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A non-parametric model of the timecharter-equivalent spot freight rate in the Very Large Crude oil Carrier market

by

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Non-technical Summary

This paper presents a new way of modelling the timecharter equivalent spot freight rate in the VLCC market. Using monthly data from January 1989 to December 1998, the empirical results indicate that high freight rates are expected to drift downwards while the expected change at low to medium freight rate levels is zero. Moreover, the rate of change (volatility) is increasing progressively in the freight rate level. The market price of freight rate risk is close to zero for most freight rate levels indicating that shipowners are not compensated for the risk associated with trading in the spot market.

1. Theoretical background

Consider a continuous-time diffusion process, satisfying a time-homogeneous stochastic differential equation (SDE):

$$dX_t = \mu\left(X_t\right)dt + \sigma\left(X_t\right)dZ_t \tag{1}$$

where Z is a standard Brownian motion, and the drift and diffusion terms μ and σ are, respectively, the instantaneous mean and variance of the process. Following the notation of Stanton (1997), the conditional expectation of an arbitrary function f can be written, under suitable restrictions on μ, σ, in the form of a Taylor series expansion:

$$E_t\left[f\left(X_{t+\Delta}, t+\Delta\right)\right] = f\left(X_t, t\right) + Lf\left(X_t, t\right)\Delta + \frac{1}{2}L^2 f\left(X_t, t\right)\Delta^2 + \ldots + \frac{1}{n!}L^n f\left(X_t, t\right)\Delta^n + O\left(\Delta^{n+1}\right) \tag{2}$$

where L is the infinitesimal generator of the process $\{X_t\}$. Ignoring all higher-order terms gives us a first-order approximation for Lf:

$$Lf\left(X_t, t\right) = \frac{1}{\Delta}E_t\left[f(X_{t+\Delta}, t+\Delta) - f(X_t, t)\right] + O(\Delta) \tag{3}$$

To derive approximations of the drift, μ, consider the function f(x,t) ≡ x. From the definition of L we have that the drift μ(x) = Lf(x,t). Substituting into equation (3) leads to the following first-order approximation for μ:

$$\mu\left(X_t\right) = \frac{1}{\Delta}E_t\left[X_{t+\Delta} - X_t\right] + O(\Delta) \tag{4}$$

Similarly, to construct approximations to the diffusion, σ, consider the function $f(x,t) \equiv (x - X_t)^2$. From the definition of L, we have:

$$Lf\left(x, t\right) = 2\left(x - X_t\right)\mu(x) + \sigma^2(x) \quad \text{and so} \tag{5}$$

$$Lf\left(X_t, t\right) = \sigma^2\left(X_t\right) \tag{6}$$

Substituting into equation (3) yields a first-order approximation for σ^2:

$$\sigma^2(X_t) = \frac{1}{\Delta} E_t\left[\left(X_{t+\Delta} - X_t\right)^2\right] + O(\Delta) \tag{7}$$

In general, the higher the order of the approximation, the faster it will converge to the true drift and diffusion of the process given in equation (1), as we observe the variable X_t at finer and finer time intervals. Unfortunately, the software used in this exercise (Eviews) does not allow non-parametric estimation with more than two variables.

An approximation to the market price of freight rate risk can be constructed in an analogous manner. Following Stanton (1997), the first order approximation is:

$$\lambda(X_t) = \frac{\sigma(X_t)}{\Delta\left(\sigma^{(1)}(X_t) - \sigma^{(2)}(X_t)\right)} E_t(R^{(1)}_{t,t+\Delta} - R^{(2)}_{t,t+\Delta}) + O(\Delta)$$

where $R^{(i)}_{t,t+\Delta}$ is the holding period return on asset i between times t and t + Δ and $\sigma^{(i)}$ is the instantaneous volatility of asset i.

