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**An Econometric Analysis of the Dry Bulk Shipping Industry;
Seasonality, Market Efficiency and Risk Premia**

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A Thesis Submitted for the Degree of PhD
in
Applied Econometrics

City University Business School

Department of Shipping, Trade & Finance

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey-Fuller unit root test
AIC	Akaike Information Criterion
ARCH	Autoregressive Conditional Heteroscedasticity
ARIMA	Autoregressive Integrated Moving Average
CSZ	Capesize spot rates
CSZ1	1-year time-charter rates for Capesize vessels
CSZ3	3-year time-charter rates for Capesize vessels
CV	Cointegrating Vector
DL	Delivery of newbuilding vessels
ECT	Error Correction Term
ECM	Error Correction Model
EG	Engle-Granger two-step test for cointegration
EHTS	Expectations Hypothesis of the Term Structure
EMH	Efficient Market Hypothesis
GARCH	Generalised Autoregressive Conditional Heteroscedasticity
GARCH-M	GARCH in mean
EGARCH	Exponential GARCH
EGARCH-M	Exponential GARCH in mean
GIR	Generalised Impulse Response
GMM	Generalised Method of Moments
HEGY	Hylleberg, Engle, Granger and Yoo seasonal unit root test
HSZ	Handysize spot rates
HSZ1	1-year time-charter rates for handysize vessels
HSZ3	3-year time-charter rates for handysize vessels
I(b)	Integrated variable of order b
K	Fleet size or stock of fleet
LCSZ	Log of Capesize spot rates
LCSZ1	Log of 1-year time-charter rates for Capesize vessels
LCSZ3	Log of 3-year time-charter rates for Capesize vessels
LFR	Long term equilibrium freight rate
LHSZ	Log of Handysize spot rates
LHSZ1	Log of 1-year time-charter rates for handysize vessels
LHSZ3	Log of 3-year time-charter rates for handysize vessels
LL	Log Likelihood
LPMX	Log of Panamax spot rates
LPMX1	Log of 1-year time-charter rates for Panamax vessels
LPMX3	Log of 3-year time-charter rates for Panamax vessels
LR	Likelihood Ratio Test
LS	Tonnage Losses
OC	Operating Costs
OIR	Orthogonalised Impulse Response
OLS	Ordinary Least Squares
OR	Order Book, Vessels on order
PMX	Panamax spot rates
PMX1	1-year time-charter rates for Panamax vessels
PMX3	3-year time-charter rates for Panamax vessels
PP	Philips and Perron unit root test
Q^s	Supply of shipping services
Q^d	Demand for shipping services
RE	Rational Expectations
RV	Revenue form operation

SACF	Sample Autocorrelation Function
SPACF	Sample Partial Autocorrelation Function
SBIC	Schwarz Bayesian Information Criterion
SC	Scraping
SP	Speed
SURE	Seemingly Unrelated Regressions Estimation
TCE	Time-charter equivalent of spot rates
VAR	Vector Autoregressive Model
VECM	Vector Error Correction Model
WHITE	White test for heteroscedasticity
Δ LCSZ	Change in log of Capesize spot rates
Δ LCSZ1	Change in log of 1-year time-charter rates for Capesize vessels
Δ LCSZ3	Change in log of 3-year time-charter rates for Capesize vessels
Δ LHSZ	Change in log of Handysize spot rates
Δ LHSZ1	Change in log of 1-year time-charter rates for handysize vessels
Δ LHSZ3	Change in log of 3-year time-charter rates for handysize vessels
Δ LPMX	Change in log of Panamax spot rates
Δ LPMX1	Change in log of 1-year time-charter rates for Panamax vessels
Δ LPMX3	Change in log of 3-year time-charter rates for Panamax vessels

TABLE OF SYMBOLS

B	Back-shift operator
$D_{i,t}$	Seasonal dummy variables (centralised dummies when specified, $i=1, \dots, 12$ for monthly data)
E_t	Expectations operator on information available at time t
exr_t	Excess holding period return
FR_t	Spot freight rate at time t
σ^2	Variance
σ_t^2	Time-varying variance
I_n	$(n \times n)$ Identity matrix
P_t	Price of ship (or stock price when specified) at time t
P_t^{NB}	Newbuilding Ship Price at time t
P_t^{SH}	Second-hand Ship Price at time t
P_t^{SC}	Scrap Price at time t
$Q_{i,t}$	Relative seasonal dummy variables ($Q_{i,t}=D_{i,t}-D_{1,t}$, $i=2, 3, \dots, 12$ for monthly data)
S'_t	Perfect foresight spread at time t
S^*_t	Theoretical spread at time t
S_t	Actual spread at time t
TC_t^n	n period time-charter rate at time t
$iid(0, \sigma^2)$	Independently and identically distributed with zero mean and constant variance
$IN(0, \sigma^2)$	Independently and normally distributed with zero mean and constant variance
$\chi^2(n)$	Chi-square distribution with n degrees of freedom
$t(0, \sigma^2, v)$	Student- t distribution with zero mean, time-varying variance and v degrees of freedom
Π_t	Operating profit at time t
r_t	Logarithmic returns at time t
r_t^m	Market returns at time t
π_t	Log of operating profit at time t
π_{rt}	Difference between first difference of log of operating profit at time t and log of interest rate (discount rate)
Σ	Variance-covariance matrix
Σ_t	Time-varying variance-covariance matrix
Ω_t	Full information set available at time t
Λ_t	Restricted information set at time t
Δ	First difference operator
Δ^n	n period difference operator
$\sum_{i=0}^n x_i$	Summation operator over variable x from 0 to n
$\prod_{i=1}^n x_i$	Multiplication operator over variable x from 1 to n

