Transportation Research Part E xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Multivariate modeling and analysis of regional ocean freight rates☆

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ARTICLE INFO

Keywords:
Freight rates
Autoregressive models in continuous time
Cointegration
Forward freight agreements

ABSTRACT

In this paper, we propose a new multivariate model for the dynamics of regional ocean freight rates. We show that a cointegrated system of regional spot freight rates can be decomposed into a common non-stationary market factor and stationary regional deviations. The resulting integrated CAR process is new to the literature. By interpreting the common market factor as the global arithmetic average of the regional rates, both the market factor and the regional deviations are observable which simplifies the calibration of the model. Moreover, forward contracts on the market factor can be traded in the Forward Freight Agreement (FFA) market. We calibrate the model to historical spot rate processes and illustrate the term structures of volatility and correlation between the regional prices and the market factor. Our model is an important contribution towards improved modelling and hedging of regional price risk when derivative market liquidity is concentrated in a single global benchmark.

1. Introduction

The degree to which regional markets for a homogeneous good are spatially integrated across the globe will depend on the physical characteristics of international trade. The greater the trade barriers in terms of time, transport costs, and tariffs, the less integrated are regional market prices. Ocean transportation is an integral part of this picture, particularly in the global commodity markets, as the vast majority of trade is seaborne. The fact that ships and their cargoes move slowly around the world compared to other transportation modes (Hummels and Schaur, 2013) implies that regional imbalances in the physical supply and demand of a commodity cannot be immediately resolved by international trade. Yet, whenever two regional prices deviate by more than the transaction costs, commodity traders will take advantage of the spatial price arbitrage by shipping cargoes from the cheaper region to the expensive region such that prices are realigned (Pirrong, 2014). Large spatial differences in regional freight rates will have a similar effect on the physical movement of ships, as profit-maximizing shipowners will reallocate their fleet to higher-paying areas, thereby realigning regional freight rates (Adland et al., 2017). The topic of spatial market integration has been investigated empirically across many global commodity markets, notably coal (Wårell, 2006; Papiez and Smiech, 2015), natural gas (Siliverstovs et al., 2005), crude oil (Bachmeier and Griffin, 2006), petroleum products (Lanza et al., 2005), and regional ocean freight rates (Berg-Andreassen, 1996, 1997; Glen and Rogers, 1997; Veenstra and Franses, 1997). The general finding is that regional prices are non-stationary and co-integrated. Following the definition of Engle and Granger (1987), this means the time series are integrated, or I(1),

☆ We are grateful to Clarkson Research for providing us with data. The authors acknowledge financial support from the research project "Green shipping under uncertainty" partly financed by the Research Council of Norway under Grant No. 233985. We thank three referees for their valuable and constructive criticism on an earlier version of the paper.

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http://dx.doi.org/10.1016/j.tre.2017.10.014
Received 19 May 2017; Received in revised form 18 September 2017; Accepted 19 October 2017

while some linear combination between them – the cointegrating vector – is stationary, or I(0). This is consistent with the idea that regional prices must revert towards some common global stochastic trend because of the ability of cargoes and ships to continuously move from regions of oversupply towards regions of undersupply.

Having established that regional prices or freight rates are co-integrated, usually based on the test methodology of Johansen (1991), most of the above studies proceed to model them jointly in the Vector Error Correction (VEC) model framework (see, for instance, Veenstra and Franses, 1997; Lanza et al., 2005). An alternative approach is the state space representation, where the common stochastic process is unobservable and extracted empirically using, for instance, the Kalman filter approach (Chang et al., 2009). Ko (2011a,b) uses the latter methodology to derive a common stochastic trend from average freight rate indices for different vessel sizes in the drybulk freight market and assess the idiosyncratic dynamics of size effects.

For the purposes of risk management, there are numerous regional spot freight rates for drybulk carriers, but liquidity in the derivative market is concentrated in Forward Freight Agreements (FFAs) written on the weighted global average of such indices. A similar situation exists in the crude oil and fuel oil market, with a large number of regional prices available around the globe but derivative liquidity focused on one or two global benchmarks (e.g. Brent crude or Rotterdam HFO). In the context of cross hedging, the implementation and interpretation of a model becomes considerably easier if the common stochastic factor explicitly represents an observable market price on which tradable derivatives exist. In this paper we propose, for the first time, to decompose regional prices into such a common observable stochastic factor and mean-reverting, potentially correlated, regional factors. This factorization can be viewed as an extension of the famous model by Schwartz and Smith (2000), which is the price dynamics empirically argued for by Prokopczuk (2011) in his seminal work on freight futures pricing and hedging.

