LADA and LRCH are \$2,060 and \$1,560, respectively. For simplicity, the truckload options we consider are issued only once a week. Applying the option pricing formulas given above, the prices of truckload options for these two lanes with various strike prices and expiration dates are shown in Tables 2 and 3, respectively. For a given expiration date, the 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 option increases with its expiration date: a longer time horizon allows more potential fluctuations and again makes the option more valuable.

**TABLE 2 Truckload Options Prices for LADA Lane**

Unit: \$

| strike price | week 1 | week 2 | week 3 | week 4 | week 5 | week 6 | week 7 | week 8 | week 9 | week 10 | week 11 | week 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 | 112.4 | 116.3 | 120.8 | 125.4 | 130.0 | 134.6 | 139.0 | 143.4 | 147.6 | 151.7 | 155.8 | 159.8 |
| 2000 | 65.1 | 72.2 | 78.8 | 84.9 | 90.6 | 95.9 | 101.0 | 105.8 | 110.5 | 115.0 | 119.4 | 123.6 |
| 2050 | 27.5 | 37.3 | 45.1 | 51.9 | 58.0 | 63.7 | 69.0 | 74.1 | 78.9 | 83.5 | 87.9 | 92.2 |
| 2100 | 7.2 | 15.1 | 21.9 | 28.1 | 33.7 | 39.0 | 44.0 | 48.8 | 53.3 | 57.7 | 62.0 | 66.1 |

**TABLE 3 Truckload Options Prices for LRCH Lane**

Unit: $

| strike price | week 1 | week 2 | week 3 | week 4 | week 5 | week 6 | week 7 | week 8 | week 9 | week 10 | week 11 | week 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1450 | 111.7 | 114.1 | 117.1 | 120.3 | 123.6 | 127.0 | 130.3 | 133.5 | 136.7 | 139.9 | 143.0 | 146.0 |
| 1500 | 63.3 | 68.3 | 73.3 | 78.0 | 82.4 | 86.6 | 90.7 | 94.5 | 98.2 | 101.8 | 105.3 | 108.7 |
| 1550 | 23.9 | 32.0 | 38.4 | 44.0 | 49.0 | 53.7 | 58.0 | 62.1 | 66.0 | 69.8 | 73.4 | 76.9 |
| 1600 | 4.6 | 10.6 | 16.0 | 20.9 | 25.4 | 29.6 | 33.6 | 37.4 | 41.1 | 44.6 | 48.1 | 51.4 |

**Benefit of Truckload Options**

To investigate the benefits that truckload options could bring to shippers and carriers, we start with three scenarios characterized by different levels of uncertainty. We assume that the demand for truckload services follows a Poisson distribution with a weekly arrival rate $\lambda$. We set $\lambda$ equal to 3, 1 and 0.2; this corresponds to cases where an unexpected demand occurs very likely, likely, and less likely, 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 4 and 5 presents the benefits of purchasing truckload options for shippers and carriers for 12 consecutive weeks based on the prices in Tables 2 and 3; 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 4 Benefits for Shippers and Carriers: LADA Lane**