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DECLARATION

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ABSTRACT

This thesis aims to investigate four main areas of interest in the functioning of different markets in the dry bulk shipping sector using recent econometric and time series techniques. These areas include; seasonality patterns in freight markets, the efficient market hypothesis and the existence of time-varying risk premia in freight rate and ship price formation, the dynamic interrelationships between freight rate levels and spillover effects in freight rate volatilities, between sub-markets of the dry bulk sector.

The seasonal behaviour of dry bulk freight rates is measured and compared across vessel sizes, contract duration and under different market conditions. Seasonality is deterministic rather than stochastic and it varies across vessel sizes, contract durations and market conditions. In particular, freight rates for larger vessels show higher seasonal variations than smaller ones. Seasonality in spot rates is higher than time-charter rates across the size. Also, seasonal fluctuations are found to be stronger during market expansions compared to market down turns.

The validity of the expectations hypothesis of the term structure (EHTS) in the formation of both one and three-year time-charter rates is strongly rejected for all size carriers. Failure of the EHTS is attributed to shipowners' perceptions of risk regarding their decision to operate in spot or time-charter markets. Time-varying risk premia in the formation of period rates is found to be negative; shipowners are prepared to accept lower rates for the relative security of longer contracts. The higher risk involved in contracts with shorter term to maturity are thought to emanate from higher freight rate volatilities, relocation costs, risk of unemployment in spot markets as well as fluctuations in voyage costs.

Investigating the dynamic interrelationships between freight rates for different size vessels and spillover effects between volatilities in spot and period markets reveal that the interaction between freight rates in the spot market is higher than in the period markets. It is also found that there is a unidirectional transmission of volatility from larger to smaller size vessels in both spot and period markets.

Finally, results strongly reject the EMH in the market for newbuilding and second-hand dry bulk vessels. Failure of the present value model and price efficiency is attributed to the risk associated with holding these assets. Results of Generalised Autoregressive Conditional Heteroscedasticity in Mean (GARCH-M) models suggest that there is a positive relationship between time-varying risk and return on shipping investments, a result which is consistent with asset pricing theories in the financial economics literature.

1 CHAPTER ONE

INTRODUCTION TO DRY BULK SHIPPING MARKETS

1.1 Introduction to the dry bulk shipping industry

Bulk shipping has developed as a result of cutting transportation costs when cargo sizes are large enough to be carried in shiploads and economies of scale are prominent in transportation. This goes back a few centuries when coal trade was established between North England and London, small wooden ships were fully loaded with coal to meet the increasing coal demand. Nowadays, the number of commodities carried on a “one ship, one cargo” basis has increased, thanks to the increasing demand for raw materials and energy commodities, liberalisation in international trade, transnationalisation of industrial processes as well as technological advances in shipbuilding and design.

The growth in international trade in the last century led to a tremendous expansion of the bulk shipping fleet to match the requirements for seaborne bulk trade. Since 1939, the size of the merchant fleet has increased (from 65,059 gt to 546,739 gt) and the number of ships tripled (from 30,000 to 88,000) ¹. Today, the world dry bulk fleet constitutes one third of the world fleet in terms of capacity with 6000 ships providing 260 million dwt (see Fearnleys). In 1998, total world seaborne trade in dry bulk commodities reached 1,882 mt (see Clarksons Research Studies), of which 1,162 mt were five major dry bulk commodities; that is, 416 mt of iron ore, 452 mt of coal, 208 mt of grain and 86 mt of bauxite, alumina and phosphate rock, and 689 mt of minor dry bulk commodities.

On the other hand, technological developments led to more sophisticated and larger ship designs, aiming not only to realise the economies of scale but also to match specific cargo and trading route requirements. The latter depend very much on commodity trade patterns and industrial production processes in the world economy. As a result of these facts, bulk shipping may be broadly divided into different sectors depending on the nature of the cargo they carry; that is, liquid bulk and dry bulk and sub-sectors for each of these broad categories. For example, the dry bulk sector comprises of three main sub-sectors according to the cargo carrying capacity of vessels. These are handysize (30,000 dwt), panamax (60,000 dwt) and

¹ The statistics are for ships of 1000 gr (gross registered ton) and over, source Institute of Shipping Economics and Logistics (Bremen).

capsize (120,000 dwt) markets. The tanker sector is also differentiated into four main sub-sectors; that is, handysize (30,000 dwt), Aframax (80,000 dwt), Suezmax (160,000 dwt) and VLCC (250,000 dwt) markets.

