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**A discrete-time stochastic partial equilibrium model of the spot  
freight market**

by

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# **A discrete-time stochastic partial equilibrium model of the spot freight market**

**Roar Adland<sup>1</sup> and Siri P. Strandenes<sup>2</sup>**

## Abstract

This paper presents a stochastic extension of the classical partial equilibrium models of the spot freight market. The supply in the model is based on microeconomic analysis of the supply characteristics of a given fleet and orderbook, in this case the VLCC fleet, and stochastic demolition and ordering behaviour. Combined with stochastic demand, the model is used to simulate scenarios for the future VLCC spot freight rate.

**Keywords:** stochastic partial equilibrium, bulk shipping, spot freight rates, tankers

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## 1. Introduction

Starting with Koopmans (1939), the functioning of the freight markets and modeling of the spot freight rate in bulk shipping have been the topic of much research in maritime economics. Broadly speaking, two schools of thought have developed. Firstly, in line with the classical literature, many researchers have focused on modeling the demand and supply for transportation using either static supply/demand models (see, for instance, Zannetos, 1966; Norman and Wergeland, 1981; Evans, 1994) or dynamic econometric models (see, for instance, Eriksen and Norman, 1976; Strandenes, 1986; Beenstock and Vergottis, 1989; Lensberg and Rasmussen, 1992). In recent years, inspired by developments in financial economics, the focus has been on modeling the freight rate directly in a stochastic model, such as the Ornstein-Ühlenbeck process (Bjerksund and Ekern, 1995; Tvedt, 1997; Martinussen, 1993), the Geometric Mean Reversion (GMR) process (Tvedt, 1997), or a nonparametric model (Adland, 2003).

Both of these approaches have drawbacks. Supply/demand models must typically rely on a large number of variables, some of which can be difficult to assess (such as vessel speed, vessel utilization), a large set of simultaneous equations and weak econometric relationships (see, Birkeland, 1998, for a general discussion). The stochastic freight rate models, on the other hand, basically disregard all information that is not embedded in the current spot freight rate level and the past freight rate process. In other words, important information, such as the size of the current orderbook and the current age profile of the fleet, is not taken into account. The only previous academic work to try to bridge the apparent gap between the two approaches to freight rate modeling is Tvedt (1996, 2003) who develops a continuous-time stochastic partial equilibrium model of the freight and newbuilding market. Tvedt finds that the resulting equilibrium freight rate process is close to that of a standard geometric mean reversion process. However, Tvedt's model is highly theoretical and does not explicitly model the time-varying shape of the supply curve, or the scrapping and ordering behaviour.

The main contribution of this paper is to model the interaction of the supply and demand curves in a stochastic partial equilibrium framework in combination with microeconomic modeling of the time-varying shape of the supply curve. The model incorporates stochastic ordering and scrapping dynamics, and tracks the corresponding changes in the composition and physical specifications of the fleet. It is developed directly in discrete time, thereby avoiding the problems associated with empirical estimation of discrete approximations of stochastic differential equations, as discussed in Merton (1980) and Lo (1988), among others. It is worth noting that while the empirical estimations in this paper concern the VLCC fleet, the model is general in nature and can be adapted to all other sub-sectors of the bulk shipping market.

The remainder of this paper is structured as follows. Section 2 reviews the results in the classical maritime economic literature on supply and demand functions in bulk shipping. Section 3 presents the fleet data and the framework for modeling the supply curve, as well as the dynamics of demolition and new deliveries. Section 4 presents the demand data and contains sample simulations of the model. Section 5 contains concluding remarks and suggestions for future improvements.

## **2. Freight market equilibrium theory**

The freight markets in bulk shipping are usually held as textbook examples of perfectly competitive markets (see, for instance, Norman, 1979). Accordingly, the market freight rate is determined by the marginal cost of the marginal vessel required to satisfy the demand for transportation. The short-term supply curve indicates the amount of transportation willingly supplied by the fleet at a given freight rate. In the classical maritime economic literature, starting with Koopmans (1939), the short-term supply curve in bulk shipping is characterized by two distinct regimes, distinguished by whether the fleet is fully employed. When all vessels in the fleet are employed, the only possibility to increase the supply of transportation in the short term is through higher utilization of the existing ships. This can be achieved through higher vessel speed, reduced port time, shorter ballast legs, and delaying regular maintenance. However, this increase is limited by technical constraints and implies a higher marginal cost of operation due to higher fuel consumption and increased wear and tear. When the fleet sails at close to the maximum capacity, the supply function becomes almost perfectly inelastic with the result that demand rationing takes place through very high freight rates. When the available supply exceeds demand, leading to lower freight rates and vessel unemployment, the least cost-efficient vessels will withdraw from the market, resulting in a series of perfectly elastic steps in the short-term supply function. Accordingly, Koopmans (1939) proposed a short-term supply curve that is very elastic when tonnage is unemployed (low freight rates) and very inelastic during periods with full employment (high freight rates). This characteristic shape has later been confirmed in several empirical works, for instance, Zannetos (1966), Devanney (1973), and Norman and Wergeland (1981). In the classical literature, the ‘refusal rate’ below which the vessel no longer supplies transportation is assumed to be its lay-up point, i.e. the time charter equivalent (TCE) spot freight rate at which the shipowner is indifferent between lay-up and operation. The lay-up problem was first investigated by Mossin (1968) and later discussed in Dixit and Pindyck (1994) and Tvedt (1997), among others. As there are switching costs related to putting the vessel in lay-up, this threshold rate must be slightly lower than its daily operating cost less the daily lay-up cost (see, for instance, Mossin, 1968). For lay-up to ever be economical, the daily lay-up cost

must be lower than the daily operating cost, implying that the refusal rate must be positive. Accordingly, the TCE spot freight rate for any vessel must be bounded from below<sup>3</sup>.