Unit: $1,000

<table>
<tr><th rowspan="2" colspan="3">Scenario</th><th colspan="4">Strike Price</th><th rowspan="2">Without Options</th></tr>
<tr><th>1.95</th><th>2.00</th><th>2.05</th><th>2.10</th></tr>
<tr><td rowspan="3">A<br>(λ=3)</td><td colspan="2">Transportation Costs</td><td>72.36</td><td>74.24</td><td>75.89</td><td>76.77</td><td>76.86</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>4.50</td><td>2.62</td><td>0.97</td><td>0.09</td><td>-</td></tr>
<tr><td>Carrier</td><td>-2.86</td><td>-1.46</td><td>-0.20</td><td>0.39</td><td>-</td></tr>
<tr><td rowspan="3">B<br>(λ=1)</td><td colspan="2">Transportation Costs</td><td>25.56</td><td>26.24</td><td>26.85</td><td>27.23</td><td>27.04</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>1.48</td><td>0.80</td><td>0.19</td><td>-0.19</td><td>-</td></tr>
<tr><td>Carrier</td><td>0.16</td><td>0.36</td><td>0.58</td><td>0.67</td><td>-</td></tr>
<tr><td rowspan="3">C<br>(λ=0.2)</td><td colspan="2">Transportation Costs</td><td>6.06</td><td>6.24</td><td>6.37</td><td>6.40</td><td>6.11</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>0.05</td><td>-0.13</td><td>-0.26</td><td>-0.29</td><td>-</td></tr>
<tr><td>Carrier</td><td>1.59</td><td>1.29</td><td>1.03</td><td>0.77</td><td>-</td></tr>
</table>

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 from -1.9% to 4.5% per month, while the effect on carriers is between -3.2% and

10.5% per month. We expect actual shipper benefits to 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 corresponds to one of the conditions necessary for options to be successful – uncertainty. When demand uncertainty is low, so are the benefits of truckload options. However, one interesting observation is that the total benefit for each case is positive. That is regardless of 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.

**TABLE 5 Benefits for Shippers and Carriers: LRCH Lane**

Unit: $1,000

<table>
<tr><th colspan="3" rowspan="2">Scenario</th><th colspan="4">Strike Price</th><th rowspan="2">Without Options</th></tr>
<tr><th>1.45</th><th>1.50</th><th>1.55</th><th>1.60</th></tr>
<tr><td rowspan="3">A<br>(λ=3)</td><td colspan="2">Transportation Costs</td><td>46.60</td><td>48.23</td><td>49.85</td><td>51.29</td><td>52.31</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>5.71</td><td>4.08</td><td>2.46</td><td>1.02</td><td>-</td></tr>
<tr><td>Carrier</td><td>-4.17</td><td>-3.03</td><td>-1.81</td><td>-0.66</td><td>-</td></tr>
<tr><td rowspan="3">B<br>(λ=1)</td><td colspan="2">Transportation Costs</td><td>13.25</td><td>13.73</td><td>14.20</td><td>14.57</td><td>14.48</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>1.23</td><td>0.75</td><td>0.28</td><td>-0.09</td><td>-</td></tr>
<tr><td>Carrier</td><td>0.31</td><td>0.30</td><td>0.37</td><td>0.45</td><td>-</td></tr>
<tr><td rowspan="3">C<br>(λ=0.2)</td><td colspan="2">Transportation Costs</td><td>4.55</td><td>4.73</td><td>4.89</td><td>5.04</td><td>4.81</td></tr>
<tr><td rowspan="2">Benefit</td><td>Shipper</td><td>0.26</td><td>0.08</td><td>-0.08</td><td>-0.23</td><td>-</td></tr>
<tr><td>Carrier</td><td>1.28</td><td>0.97</td><td>0.73</td><td>0.59</td><td>-</td></tr>
</table>

## CONCLUSIONS

This paper introduces truckload options as a means of hedging uncertainty in price, demand and supply of truckload services. Before deriving truckload options pricing formula, the dynamics of spot truckload prices need to be modeled. For simplicity, we model the spot prices as a mean-reverting O-U process and obtain a closed-form pricing formula for a European type call option.

We then explore a numerical example based on real data for two selected lanes from a websites that matches buyers and sellers of truckload services. We apply two estimation methods (variogram analysis and maximum likelihood) to estimate the three parameters of our spot price model and obtain very similar results. We then use these estimates to value truckload options.

An exploration of scenarios based on different levels of uncertainty show that while not all parties may always win, the total benefit of any situation is positive. This shows that truckload options could be valuable tools to the trucking industry. In addition, if non-quantitative and side benefits are included, we expect truckload options to be even more valuable. Some of these benefits include guaranteed truckload services and decrease storage costs for shippers, as well as compensation for 'deadhead' movements for carriers. Moreover, dynamic trading strategies would further increase the benefits of having truckload options, as they would provide even more flexibility.