2. Empirical results

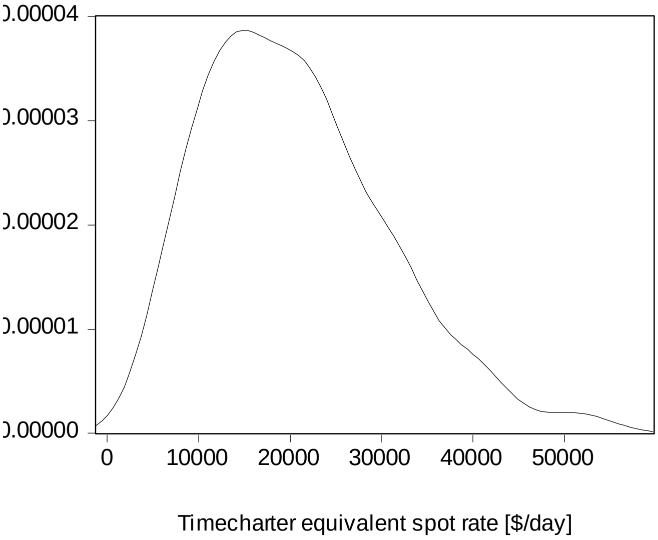
A kernel estimation procedure is used to estimate the conditional expectations in (4) and (7). The data used to form the density estimators consists of discrete observations of the spot freight rate $\{X_1,\ldots,X_n\}$ sampled at interval Δ. The non-parametric kernel estimator of the marginal density is given by:

$$\hat{f}(u) = \frac{1}{n}\sum_{t=1}^{n}\frac{1}{h_n}K\left(\frac{u - x_t}{h_n}\right) \tag{8}$$

where K(·) is a kernel function that integrates to one and h_n the bandwidth.

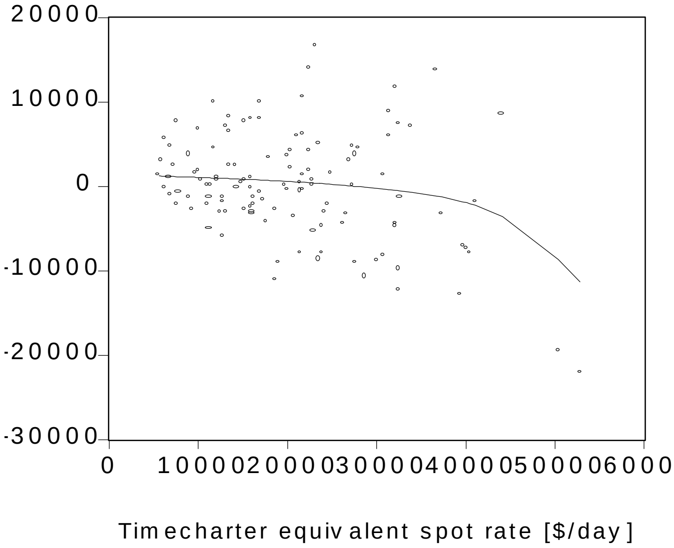
One can think of (8) as being a "smooth histogram" where the density at any point is estimated as the average of densities centered at the actual data points. Some regularity conditions and restrictions on the choice of the kernel and bandwidth apply. However, results in the kernel estimation literature show that any reasonable kernel gives almost optimal results. In this case, the Gaussian kernel has been used. Using Silverman (1986) rule of thumb, which is incorporated in the software, the optimal bandwidth for our data is h = 3424.2.

Figure 1: Estimated marginal density of spot freight rate



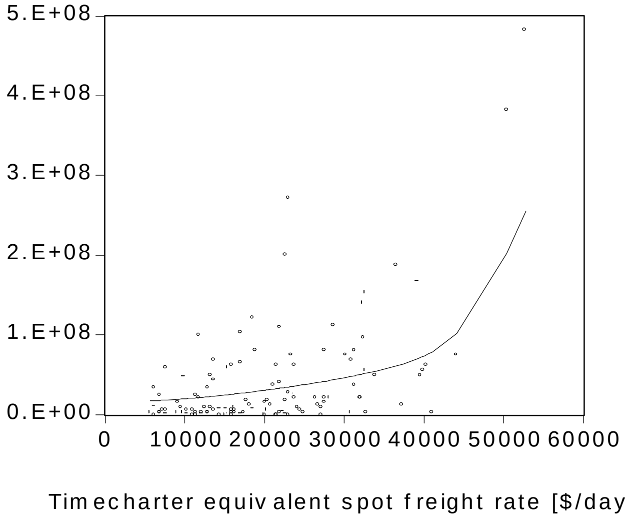
Given the estimated density, one can calculate any desired moments from the distribution. Note that the first-order approximations to the conditional expectations (4) and (7) is equivalent to determining a non-linear regression line between the monthly changes/squared changes and the freight rate the previous month.