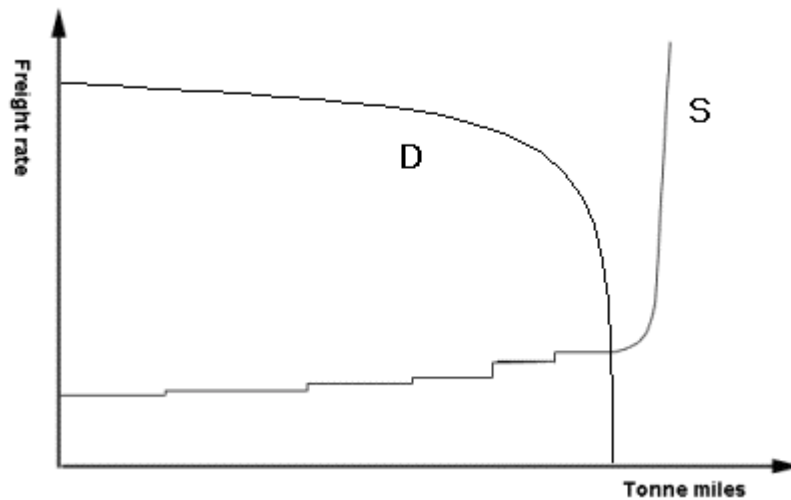
The demand for transportation is governed by changes in world consumption of bulk commodities, as well as changes in the geographical demand and supply pattern. The demand for transportation in bulk shipping is often taken to be independent of freight rates (see, for instance, Koopmans, 1939; Hawdon, 1978; Beenstock and Vergottis, 1989; Norman and Wergeland, 1981). While this is a fair assumption under normal freight market conditions, some researchers have argued that the demand for ocean transportation will become more elastic with respect to the freight rate when freight rates are very high relative to the value of the cargo. Firstly, as noted first by Koopmans (1939) and later investigated empirically by Strandenes and Wergeland (1982), when freight rates are extremely high, the importer may try to find an exporter that is closer, in order to reduce transportation costs. As a result, the average transportation distance decreases, possibly leading to lower demand. Secondly, if the demand for a commodity is price elastic and the freight rate element in the CIF price is high, the implicit elasticity for transportation may be substantial due to the potential for substitution of the commodity (for instance, oil vs. coal). Thirdly, if the freight rate becomes extremely high in a particular bulk shipping segment, other vessel sizes/types, or even other modes of transportation such as pipelines, may become competitive. Strandenes (1981) estimated cross elasticities and found that tankers in adjacent size groups are substitutes. Hence, maritime economic theory suggests that the demand for ocean transportation becomes more elastic with respect to freight rates at high freight rates until the demand becomes perfectly elastic at some unknown but extremely high freight rate level  $\bar{X}$  (see also, Tvedt, 1996). The maximum freight rate is the rate that absorbs all profit from international trade and results in a net loss equal to the loss of goodwill and/or the penalty of contractual default. Even if the increasing transportation cost can be transferred to the consumer, there will come a point where either other vessel types or modes of transportation (for instance, pipelines) can economically substitute bulk vessels, or where there is no further demand for the commodity. The resulting stylized shape of the theoretical short-run demand and supply curves in bulk shipping is illustrated in the figure below.

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<sup>3</sup> However, a given freight rate (\$/ton) and fuel price may result in a positive TCE spot freight rate for a cost-efficient vessel, and negative daily earnings for an old inefficient vessel (which would not accept employment).



**Figure 1: Short-term supply and demand in bulk shipping**



It is worth noting that the supply function is not, strictly speaking, a unique function of the freight rate in the presence of entry/exit costs for lay-up. In the presence of non-zero switching costs, the threshold freight rate for entering lay-up will lie above the break-even rate (defined as the daily operating cost less the daily cost in lay-up). Conversely, the threshold freight rate trigger rate for exit from lay-up will be above the break-even freight rate. Consequently, there will exist a range of freight rates where a vessel is either trading or in lay-up depending on the previous path of the freight rate.

### **3. The supply model**

#### **Introduction**

In line with the classical literature, we model the short-term fleet supply function as the sum of the supply functions of all the ships in the fleet. We consider ‘short term’ to be a period of one month, equal to the time step in our discrete-time model. This is largely for the sake of convenience, as it corresponds to the frequency of our freight rate and demolition/contracting data. However, it can also be argued that a time period of one month is sufficient to make and execute decisions that will affect supply in the short run, such as scrapping a vessel or taking it out of lay-up. Furthermore, the typical loaded trip lasts between two weeks and one month in deep sea bulk shipping.