The aim of this chapter is to introduce the dry bulk shipping sector and establish the theme of the research in this thesis. The chapter starts with an overview of the dry bulk market and its contribution to the international transport by connecting the sources of supply and demand for raw materials. Recent trends and developments in supply and demand for dry bulk shipping, which led to segmentation of this sector, are also discussed and important factors causing such segmentation such as commodity parcel size, port restrictions, and changes in the pattern of world trade in dry bulk commodities, are highlighted.

Details of different forms of shipping contracts along with their cost structures are presented and the conditions of perfect competition in the dry bulk market are reviewed. The theory of efficient market hypothesis and its implications for the dry bulk freight market and the market for dry bulk vessels are discussed. In relation to the market segmentation in the dry bulk sector and the efficient market hypothesis, the motive and the need for further research and investigation of certain areas are highlighted. Finally, objectives of the thesis are set and contributions of the study are highlighted.

1.2 Market Segmentation of the Dry Bulk Shipping Industry

The enormous growth in international commodity trade along with developments in the shipbuilding industry in the past forty years or so, is a manifestation of liberalisation in international trade and the inherent economies of scale existent in seaborne commodity transportation. This has encouraged the construction of specialised ships of various sizes, which can be employed in the transportation of certain types of commodities over world trading routes. Therefore, different sub-markets within the dry and the liquid bulk sectors with distinguishing characteristics in terms of supply, demand, operations, risk and profitability have developed.

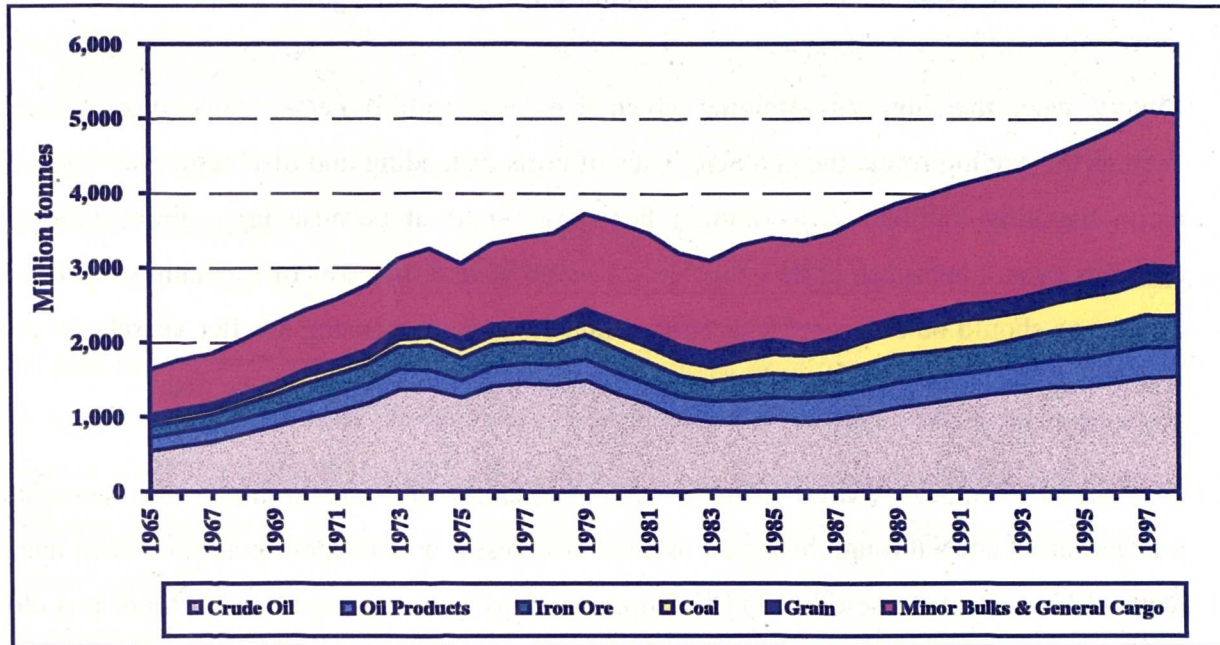
Generally speaking, in international transportation the charterers' decision to hire a certain type of vessel for ocean transportation of a certain commodity depends on three main factors; i) the type of the commodity transported, ii) the parcel size, and iii) the route and ports of load and discharge characteristics.

Different types of commodities, which are generally distinguished for shipping operations, market analysis and research, are classified as: liquid bulk, dry bulk, general cargo and unitised (containers). There are also special cargoes such as natural gas or refrigerated cargoes, automobiles, forest products and live-stocks, which require special types of ships for transportation.

Since it is the type of commodity that determines which type of ship the charterer requires for transportation of his/her commodity, any change in the trade pattern for that commodity is reflected in the demand and freight rate for that type of vessel. For example, industrial developments in the Far East, especially South Korea and China in the past two decades have increased the demand for capesize vessels in that region (route). As another example, the demand for capesize vessels in the Atlantic has been reduced due to the decline in the European Union's grain imports from the United States after the 1980's, due to the increase in the EU's grain production.

Figure 1.1 illustrates the evolution of seaborne trade in major dry and liquid bulk commodities between 1963 to 1998. It also shows that the volume of international seaborne trade in bulk commodities has doubled since the 1960's.