In addition to the pricing issue, several conditions are necessary for the success of our proposed options: uncertainty, hedging effectiveness, liquidity and institutional robustness (5). Without uncertainty, options would have no value. Hedging effectiveness is the ability of the contract to hedge the uncertainties of interest, and market liquidity means that a seller is able to find a buyer without much difficulty. These are the main reasons for BIFFEX's failure, which was once traded in maritime derivatives markets. To implement truckload options trading, a specialized institution could be created to implement a selected trading mechanism and oversee transactions. Such an institution could evolve from one of the current transportation marketplaces provided it reaches a large enough size and accepts to provide information about equilibrium prices and exchange volumes. Alternatively, truckload options could be exchanged at an existing financial or commodity trading exchange, such as the New York Mercantile Exchange.

Each of the necessary conditions mentioned above deserves additional study. Besides, future research could also explore: 1) if more information can be obtained from other spot rate statistics, such as the maximum and the minimum prices over specific durations; 2) the benefits of truckload options under different price processes; and 3) the value of options in the context of a network (we focused here on options for single lanes).

**ACKNOWLEDGEMENTS**
This study was partially supported by the University of California Transportation Center (UCTC). The authors gratefully acknowledge this support. The opinions presented herein are those of the authors alone and not the opinions of the UCTC. The authors also thank Dr. Knut Solna for very helpful comments. We also thank the anonymous reviewers for their careful reviews. As usual, all remaining errors are our responsibility alone.

**REFERENCES**

1. ATA. U.S. Freight Transportation Forecast to 2018. American Trucking Associations, Alexandria, VA, 2007.
2. Kirkeby, K. Transportation: Commercial, Industry Surveys. Standard & Poor's, New York, 2007.
3. Caplice, C. Electronic Markets for Truckload Transportation. Production and Operations Management 16 (4), 2007, pp. 423-436.
4. Tibben-Lembke, R.S., and D.S. Rogers. Real Options: Applications to Logistics and Transportation. International Journal of Physical Distribution and Logistics Management 36 (4), 2006, pp. 252-270.
5. Tsai, M.T., A. Regan, and J.D. Saphores. Freight Transportation Derivatives Contracts: State of the Art and Future Developments. Transportation Research Board, 87th Annual Meeting Proceedings, Washington D.C., 2008.
6. Dixit, A.K., and R.S. Pindyck. Investment under Uncertainty. Princeton University Press, NJ, 1994.
7. Pilipovic, D. Energy Risk. McGraw-Hill, New York, NY, 1997.
8. Karlin, S., and H.M. Taylor. A Second Course in Stochastic Processes. Academic Press, Inc. San Diego, CA, 1981.
9. Truckload Rate Homepage. www.truckloadrate.com. Accessed Oct., 2007 through June, 2008.

10. Fouque, J.P., G. Papanicolaou, and R.K. Sircar. Derivatives in Financial Markets with Stochastic Volatility. Chapter 4, Cambridge University Press, Cambridge, U.K., 2000.
11. Bouchaud, J.P., and M. Potters. Theory of Financial Risk and Derivative Pricing. Chapter 4, 2nd edition, Cambridge University Press, Cambridge, U.K., 2003.
12. Cressie, N. Fitting Varioagram Models by Weighted Least Squares. Mathematical Geology 17 (5), 1985, pp. 563-586.
13. Schwartz, E.S. The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging. The Journal of Finance 52 (3), 1997, pp. 923-973.
14. Bjork, T. Arbitrage Theory in Continuous Time, 2nd Edition. Oxford University Press, New York, 2004.
15. Bureau of Transportation Statistics. Commodity Flow Survey. U.S. Department of Transportation, Washington, D.C., 2002.