As the term ‘partial equilibrium’ implies, we are only concerned with freight market equilibrium within a particular bulk ship sector, in this case the market for Very Large Crude

Carriers (VLCCs). This is tantamount to saying that the VLCC market can be modeled as a separate market from the rest of the tanker market. The degree of integration between the freight markets for different vessel sizes has been investigated by, for instance, Strandenes (1981) and Glen (1990). Glen suggests that the tanker business became segmented during the 1970s. He argues that the large spread in vessel size implies that several vessel classes are no longer substitutable between routes due to draft restrictions in ports and canals. Strandenes (1981), using data from the 1960s and 1970s, argues that changes in the supply/demand balance in one sub-sector will ripple through to the other sub-sectors and that the freight market is integrated. In practice, there appears to exist largely distinct trades for each vessel size, determined primarily by hauling distance and standardized sizes of the cargo stems (e.g. due to the storage capacity in the loading or discharging port). It is clear, however, that the freight rate development between these market segments is correlated due to the potential for substitution. On average, there will exist a significant positive freight rate differential between e.g. a Suezmax tanker and a VLCC trading on the same route due to the economies of scale offered by the larger vessel. It is only when this freight rate spread breaks down, for instance due to short-term shortage of VLCC tonnage in the loading area that the Suezmax tankers will be in direct competition through cargo splits. It is also worth noting that while smaller vessels can always substitute VLCCs, the opposite need not be possible due to physical restrictions. Offshore transfer from large to smaller vessel, as is done on a permanent basis off the US east coast, is a costly alternative in this case.

Moreover, we ignore the potential for short-term geographical freight rate differences due to unexpected changes in demand in a particular loading area. In practice, the position of open vessels and new cargoes will usually be circulated on the market (and fixed) far in advance (in the order of 4 – 6 weeks for VLCCs), accounting for the time required to position the necessary tonnage. Accordingly, we assume that the spot freight market within a particular sub-sector behaves as a single market in the short term, despite the large geographical spread. This is tantamount to saying that the vessels in the fleet are distributed across routes such that there is no geographical arbitrage. In other words, an owner is indifferent between the different destinations on offer at any point in time and all voyages on offer in the spot market will provide the same return in terms of \$/day. Given the large number of owners and shipbrokers who perform voyage calculations in an attempt to seek the best possible employment for their vessels, this would seem to be a reasonable assumption. However, the market is increasingly influenced by regulations and age restrictions, creating a two-tier market and disturbing competition. See Strandenes (1999) for a simulation of such a two-tier tanker market. As an important corollary to the above assumption, we can calculate the ‘refusal rate’ across the fleet in terms of \$/tonne or Worldscale (WS) as if all vessels traded on the same route. This is the basis for estimating the fleet supply function in the following.

### **The data**

Clarkson Research (2003) provided the vessel specifications of the 431 vessels in the VLCC fleet (200,000 DWT+) as of November 1, 2003. The chosen attributes for each vessel are listed below (with data coverage in parenthesis):

- Vessel name (100%)
- Status (in service, storage, or laid up) (100%)
- Build year/month (100%)
- Deadweight (100%)
- Engine make (94.0%)
- Horsepower (92.3%)
- Design speed (88.4%)
- Fuel consumption (46.8%)

Where the design speed or fuel consumption was not available, a comparison was made of engine make, deadweight, and horsepower with similar vessels in order to arrive at an estimate, eventually creating a full dataset with respect to vessel speed and fuel consumption. While this process is likely to have introduced some measurement error, the impact is marginal compared to the volatility of demand.

For the purposes of estimating the ‘refusal rate’ for each vessel in the fleet we chose the round voyage between the Arabian Gulf (Ras Tanura) and Japan (Chiba). The voyage details are given in the table below.

**Table 1: Voyage details**

Laden/ballast distance	6605 nm
Port time	4 days
Sea margin*	5%
Port costs	\$140,500
Bunker price	\$160/tonne
Load factor	95%
Broker commission	1.25%
Worldscale flat rate (2003)	\$12.15/tonne
Newbuild operating cost	\$7,000/day
Age factor for OPEX	1.5%

\* Sea margin refers to the average added voyage time due to adverse weather etc.