Figure 1.1: Pattern of International Seaborne Trade in Major Commodities



Source: Fearnleys

The second factor that a charterer (shipper) should bear in mind before taking any decision to hire a vessel is the conventional shipment size of each commodity, generally known as “commodity parcel size”. This is defined as the amount of cargo in tons that can be carried by sea considering the economies of scale and associated transportation and storage costs for that commodity. The commodity parcel size also depends on the economics of the industrial process or consumption of such commodities as raw materials for industrial goods and other finished products. For certain commodities such as iron ore, crude oil and coal, the economies of scale in sea transportation have reduced the transportation costs to such an extent that it is most economical to hire large vessels for carriage of these commodities by sea. Therefore, parcel sizes for those commodities are quite large (e.g. for crude petroleum the parcel size is ranging from 80,000 to 450,000 tons and for iron ore 80,000 to 300,000 tons). On the other hand, commodities like petroleum products and agricultural commodities are carried in smaller shipments. For both agricultural commodities and petroleum products the parcel sizes range from 12,000 to 60,000 tons, again depending on the type of cargo transported. This is mainly because of the perishable nature of agricultural commodities and

the fact that these commodities need specialised storage facilities (e.g. special silos). Therefore, traders prefer smaller shipments to be able to store and market these products in time. In addition, the higher storage and inventory costs of agricultural commodities and oil products compared to lower value goods such as iron ore, coal and crude oil, suggest that it is more economical to transport these commodities in smaller consignments.

Finally, when the shipper is deciding which size vessel to hire, he/she must consider factors such as the trading route, the characteristics of ports of loading and discharging draught, and cargo handling facilities. The draught factor is important because large ships with deep draughts cannot approach ports with shallow harbours and the costs of lightening them at the anchorage should be compared against the capacity loss when using smaller vessels. In ports where cargo-handling facilities are lacking small and geared vessels are needed.

In general, shippers (cargo owners and charterers) try to minimise the associated transportation costs through hiring an optimal size vessel by considering all the above named factors. As a result, these costs and size optimisations bring up the idea that there is a close relationship between certain types of commodities and vessel sizes; i.e. certain classes of vessels are employed in transportation of particular commodities on specific routes.

Table 1.1 summarises three broad categories of vessels distinguished in the dry bulk sector and the associated cargo types and routes that these vessels trade in. Handysize vessels (25,000–35,000dwt capacity) are mainly engaged in transportation of grain commodities from North and South America and Australia to Europe and Asia, and minor dry bulk commodities such as bauxite and alumina, fertilisers, rice, sugar, steel and scrap around the world. Due to their small size, shallow draught and cargo handling gears, these vessels are quite flexible in terms of the trading routes and ports that they can serve. Panamax vessels (50,000–65,000 dwt) are used primarily in coal, grain and to some extent in iron ore transportation, from North America and Australia to Japan and West Europe. These vessels are not equipped with cargo handling gears and have deeper draught, therefore they are engaged in transportation of fewer commodities than handysize bulk carriers, since they are not as flexible. The majority of the capesize (80,000dwt and over) fleet is engaged in transportation of iron ore from South America and Australia to Japan, West Europe and North America and also in coal transportation from Australia and North America to Japan

and West Europe. Due to their deep draught and limited number of commodities that they transport, the operation of these vessels in terms of trading routes and ports they can approach is restricted.

Table 1.1: Different size vessels with their respective cargo and routes

Vessel	Size in dwt	Cargo	Main routes
Capesize	120,000dwt	Iron ore and Coal	Brazil and Australia to Far East, North-West Europe and U.S East Coast.
Panamax	65,000dwt	Iron, Coal and Grain	Australia and North America to North-West Europe and Japan.
Handysize	30,000dwt	Grain, Coal and Minor Bulk Cargo	Almost all over the world.

It has also been argued in the literature that the risk/return characteristics of dry bulk carriers vary across vessel sizes (see, for example, Kavussanos (1996a and 1997)). In particular, Kavussanos (1996a and 1997) shows that freight rate volatilities and second-hand ship price volatilities are higher for larger vessels compared to smaller ones and relates such differences to operational flexibility and trading restrictions of larger vessels. Such strong contrast in risk/ return and operational profitability among different size of dry bulk carriers stems from differences in their supply, demand, freight rate and price determination factors which reflect their trading and operational flexibility. This in turn implies a high degree of disaggregation in this shipping sector.

1.3 Market Conditions in the Dry Bulk Freight Market

One of the most important features of any market for analysis purposes is the degree of competition prevailing in the market. On one extreme are markets in which there is perfect competition and no individual seller can influence the market price. On the other extreme the market might be monopolistic, in which case price is set by the monopolist taking account of a downward sloping demand curve and production costs. In between these two extremes, there are oligopolistic market conditions under which a group of sellers might be able to collude and set prices. It is therefore essential to recognise the degree of competition prevailing in a market before analysing it.

In markets where perfect competition exists, sellers and buyers always search for the best offer, through a range of offers. The price at which contracts are settled at each point of time, the equilibrium price, is determined through the interaction between supply and demand.