Figure 2: Estimated drift of freight rate process



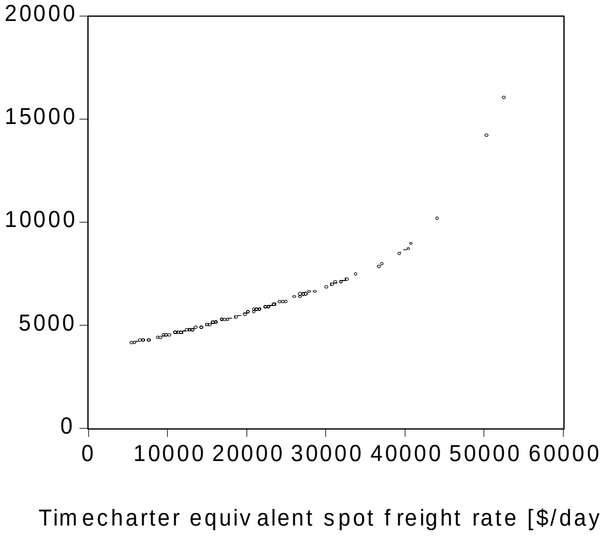
Looking first at figure 2, we see that the estimated drift does not look linear. For low and medium values of the spot freight rate, there is only very slight mean reversion. As the freight rate increases beyond about $35,000 per day, the estimated drift drops sharply. This is in line with the notion of mean reversion. The decline in the drift that we estimate at high freight rates has the effect of preventing freight rates from exploding towards infinity, despite the increase in volatility. However, there are too few observations to get a statistically confident estimate. This emphasizes the greater data requirements of non-parametric techniques compared with their parametric counterparts. Unfortunately, the kernel regression option in Eviews does not incorporate the calculation of confidence bands. Numerical methods such as the Kunsch (1989) block bootstrap algorithm could have been used for this purpose, but it seems clear that the low number of highly scattered observations would lead to wide bands. Presumably it would not be possible to reject that the drift $\mu = 0$ for most freight rate levels at the 95% level of confidence.

Figure 3: Estimated $\sigma^2(X)$ of freight rate process



As for the estimated $\sigma^2(X)$, it increases with the freight rate, implying increasing volatility in the freight rate level. However, the diffusion process is given by the square root of the estimates, depicted in the figure below.

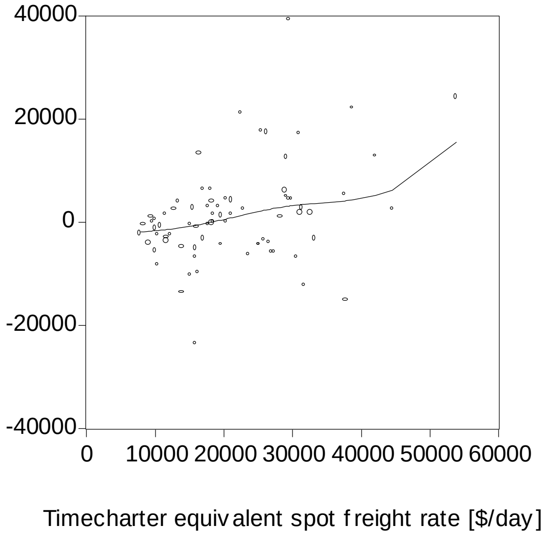
Figure 4: Estimated diffusion function



The estimated instantaneous rate of change (volatility) clearly increases in the freight rate level. For low and medium freight rates, the diffusion function $\sigma(X)$ is close to linear, while it is increasing progressively for very high freight rates. Again, however, the low number of observations makes inference dubious. Moreover, it is natural to assume that $\sigma(0) = 0$, a condition which prevents freight rates from becoming negative. This is not imposed in the estimation above.

The only available market prices for freight rate dependent assets are the vessels themselves. However, these assets pay dividends, in the sense that any daily profit from operation is paid to the owner. Thus, to get a consistent time series for a "non-dividend" paying asset, these profits & losses need to be added to the asset value in any given period. The two assets are a five-year old and a ten-year old VLCC. The resulting non-parametric estimate for the market price of freight rate risk is illustrated below.