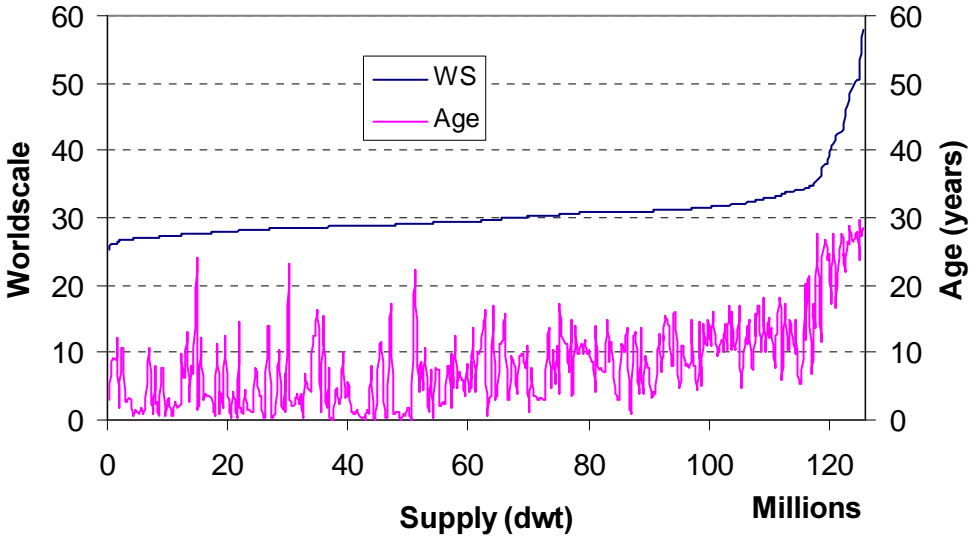
Speed optimization has played an important role in most of the existing supply/demand models (see, for instance, Norman and Wergeland, 1981; Strandenes, 1986; Beenstock and Vergottis, 1989). Based on the prevailing bunker price, the optimal choice of speed is typically thought to be a trade off between fuel costs and the opportunity cost of time. As Birkeland (1998) points out, although this may be a reasonable theoretical assumption, it is questionable to what extent speed optimization is done in practice today. Modern motor vessels have a rather narrow technical margin of speed adjustment due to maneuvering and engine restrictions. However, for old turbine tankers, speed adjustment would have been much more important for profitability. Adverse weather conditions, charter party clauses on lay-days for a voyage charter, and the speed clause for a time charter party, will often determine the choice of speed in practice. Here we assume that all vessels trade at their design speed less a 5% sea margin. The bunkers cost is assumed to be constant, although future versions may incorporate a stochastic fuel price. The port costs are also assumed to be size invariant, although in practice this will not hold.

For simplicity, we also assume a constant load factor of 95%. Typical VLCC cargo stems are in the order of 250,000 – 270,000 tonnes (or two million barrels, depending on crude grade), even if the chartered vessel has a significantly higher deadweight. Hence, large modern vessels around 305,000 DWT will typically sail the loaded leg with an average load factor that is lower than 95%. Indeed, for the period February 2002 to April 2003, the actual average was found to be 90.8% based on our analysis of 1165 VLCC fixtures. Accordingly, this assumption may lead to overestimation of the breakeven spot rate and it may be more appropriate to use a constant stem size. Finally, we assume that all vessels perform a simple return voyage, with no backhaul cargo and an identical loaded/ballast leg. For the AG – Far

East VLCC trade this is a realistic assumption, as crude oil exports in VLCCs from Asia are non-existent.

The resulting VLCC supply function as of November 1, 2003, is illustrated in the Figure 2 below along with a plot of the age of the respective vessels. The supply function clearly conforms to the characteristic shape proposed by Koopmans (1939) and later empirical works (see, for instance, Zannetos, 1966; Devanney, 1973; Norman and Wergeland, 1981). In comparison with the age distribution, it is evident that the remaining 1970s-built fleet accounts for the steeper supply function when the fleet is sailing at close to full capacity. This is primarily because of the higher fuel consumption of these turbine driven vessels and we can already conclude that once these vessels have all been faced out over the next few years, the VLCC supply function will become rather elastic, except at full utilization of the fleet capacity, due to a high degree of homogeneity of the fleet. It is also worth pointing out that some of the old Ultra Large Crude Carriers (ULCC) appears comparatively cost efficient, with operating breakeven around WS 30. However, this is largely due to the lenient load factor assumption and, in practice, ULCCs often have to accept part cargoes. The average load factor for a ULCC (350,000 DWT+) was only 84.9% in the period February 2002 to April 2003 (Clarkson Research, 2003).

**Figure 2: VLCC supply curve as of November 1, 2003**



Having created the starting point for the supply function, the next step is to model the dynamic response of the supply side to changes in the freight market. The basic structure of our discrete-time freight market model is as follows:

1. At time  $t_j$ , derive the supply/demand equilibrium freight rate
2. Add new deliveries to the fleet as per the orderbook
3. Generate new ordering conditional on the freight rate at time  $t_j$
4. Generate demolitions conditional on the freight rate at time  $t_j$
5. Estimate the new supply function
6. Simulate the demand at time  $t + \Delta$
7. Derive the new equilibrium freight rate

With  $\Delta = 1$  month, it is implicitly assumed that shipowners decide on their actions with regard to ordering and demolition based on the freight rate at the beginning of the month, and execute such decisions over the month. The above structure largely overcomes the circular dependence between demolition activity and the freight rate. On the other hand, the structure introduces ‘short-sightedness’ in the behavior of the supply side. Whether this is appropriate is an empirical question. The following sections describe the modeling of the demolition and ordering processes in some detail.