For perfect competition to exist certain conditions must be satisfied. In the case of tramp shipping markets these conditions are; ease of entry and exit into the market, the large number of participants (sellers and buyers), homogeneity of the product (service), the mobility of assets and services which the owners provide and efficient information dissemination. The following sections discuss the nature and importance of these conditions with respect to competition in dry bulk shipping markets.

1.3.1 No barriers to entry and exit

The shipping business has always been an easy profession to enter as long as the investor could afford the required initial investment (ship purchase). This is especially evident from the expansion of the industry during the past 50 years. During this period many private investors have been attracted to the shipping business, especially the dry bulk sector, due to the profitability of this market, which is higher compared to other sectors of the economy, at least at times (see Stopford 1997, page 71). Availability of special and lenient financing terms on newbuilding or second-hand vessels for potential investors through banks and financial institutions shows that it is not very difficult to enter into shipping operation. Moreover,

operational simplicity and the existence of management companies allow investors to participate in the market without any particular prior knowledge of shipping operations. At the same time, there are no barriers for investors to exit the industry by liquidating the company or selling off their vessels and leaving the business after even a short period of involvement.

The argument of ease of entry and exit is also true for operating or switching between different routes, when each route is considered as a separate market. There are no barriers to restrict owners or operators to enter into a particular trade or switch between trading routes. This is in contrast to liner shipping where oligopolistic market conditions exist. Ease of entry and exit also allows owners and operators in the market to search and operate in routes with higher returns. As a result, any opportunity for making excess profit in a particular route may be eliminated in a relatively short period.

It can also be argued that there is no complication to prevent shipowners and charterers to switch between contracts with different times to maturity; namely, spot and time-charter contracts in order to maximise their profit and minimise their costs. The only problem is that once a time-charter contract is agreed upon, both parties should fulfil their obligations until the terminal date of the contract. However, for short term time-charter contracts, say 6 to 12 months, flexibility and ease of switching between different charter markets ensures perfect competition in both spot and period markets.

1.3.2 Number of market participants

It is well known that in markets where the number of participants are limited, there is always the possibility that prices are affected by a group if not by one participant. In such markets, as in the case of the liner shipping industry, a few buyers or sellers control a large share of demand or supply. Therefore, they may virtually control the pricing mechanism of the market by timing their entry or exit.

The large number of participants (owners and charterers) in the dry bulk market is a necessary condition for the existence of perfect competition. On the one hand, the large number of private shipowners and shipping companies as well as state owned companies

prevents any single company or a group of them to influence the supply for freight services and as a result freight rates. On the other hand, the number of charterers, in the form of private importers, government agencies and trading companies, is large enough to prevent demand being influenced by a single agent or a group of them.

1.3.3 The homogeneity of the product (shipping services)

An important condition, which should be satisfied for the perfect competition to prevail in a market, is that products offered and demanded in that market must be homogeneous. In other words, there should not be any diversity in products in terms of quality and price. In contrast to the liner shipping industry, in which services offered may vary according to the quality, speed and price, the services offered by shipowners and demanded by charterers in the dry bulk market is believed to be homogeneous; that is, there is no product differentiation in this market. For example, the product (services) offered by bulk shipowners cannot be distinguished through advertising, trademarks, branding or even reputation and relationships. In fact, it is the standard nature of the product offered by shipowners and demanded by shippers that prevents any single or a group of participant in the market to take advantage and over price the product or depress the market.

The main reason behind this is that commodities transported by bulk shipping sector are relatively low value cargoes and can be shipped on the basis of “one commodity one ship”. Therefore, as long as there are a large number of participant in the market, shippers generally look for the lowest freight rate offered in the market to fulfil their requirements and shipowners do not offer any tonnage at a lower than that pertaining in the freight market.

1.3.4 Efficient information dissemination

Efficient information dissemination is a necessary condition for the existence of perfect competition in the market. This is because access to up to date information prevents any owner or a group of owners to take any opportunity to influence a trading route or market. In fact, this is due to the existence of institutions such as the Baltic Exchange, the Lloyd’s Maritime Information Services and Lloyd’s Register of Shipping as well as brokers and

chartering firms around the world which are involved in collecting shipping information and publishing reports on a regular basis. However, recent advances in information technology has improved information dissemination in the industry and enabled many owners, brokers, and charterers to, not only keep track of the market, but also to look for the best offer and fix the best available contract. Apart from a vast number of periodicals and publications reporting current market conditions, recent fixtures and future forecasts, there are also online information networks (Bloomberg, Reuters, Shipping Intelligence Network, etc.) connecting brokers and agents around the world. Such networks enable agents to obtain up to date information on latest news about market conditions, supply, demand and fixtures in different routes and trades.

1.3.5 Mobility of ships and competition

As Zannetos (1966) mentions, an important factor, which contributes to the existence of perfect competition condition in international shipping, is the fact that the assets that provide the service in the market are mobile. Mobility of shipping services allows owners to take any possible opportunity to relocate the vessel(s) to those areas, which are expected to generate higher revenues. This, in turn generates a higher supply in the region and eliminates any extra profit making opportunity. Therefore, it is the mobility of ships and shipping services that prevents influence of just a few owners on the market in a region or trading route, which is a necessary condition for the existence of perfect competition in the shipping industry.