Figure 5: Estimated market price of freight rate risk



The market price of risk is close to zero for low and medium freight rates and increasing in the freight rate level, corresponding to an increasing premium for bearing freight rate risk. For high freight rates, although there are few observations, the estimates suggest a large positive market price of freight rate risk. This is consistent with the observed freight rate premium in the spot market (on average). The drift in a risk-neutral world is given by the difference ($\mu(X)$ - $\lambda(X)$), thus the market price of risk has the effect of reinforcing the mean reverting property of the risk-neutral drift term.

3. Implications for vessel valuation

By using third- and fourth-order polynomial approximations for the drift, diffusion, and market price of risk (ref. appendix), it is straightforward to calculate the vessel value (the expected present value of future earnings) using Monte Carlo simulation of the risk-adjusted freight rate process. In the table below, the results are compared to vessel values calculated using $\lambda = 0$ as in previous research (e.g. Tvedt 1997).

Table 1 : Effect of price of risk on vessel valuation

Freight rate	Vessel value [million]	Vessel value ($\lambda = 0$)	Difference
$10,000/day	5.257	5.041	4.1%
$20,000/day	5.717	5.517	3.4%
$30,000/day	8.235	7.522	8.7%
$40,000/day	14.373	11.307	21.3%

Calculated using risk-free rate of $r = 6\%$ p.a., scrap value $S = \$5$ million, lay-up level $m = \$2{,}000$/day and a maximum remaining trading life of $T = 10$ years.

The introduction of a non-zero market price of risk has a large impact on the vessel valuation, and more so for high freight rates.

4. Conclusions

By not specifying a particular parametric form, non-parametric techniques avoid the possibility of misspecification, but at the expense of greater estimation error than their parametric counterparts. As Jiang (1998) points out, the approximations used in this paper can be extremely non-robust in that the estimates can be very sensitive to the sampling path. Moreover, the performance of the "naïve" first-order approximations deteriorates as the sampling frequency and the number of observations decrease, and the approximation errors introduced may be significant when monthly observations are used. However, as a first cut, the results are interesting. The hypotheses regarding mean reversion and increasing volatility in the freight rate level have support in the data, and a functional form of the market price of risk has never been documented in this market previously. Moreover, the introduction of a non-zero market price of risk has a large impact on the vessel valuation.

Appendix A: Parameterizations of μ, σ and λ

```
Dependent Variable: SIGMA
Method: Least Squares
Sample(adjusted): 1 119
Included observations: 119 after adjusting endpoints
SIGMA=C(1)+C(2)*TCE+C(3)*TCE^2+C(4)*TCE^3
==========================================================================
                         Coefficient   Std. Error   t-Statistic     Prob.
==========================================================================
           C(1)             2572.952     118.1853      21.77049    0.0000
           C(2)             0.277964     0.016633      16.71162    0.0000
           C(3)            -1.02E-05     6.85E-07     -14.87203    0.0000
           C(4)             1.81E-10     8.37E-12      21.62400    0.0000
==========================================================================
R-squared                   0.991593   Mean dependent var        5803.109
Adjusted R-squared          0.991374   S.D. dependent var        1704.033
S.E. of regression          158.2658   Akaike info criterion     12.99946
Sum squared resid           2880526.   Schwarz criterion         13.09288
Log likelihood             -769.4681   Durbin-Watson stat        0.256956
==========================================================================
```

```
Dependent Variable: MU
Method: Least Squares
Sample(adjusted): 1 119
Included observations: 119 after adjusting endpoints
MU=C(1)+C(2)*TCE+C(3)*TCE^2+C(4)*TCE^3+C(5)*TCE^4
==========================================================================
                         Coefficient   Std. Error   t-Statistic     Prob.
==========================================================================
           C(1)             524.6533     81.28997      6.454097    0.0000
           C(2)             0.205725     0.016279      12.63764    0.0000
           C(3)            -2.06E-05     1.08E-06     -19.13366    0.0000
           C(4)             6.92E-10     2.83E-11      24.44634    0.0000
           C(5)            -8.63E-15     2.54E-16     -33.98978    0.0000
==========================================================================
R-squared                   0.998733   Mean dependent var        239.1783
Adjusted R-squared          0.998689   S.D. dependent var        1577.832
S.E. of regression          57.12908   Akaike info criterion     10.96961
Sum squared resid           372065.4   Schwarz criterion         11.08638
Log likelihood             -647.6919   Durbin-Watson stat        0.434870
==========================================================================
```

```
Dependent Variable: LAMBDA
Method: Least Squares
Sample(adjusted): 1 75
Included observations: 75 after adjusting endpoints
SLAMBDA=C(1)+C(2)*STCE+C(3)*STCE^2+C(4)*STCE^3
==========================================================================
                         Coefficient   Std. Error   t-Statistic     Prob.
==========================================================================
           C(1)            -6426.709     629.2856     -10.21271    0.0000
           C(2)             0.604703     0.081710      7.400579    0.0000
           C(3)            -1.73E-05     3.12E-06     -5.532314    0.0000
           C(4)             2.45E-10     3.58E-11      6.850036    0.0000
==========================================================================
R-squared                   0.967162   Mean dependent var        1060.938
Adjusted R-squared          0.965774   S.D. dependent var        2681.105
S.E. of regression          496.0094   Akaike info criterion     15.30293
Sum squared resid           17467801   Schwarz criterion         15.42652
Log likelihood             -569.8597   Durbin-Watson stat        0.560160
==========================================================================
```