### **The scrapping volume**

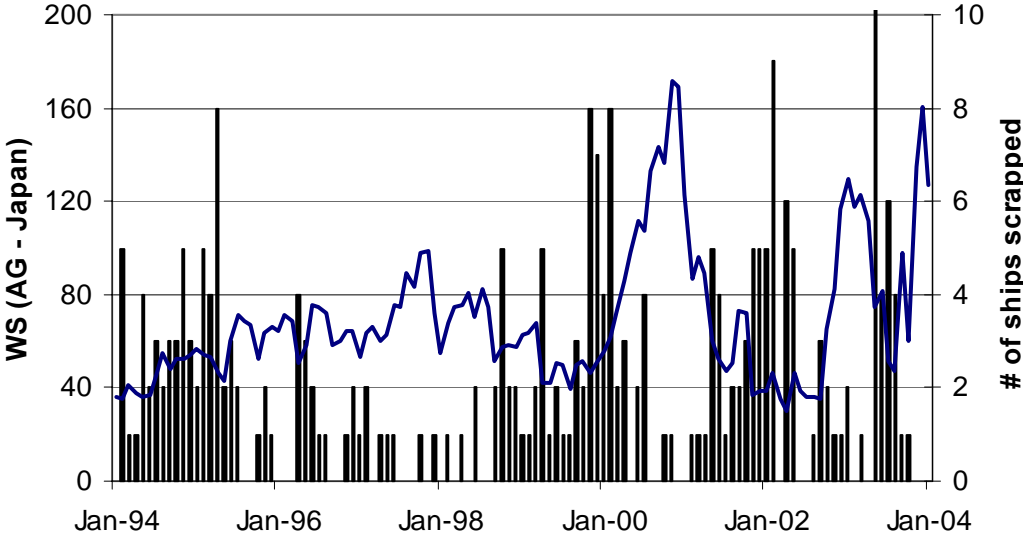
The owner of a vessel has the option to scrap it at a time of his choosing, possibly subject to an age limit imposed by legislation such as MARPOL 13G. Conditional on optimal exercise of the scrapping option in the future, it is optimal to scrap a given vessel if the expected value of continued trading is less than its scrap value. However, in a competitive shipping market with substantial surplus capacity, every ship owner has an incentive not to scrap his vessel and keep his sunk capital alive; hoping everybody else will scrap their vessels first (see Dixit, 1992, for a general discussion). This may well be rational behaviour, given the circular dependence between the scrapping volume and the freight rate process. However, it implies that scrapping will often be postponed compared to what is “optimal” under the assumption that the freight rate process is independent of the actions of the individual shipowner. Unfortunately, the result can be long periods of low operating profits with insufficient exit of capacity from the industry (Dixit, 1992). If the scrapping decision is partly a strategic decision (it may also be a result of policy<sup>4</sup>), the scrapping volume will not be a function of any set of economic state variables.

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<sup>4</sup> Some ship owning companies may have a policy to not operate vessels above a certain age limit.

We propose that the scrapping volume follows a stochastic Poisson process where the expected number of ships scrapped in the time interval  $\Delta$  is a function of the freight market conditions on date  $t_j$ . This approach has several advantages. Firstly, the number of scrapped vessels in the time interval  $\Delta$  will be a stochastic integer value, accounting for the randomness of demolition volumes and the obvious fact that deletions from the fleet must be discrete. Secondly, since the expected scrapping rate (more commonly known in statistics as the ‘arrival rate’) can be estimated directly from the historically observed scrapping volumes, we bypass the circular dependence problem. Thirdly, we do not make the unrealistic assumption that the actual scrapping volume is as deterministic function of the market variables as in extant research (see, for instance, Beenstock and Vergottis, 1989). Instead, we let the *expected* scrapping volume depend on the market conditions and impose uncertainty on the process. The stochastic nature of demolition volumes is clearly illustrated in the graph below, which plots the monthly number of vessels scrapped along with the spot freight rate. The graph highlights the inverse relationship between scrapping volume and freight rates.

**Figure 3: Monthly VLCC demolition (1994 - 2003)**



Source: Clarkson Research Studies (2003)

The main drawback of the proposed specification is that the memory of the Poisson process is reset once scrapping occurs and on each date  $t_j$ . However, while we cannot easily account for the potential presence of a ‘contagion effect’ where one demolition sale is immediately followed by a rush of subsequent sales, the potential path dependency in the scrapping volume can be accounted for by making the average scrapping rate a function of the scrapping

volume in the previous period. Such path dependency could be induced, for instance, by slowly changing market sentiment or the ‘waiting game’ described by Dixit (1992).

Let  $\lambda_j$  be the average scrapping rate and  $S_j$  be the number of ships scrapped, such that  $E(S_\Delta) = \lambda_j \cdot \Delta$  is the expected number of scrapped vessels in the next time interval  $\Delta$ , conditional on the information set available on date  $t_j$ . According to the Poisson distribution with parameter  $\lambda_j \cdot \Delta$ , the probability of  $k$  ships being scrapped in the next interval  $\Delta$  is then:

$$P(S_\Delta = k) = \frac{e^{-\lambda_j \Delta} (\lambda_j \Delta)^k}{k!} \quad \text{for } k = 0, 1, 2, \dots \quad (1)$$

In practical implementation of the model, the number of scrapped ships in the next interval  $\Delta$ , conditional on the market conditions on date  $t_j$  is found by Monte Carlo simulation of the Poisson experiment (see, for instance, Law and Kelton, 2000, p. 478).