1.4 Shipping Freight Contracts

Shipping offers a service, which the shipowner provides for the charterer or cargo owner for an agreed amount of money per day or per ton of cargo, known as the freight rate. This service is provided under certain contractual agreements, which is called the charter party. Depending on the type and duration of the service required by charterers, different types of charter contracts have been developed in international shipping. These can be distinguished into five main types: single voyage charter; contract of affreightment; trip charter; time-charter; and bare boat charter. Under each type of contract, methods of payment are standardised and costs and expenses are allocated to agents involved. The following provides a brief description of each type of contract.

1.4.1 Single -voyage charter contracts

Voyage charter contracts are shipping contracts in the spot market, under which the shipowner agrees to transport a cargo load from the loading port to a discharging port (destination) in return of a sum of money known as freight. The freight paid by the charterers (cargo owners) is normally in \$/ton of cargo or as a lump-sum. Once the cargo has been discharged safely, the contract is fulfilled and the shipowner's responsibility is over. For example, the first row of Table 1.2 reports an actual fixture of a single voyage charter contract. In this fixture, "Maran Coal" (the shipper) has employed "Florita" (a panamax bulk carrier) to transport a coal cargo between 54,000 to 66,000 tons, from Mobile in the US Gulf to Iskenderun in Turkey at the end of August 2000 at \$10.85 per metric ton.

Table 1.2: Examples of reported fixtures for different types of shipping contracts

Contract type	Fixture report
<i>Voyage charter</i>	<i>Mobile to Iskenderun - Florita, 60,000t \pm 10%, \$10.85, fio, 30,000t/12,000t, end Aug. (Maran Coal)</i>
<i>Trip-charter</i>	<i>Dynamic (29,332 dwt, Panamanian, 13k on 28t + 2t, built 1979) delivery Recalada Aug 21-25, trip redelivery South Brazil, \$7,500 daily. (Dantas)</i>
<i>Period-charter</i>	<i>Darya Radhe (73,705 dwt, Hong Kong, 13.5k on 30t, built 1999) delivery Jorf Lasfar end Aug-early Sept, for three to five months trading, \$12,000 daily. (Kingston Maritime)</i>

Source: Lloyds list, Friday, August 18 2000.

The time periods by which the ship is allowed to report to the loading port, lay/can², is defined in the charter-party. There are also other terms in the charter-party which define different conditions under which the cargo has to be transported³, including time allowed for loading and discharging and any differentials which should be considered in the calculation of demurrage and dispatch⁴. For instance, in the above example the loading rate is specified as 30,000 tons per day and the discharge rate is 12,000 tons per day, which means 2 days loading and 5 days discharging time for 60,000 tons of coal. However, more details on loading and discharging terms; i.e., the laytime, along with other clauses on payments and any default, can be found in the charter party. The term *fi*o (free in and out) means that the vessel can enter and exit both the loading and discharging ports free without trimming.

In this type of shipping contract, the shipowner is responsible for all expenses incurred during the voyage. These expenses are categorised into four main types; that is, voyage costs, operating costs, capital costs and cargo-handling costs (see section 1.5 for definitions of these costs). In some cases, depending on the contract, the charterer is responsible for the cargo-handling costs.

1.4.2 Contracts of Affreightment

Contracts of Affreightment (CoA) are those shipping contracts in which the shipowner agrees to transport specified amounts of cargo from the loading port or area to the discharging

² Lay/can or Laydays/Cancelling are the earliest and latest dates a ship can tender her Notice of Readiness. If a ship tenders the Notice of Readiness after the cancelling date, the cargo owner has the right to cancel the charter contract. If the ship arrives and tenders her Notice of Readiness before the laydays commence, the cargo owner does not have to accept the Notice of Readiness until the commencement of the laydays.

³ An example of a basic general charter-party is the BIMCO "Gencon". The principal sections in the BIMCO "Gencon" can be subdivided into six major sections. Section 1 includes details of the ship and the contracting parties such as the name of the ship, shipowner, charter, broker as well as the ship's size, position, cargo capacity and the brokerage fee. Section 2 includes the description of the cargo, the name and the address of the shipper. In section 3 the terms on which the cargo must be carried are given. These include the dates on which the vessel should be available at the loading port, the loading area (port), the discharging port(s), laytime, demurrage and payments of loading and discharging. Section 4 includes the terms of payment; that is, the freight rate, method of payment, currency, etc. Section 5 sets penalties for any non-performance or defaults and section 6 includes administrative clauses such as appointments of agents, issuing bills of lading and matters on arbitration in case of any disputes.

⁴ The terms demurrage and dispatch are used for the calculation of the delays in loading and discharging due to unexpected events such as weather, stevedores strike, cargo availability and cargo gear failures. Demurrage is the difference the charterer has to pay the shipowner for delays exceeding the contract duration. Dispatch, which is normally considered to be half of demurrage, is paid by the shipowner to the charterer to compensate for early termination of the contract due to a quick discharge.

port(s). This is normally the case when the amount of cargo is large and cannot be transported in a single shipment. For example, in the case of industrial commodities such as coal and iron ore, steel mills purchase large amounts of iron ore or coal (e.g. 1 or 2 million tons), in order to secure their supply of raw materials for a long period whilst minimising their storage space and inventory. Therefore, shipments of coal or iron ore from the supply area to the steel mill can take place over a period of time on a regular basis, using CoAs at a fixed rate.