Appendix B: Data

TC equivalent, built
mid-1970's
Values refer to average of period
[USD/day] from Fearnleys

Jan-89	18665
Feb-89	7675
Mar-89	5634
Apr-89	6981
May-89	11900
Jun-89	16451
Jul-89	14425
Aug-89	14403
Sep-89	17020
Oct-89	27126
Nov-89	30181
Dec-89	21499
Jan-90	21923
Feb-90	23136
Mar-90	39651
Apr-90	32649
May-90	22881
Jun-90	23681
Jul-90	28721
Aug-90	18086
Sep-90	21498
Oct-90	13561
Nov-90	21854
Dec-90	32313
Jan-91	44128
Feb-91	52819
Mar-91	30867
Apr-91	22599
May-91	36742
Jun-91	50386
Jul-91	30823
Aug-91	32157
Sep-91	27466
Oct-91	32167
Nov-91	27718
Dec-91	18727
Jan-92	16138
Feb-92	12999
Mar-92	7215
Apr-92	9781
May-92	11304
Jun-92	6329
Jul-92	12035
Aug-92	12806
Sep-92	11511
Oct-92	11788
Nov-92	21707
Dec-92	21456
Jan-93	20929
Feb-93	17504
Mar-93	15990
Apr-93	15826
May-93	13549
Jun-93	15986
Jul-93	23869
Aug-93	16013
Sep-93	17031
Oct-93	16272
Nov-93	15116
Dec-93	12512
Jan-94	9560
Feb-94	6823
Mar-94	7846
Apr-94	7104
May-94	6179
Jun-94	6035
Jul-94	9179
Aug-94	12986
Sep-94	11210
Oct-94	11317
Nov-94	10189
Dec-94	12213
Jan-95	13315
Feb-95	10440
Mar-95	11174
Apr-95	8998
May-95	7781
Jun-95	15412
Jul-95	22984
Aug-95	23038
Sep-95	17851
Oct-95	13681
Nov-95	20149
Dec-95	19882
Jan-96	20123
Feb-96	23795
Mar-96	19092
Apr-96	10121
May-96	17007
Jun-96	25100
Jul-96	26842
Aug-96	23647
Sep-96	15027
Oct-96	15385
Nov-96	16142
Dec-96	13277
Jan-97	20301
Feb-97	22413
Mar-97	24341
Apr-97	21251
May-97	27272
Jun-97	27594
Jul-97	31395
Aug-97	37347
Sep-97	33986
Oct-97	41059
Nov-97	39304
Dec-97	26388
Jan-98	21833
Feb-98	28198
Mar-98	32711
Apr-98	31533
May-98	40490
Jun-98	32700
Jul-98	40100
Aug-98	32700
Sep-98	20400
Oct-98	24700
Nov-98	22600
Dec-98	26700

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