### **The delivery volume**

If we assume that newbuilding projects cannot be accelerated, postponed, or cancelled, the number of new deliveries over the next time interval,  $N_j$ , is known with certainty and depends only on the composition of the global orderbook on date  $t_j$ . In practice, negotiated postponement and cancellations of newbuilding projects may occur during poor freight markets, even though the latter involves high cancellation fees. At the other end of the market, the acceleration of a newbuilding project, for instance through extensive use of overtime at the shipyard, may be economically viable. Hence, a more sophisticated version of the model could allow the delivery rate to be an increasing function of the current freight rate level.

Conditional on the assumption above, the delivery volume  $N_j$  is known with certainty until the earliest future date at which a vessel ordered today can be delivered. Beyond this date, the delivery volume is a stochastic variable that depends on the volume of new orders placed and the time lag between order and delivery. In general, this time lag will be a function of the market conditions and orderbook on the date the order was placed. For instance, it seems fair to assume that the delivery lag is an increasing function of the size of the total world orderbook, as in Strandenes (1986). It is worth noting that the freight rate process cannot be a Markovian process (without memory), as the number of new deliveries  $N_j$  at time  $t_j$  will depend on actions taken in the past. Nevertheless, most recent research works on stochastic freight rate models (see, for instance, Tvedt, 1997; Martinussen, 1993; Bjerksund and Ekern, 1995; Adland, 2003) assume that the process is Markovian. Tvedt (1996) proposes that the Markov property can be preserved by assuming that the delivery rate is a fixed fraction of the

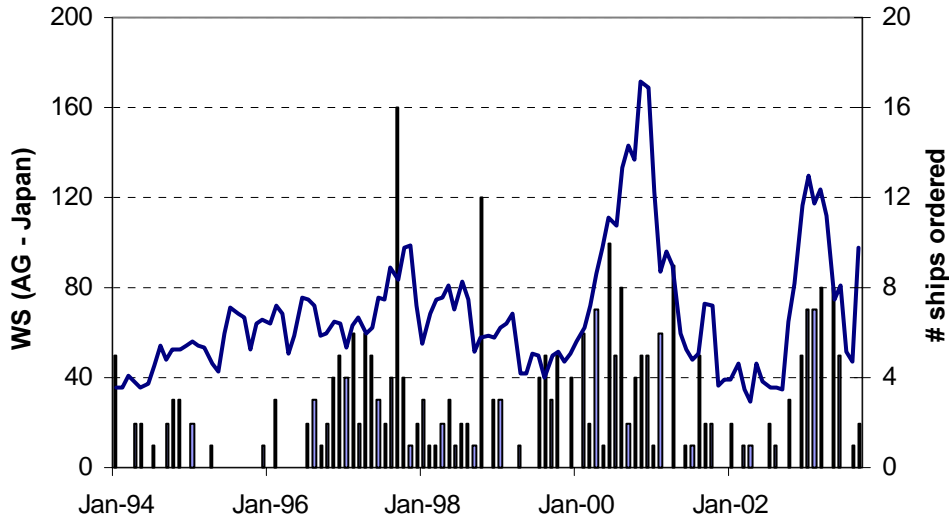


size of the current orderbook. However, the latter assumption is not likely to produce a realistic delivery schedule, as it would overestimate the deliveries during the early stages of a boom market when the orderbook is building up.

The ordering behaviour of shipowners has been the subject of much interest in maritime economic literature ever since Tinbergen (1931) and Einarsen (1938) investigated the shipbuilding cycle. For instance, Zannetos (1966, p. 190) states “the pattern of orders placed during rising rates leaves little doubt that the greatest part of each ‘new’ supply is initiated without regard to over-all interdependencies“. Suppose each owner independently evaluates the prospects of a newbuilding project. If the owner observes that no other firm has ordered a new vessel, he may infer that their evaluations were insufficiently favorable, and adjust his own evaluations downward. However, once one shipowner invests, others adjust their own judgments upwards, and may quickly follow the first order. Moreover, if owners believe that shipbuilding capacity is a scarce resource, ordering has a strategic value as their actions preclude new entrants from taking advantage of a strong freight market. The result is a bunching of investments and apparent “herding behavior“. If shipping investors do not realize the interdependence of their behaviour at the time of the decision, overbuilding and long periods of depressed freight rates will prevail.

As is the case for demolition volumes, the number of new contracts placed in any given period cannot be adequately described as a deterministic function. However, as is evident from Figure 4 below, owners do tend to place more orders when the spot freight market is strong.