For instance, a shipping company agrees to transport 600,000 tons of coal from Australia to Japan for a Japanese power company under a CoA over six months. Terms such as delivery frequency, amount, loading and discharging ports, and freight rate are specified in the contract. Therefore, the shipping company can use its own fleet or even charter ships which are available at the loading area to lift the cargo when appropriate and enjoy the flexibility of scheduling its vessels to optimise the operation.

This type of contract gives the charterer the advantage of having fixed transportation costs and terms for the whole cargo (e.g. 600,000 tons of coal) over a certain period, thus guaranteeing the availability of ships to transport the cargo and minimise the inventory costs. At the same time, it gives the shipowner the operational advantage in the sense that he/she can use different vessels for the transportation of the cargo and optimise operations.

The method and terms of payment in CoAs is similar to voyage charter contracts; that is, the rates are expressed in \$/ton and all costs are incurred by the shipowner. However, the frequency of payment, which is specified on the charter party, varies from contract to contract.

1.4.3 Trip-charter contracts

A trip-charter contract is defined as a shipping contract in which the shipowner agrees to hire out the vessel for a duration of a trip from the point of delivery to the point of redelivery (normally a voyage) on a dollar per day basis (\$/day). In this type of contract, the shipowner has the commercial and operational control over the vessel, while the charterer is responsible for the voyage costs during the trip (from delivery to redelivery). The delivery point is normally the loading port and the redelivery point is the discharging point; however, cases in

which the charterer hires the vessel from the discharging port on a round trip basis, are also quite common. It is also quite common to terminate the trip-charter contract as soon as the voyage ends; that is, when the discharging is completed.

The advantage of the trip-charter contract over the voyage charter for the shipowner, is that the payments are on a daily basis, therefore, any delay during the voyage is compensated, whereas single voyage contracts are charged on a \$/ton basis and delays are settled through laytime and demurrage. In the latter case, any delay during the voyage, apart from loading and discharging delays, will reduce the daily earnings of the vessel.

On the other hand, charterers may benefit from voyage cost cuts that can arise through their arrangements for bunkers and port charges. It is very common for companies operating large shipping fleets to hire their seasonal or periodical shortage of tonnage from the trip-charter market. This gives them the opportunity to operate the vessel for a single voyage in the same way as they would operate a vessel under a long term time-charter contract.

The trip-charter market and the single voyage charter market move very close together and show similar fluctuations over time. This is because under both shipping contracts the ship is hired for a single voyage. Thus, since both the charterer and the shipowner are fully aware of prevailing market conditions and transportation costs in that particular voyage and try to maximise their utility function by minimising costs and maximising their profit, any arbitrage opportunity between two types of charter contracts is eliminated instantaneously. As a result, both charter contracts cost the same for the charterer and yield the same profit to the shipowner.

An example of a trip-charter fixture is given in the second row of Table 1.2. In this example “Dynamic”, a 29,332 dwt Panamanian bulk carrier, is hired for a trip by “Dantas”. Since the charterer is responsible for voyage costs (fuel, port charges, etc.) under a trip-charter contract, the vessel’s speed (13 knots) and consumption (28 tons) figures are disclosed. In addition, the geographical location (Recalada) and the window date (Aug 21-25) at which the charterer takes the delivery, and the area for redelivery of the vessel (South Brazil), as well as the agreed charter rate per day (\$7,500/day) are specified.

1.4.4 Time-charter contracts

In this type of contract, the shipowner agrees to hire out his vessel to the charterer for a specified time period (from a round trip to several years) under certain conditions defined in the charter party. Among these conditions are: vessel's particulars (speed, consumption, etc); condition and location of the vessel during delivery and redelivery; fuel on board and trading areas, etc. In this type of shipping contract, freight rates are agreed upon and paid on a dollar per day basis (\$/day), usually every 15 days or every month. Time-charter contracts give the charterer the advantage of operational flexibility as well as security in transportation costs; i.e. the charterer can use the vessel for several voyages in different routes permitted by the contract, without worrying about delays and laytime penalties. This is because the charterer has the commercial control of the vessel, otherwise, for each shipment of cargo the charterer has to find and fix a vessel in the spot market. This might be risky for the charterer as future rates in the spot market are not known and may fluctuate considerably, thus reducing the charterer's profit margin. Time-charter contracts also give the shipowner the benefit of reliance on a secure stream of revenue, which would not be the case, when the ship is operated in the spot market. Under time-charter contracts, the charterer is responsible for the cost incurred during the voyage and the shipowner is responsible for all other costs.

The third row in Table 1.2 shows an example of a time-charter fixture. In this contract, *Darya Radha*, a dry bulk carrier is hired by Kingston Maritime for a period of 3 to 5 months at \$12,000 per day. The vessel's specifications disclosed are; the speed (13.5 knots), the consumption at that speed (30 tons per day), the year that the ship was built (1999) and the dead weight capacity of the vessel. Similar to the trip-charter fixture report, this time Fixture report also includes the geographical location at which the ship is delivered to the charterer (Jorf Lasfar) as well as the approximate date (end of August- early September 2000).