The contribution of our paper is threefold. Firstly, we develop a new continuous-time stochastic model for the joint dynamics of regional prices, the Integrated Continuous Autoregressive, or ICAR, process. Our proposed framework enables the decomposition of observed regional spot price dynamics into a non-stationary observable market factor, for which tradable contracts exist, and observable stationary regional factors (deviations from the market average). We focus on Gaussian models, but provide also some theoretical discussion and empirical evidence for leptokurtic dynamic models. Secondly, we show the link between the continuous ARMA process and the ARMA time series model, generalizing results for the specific autoregressive case in Benth and Šaltytė Benth (2013). Thirdly, we calibrate the model empirically against regional spot freight processes in the Supramax market in both discrete and continuous time, and illustrate the resulting term structures of correlations and volatility versus contract maturity.

Our findings are important for shipping industry players and maritime economic researchers alike. Notably, we bring new insight into how to model and estimate the joint dynamics of regional spot rates in both a discrete and continuous-time setting. The ease of estimation and simulation makes the model particularly interesting for stochastic scenario generation, which would form an important input in optimization models for fleet allocation (i.e. how to optimally sequence tripcharters in the bulk shipping spot market through space and time). In the context of risk management, our extension to the freight derivatives market directly addresses a practical question that all shipowners, operators and charterers trading drybulk freight derivatives must deal with: how to hedge physical regional exposure when only global averages are tradable in practice. Here, our model also brings the literature on freight derivatives forward by illustrating the implication of our model for the pricing of regional forward curves and the term structure of volatility.

The remainder of our paper is structured as follows: Section 2 derives the continuous-time cointegrated model of the spot freight rate dynamics, Section 3 presents our data and time series analysis, Section 4 derives the theoretical FFA price dynamics within our framework, Section 5 shows an application to the hedging of regional risk and Section 6 gives an outlook to non-Gaussian dynamical models. Finally, Section 7 concludes.

2. A continuous-time cointegrated model for the freight rate spot dynamics

In this section we develop a continuous-time stochastic model for the dynamics of freight rates. To distinguish continuous-time stochastic processes from time series, we will use the notation $Y(t)$ for a continuous time process, while we apply the notation y_t for a time series model (with time t in that case being discrete). In this section and in the remainder of the paper, we let $(\Omega,\mathscr{F},P)$ define a complete probability space, equipped with a filtration $\{\mathscr{F}_t\}_{t\geqslant 0}$.

First, recall from Brockwell (2001) that a real-valued stochastic process Y is called a CAR(p)-process for $p\in\mathbb{N}$, if $Y(t)=\mathbf{e}_1^\top\mathbf{Z}(t)$ where $\mathbf{Z}\in\mathbb{R}^p$ is the vector-valued Ornstein–Uhlenbeck process given by

$$d\mathbf{Z}(t)=A\mathbf{Z}(t)dt+\sigma\mathbf{e}_p dB(t),\quad \mathbf{Z}(0)=\mathbf{Z}^0\in\mathbb{R}^p, \tag{1}$$

for a Brownian motion B. Here, $\{\mathbf{e}_k\}_{k=1}^p\subset\mathbb{R}^p$ is the canonical basis of $\mathbb{R}^p$ and $\sigma>0$ is a constant. The matrix $A\in\mathbb{R}^{p\times p}$ is defined as

$$A=\begin{bmatrix} 0 & 1 & 0 & 0 & \dots & 0\\ 0 & 0 & 1 & 0 & \dots & 0\\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & 0 & 0 & \dots & 1\\ -\alpha_p & -\alpha_{p-1} & -\alpha_{p-2} & -\alpha_{p-3} & \dots & -\alpha_1 \end{bmatrix}, \tag{2}$$

for positive constants $\alpha_k, k=1,\dots,p$. Hence,

$$Y(t)=\mathbf{e}_1^\top e^{At}\mathbf{Z}^0+\sigma\int_0^t \mathbf{e}_1^\top e^{A(t-s)}\mathbf{e}_p dB(s). \tag{3}$$