**Figure 4: Monthly VLCC ordering activity (1994 - 2003)**



Source: Clarkson Research Studies (2003)

Accordingly, we propose that the number of new orders placed follows a stochastic Poisson process where the average contracting rate in the time interval  $\Delta$  is a function of the freight market conditions on date  $t_j$ . Let  $\gamma_j$  be the average contracting rate and  $O_j$  be the number of new VLCC orders placed, such that  $E(O_\Delta) = \gamma_j \cdot \Delta$  is the expected number of new orders in the next time interval  $\Delta$ , conditional on the information set available on date  $t_j$ . According to the Poisson distribution with parameter  $\lambda_j \cdot \Delta$ , the probability of  $k$  new orders in the next interval  $\Delta$  is then:

$$P(O_\Delta = k) = \frac{e^{-\gamma_j \Delta} (\gamma_j \Delta)^k}{k!} \quad \text{for } k = 0, 1, 2, \dots \quad (2)$$

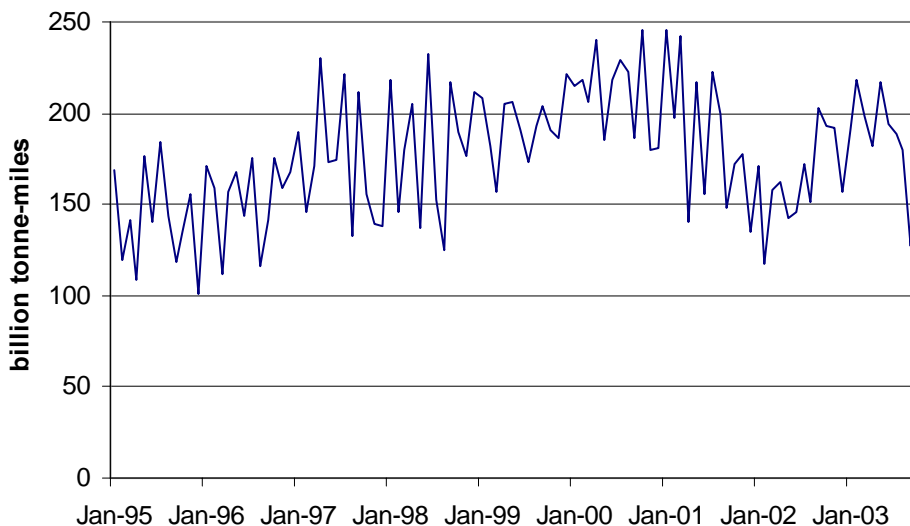
i.e. similar to the formulation of the scrapping probability. In the present version of the model, ships are assumed to be delivered a fixed number of months  $\tau$  after the orders were placed. It follows that the number of new deliveries, beyond the horizon of the current orderbook, is equal to the number of new orders placed at time  $t_j - \tau$ . A better approach would be to model the delivery lag as a function of the total orderbook (i.e. not only VLCCs), given that slots at the shipyards are typically filled in chronological order.

#### 4. Demand analysis and empirical results

In reality, the exact shape of the demand function cannot be determined empirically, and so it will always have to be based on supposition. It seems fair to assume that it is dependent on the freight rate level to some extent. If demand were perfectly inelastic with regard to the freight rate, the spot freight rate process would explode towards infinity when the fleet sails at the maximum practical capacity, which is clearly not the case. While the elasticity of demand for crude transportation from the integrated oil companies is likely to be rather inelastic, the demand from independent oil traders and ‘swing refineries’ may be quite price sensitive. The existence of such consumers will increase the elasticity of the demand for transportation. The relative CIF price per energy unit of crude oil compared to other energy sources (LNG and thermal coal) is less of an issue given that the transportation cost remains a small fraction of the price of oil even at extremely high freight rates<sup>5</sup>. In this version of the paper, for lack of a better model, we assume that the demand function is a simple linear function with respect to the freight rate. The slope of the function is calibrated so as to replicate the historical volatility in the freight market.

The graph below shows the global monthly VLCC demand (in billion tonne miles) according to reported fixtures for the period January 1995 to October 2003.

**Figure 5: VLCC demand (Jan-95 - Oct-03)**



**Source: Clarkson Research Studies (2003)**

<sup>5</sup> Even at a WS 160 for AG – Japan, equal to \$19.44/t in 2003, transportation costs are only about 10% of a \$25/bbl oil price.

We assume that the demand for VLCCs follows the following simple discrete process:

$$D_j = \eta \cdot (\alpha + \beta \cdot X_{j-1} + \varepsilon_j)$$

where  $X$  is the stochastic demand for tonne miles and  $\varepsilon$  is a normally distributed error term with mean zero and standard deviation  $\sigma$ . In addition, it is necessary to rescale the tonne-mile demand to take into account (1) the fact that the list of reported fixtures is incomplete and (2) the conversion from monthly tonne-mile demand to the equivalent DWT demand. It is assumed that  $\eta$  is constant, which is tantamount to saying that the fixture coverage and the ship speed are constant. It is worth noting that the above specification does not allow for seasonality in the demand for oil transportation, even though this is a well-known feature of the tanker markets (see, for instance, Kavussanos and Alizadeh, 2002). The demand time series in Figure 5 is found to be significant at the 10% level, and so we proceed to estimate the parameters for the process  $X_j$ . The parameter estimates for  $\alpha$  and  $\beta$  are provided in the table below.

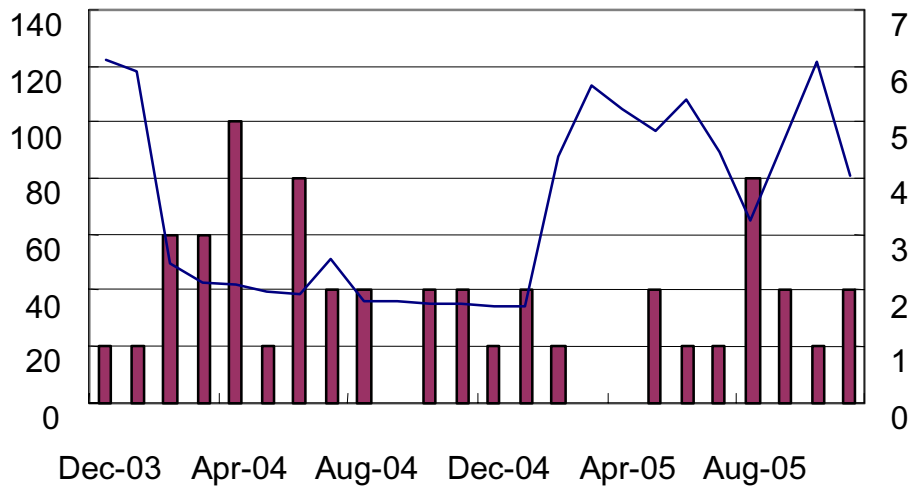
**Table 2: Demand process estimates**

<i>Parameters</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>
$\alpha$	142.499	17.577	8.107	0
$\beta$	0.1975	0.0976	2.024	0.0455
S.E. of residuals	33.774			
DW statistic	2.088			

The parameter  $\eta$  is calibrated such that the average monthly tonne-mile demand in the third quarter of 2003 produces an average model-implied spot rate equal to the observed average in the same period. This results in a parameter value of around  $\eta = 1,320$  tm/DWT.

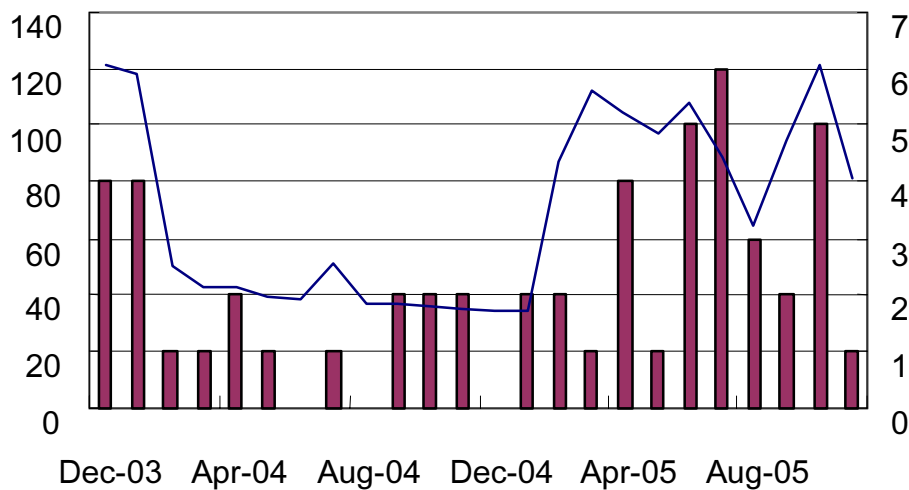
The spot freight rate scenarios in our model are then generated by imposing the stochastic demand process on the supply model, subject to the prevailing orderbook as of November 1, 2003 (Clarkson Research, 2003). The graphs below show a sample scenario of spot rate developments for a two-year simulation period.

**Figure 6 a: WSAG – Japan vs. demolitions**



Source: Clarkson Research Studies

**Figure 6 b: WSAG – Japan vs. contracting**



Source: Clarkson Research Studies

It is worth noting that the graphs above show only one of an infinite number of paths for the VLCC spot freight rate<sup>6</sup> and the corresponding demolition and ordering scenarios. The stochastic nature of the model enables the use of Monte Carlo simulation procedures to generate a large number of paths, which makes the model a useful tool in credit analysis and derivative pricing.

<sup>6</sup> We ignore the fact that Worldscale flat rates will change annually. The figures above refer to Worldscale 2003.

In addition to generating time series of spot freight rates, the model also tracks the size of the fleet, orderbook, and even the age profile and composition of the VLCC fleet at any future point in time (assuming newbuildings are of a standard design).

## **5. Summary and concluding remarks**

In this paper we have developed and estimated empirically a stochastic partial equilibrium model of a bulk shipping market. While the empirical estimates are based on data from the VLCC sector, the model is general in nature and can be applied to any other bulk shipping sub-sector.

It is evident from the simulations that the Poisson process cannot fully account for the occasional large jumps in number of new contracts/demolitions. This is consistent with the observation that the Poisson distribution cannot account for the “contagion effect” and the strategic element of contracting. It is possible that the addition of a discrete jump process, both in the scrapping and ordering functions, may be better able to capture such ‘speculative’ behaviour. This is a topic for future research.

Another avenue for expansion may be the use of a stochastic, rather than constant, fuel price.

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