In time-charter contracts, the terms of the charter party will define the owner's obligations for maintaining the vessel in a seaworthy condition for the use of the charterer. Any period in which the vessel becomes off-hire (not operational) will be excluded from the time-charter period and the owner has to reimburse the freight rate for that period. As the charterer is responsible for the voyage costs during the contract period, all the inventory, fuel and diesel

oil on board at the beginning and end of the contract are estimated and differences will be settled between the two parties.

1.4.5 Bare-boat or demise charter contracts

In cases where the charterer wants to have full commercial and operational control of the vessel but does not want to own the vessel, a bareboat charter contract is arranged. This type of contract allows the charterer to manage and run the vessel on a day to day basis and pay all the costs including voyage, operation and cargo handling, except the capital costs, which remain the owner's responsibility. Bare-boat charter contracts were popular during the 1960's and 1970's among the major oil companies. Since 1970's, major oil companies have changed their chartering strategies and use short term time-charters and the spot market for their transportation requirements.

The major incentive for charterers to enter into such contracts is that, they can have full control over the vessel without having the value of the vessel on their balance sheet. This is because excessive fluctuations in the price of the vessel can distort the figures in the balance sheet and annual financial reports. On the other hand, owners are investors who finance the vessel and do not want to get involved in the operation. The duration of this type of charter contract is normally long and may cover the whole economic life of the vessel. Freight rates are normally paid on a \$/day basis every month.

Single-voyage, trip-charter and time-charter are the most common types of contracts used in the dry bulk market. Therefore, reports and analyses are mainly based on the data collected for these three types of shipping contracts. Single-voyage and trip-charter contracts although different in their method of payment and cost allocations, they can be classified as short term or spot charter shipping contracts since they both cover only a single voyage or trip. On the other hand, time-charter contracts are long term (period) contracts and cover more than one voyage. Therefore, for the purpose of analysis in this thesis, we focus on two types of shipping contracts; namely, trip-charter or spot and time-charter contracts.

1.5 Definition and Structure of Costs in Tramp Shipping

Owning and running a ship involves different costs, which can be divided into four categories; namely, capital costs, operation costs, voyage costs and cargo handling costs. These costs depend on various factors such as size, age, speed, type and the financial structure of the purchased vessel. For example, larger vessels have higher voyage costs because they consume more fuel than smaller vessels. Older vessels may consume more bunkers than new vessels with higher fuel efficiency. A brief review of definitions of different types of costs involved in shipping operations and their allocations between parties are discussed in the following sections.

1.5.1 Capital costs

Capital costs are those costs, which cover interest and capital repayments and depend on the terms of finance of the purchase as well as the level of interest rates. There are different methods available to shipowners to finance their fleet ranging from full equity to bank loans (asset backed mortgages), bonds, public offerings and private placements. Availability of these funds to shipowners and shipping companies depends on their operational and financial capabilities, reputation and fleet size, among other factors. For example, highly reputable shipowners with a large fleet that can be used as collateral may enjoy a better financing terms than a shipowner with relatively lower levels of credit and collateral.

A vessel's capital costs depend on the current and prevailing market condition at the time when the vessel was purchased as well as the terms of finance. For example, when freight rates are high and shipowners has a secure long term time-charter contract, providers of funds may relax their terms of finance compared to periods when the market is tight and the purchaser does not have a secure contract. Furthermore, the amount of equity invested by the shipowner to purchase the vessel is inversely related to the capital cost of the vessel; that is, the lower the debt to equity ratio the lower is the capital cost. Finally, the relationship between shipowner and the financier and the creditworthiness of the shipowners are important in determining the terms of the loan and capital costs. Capital costs are generally the shipowners' responsibility.

1.5.2 Operating costs

Operating costs or fixed costs are those incurred in the day to day running of the ship whether the vessel is active or idle. These costs include crew wages, stores and provisions, maintenance, insurance, etc. Operating costs depend on the type, size and age of the vessel, management costs as well as company's strategy in manning and maintaining the vessel. The latter also depends on the flag under which the ship is sailing, since manning scales, competency of the crew, level of salaries and required maintenance levels of the vessel are controlled by flag states. For example, requirements for manning vessels under flags of convenience (e.g. Panama and Liberia) are not as strict as for those vessels sailing under British or American flags. Therefore, similar ships, when operated under different flags, may have different operating costs. Operating costs are generally the responsibility of the shipowner. The only exception is bare-boat charters, under which the charterer has full commercial and operational control over day to day operation of the vessel and therefore is responsible for operational costs.

1.5.3 Voyage costs

Voyage costs are those costs incurred in a particular voyage in which the ship is involved. These are mainly fuel costs, port charges, pilotage and canal dues. They depend on the specific voyage undertaken as well as the type and size of the vessel. For example, fuel costs are higher when the voyage is longer or vessels are older. Port charges and canal dues also depend on the size and type of vessel. For example, Suez Canal and Panama Canal tolls are based on the Net Suez Tonnage and Net Panama Tonnage⁵ of the vessel, respectively.

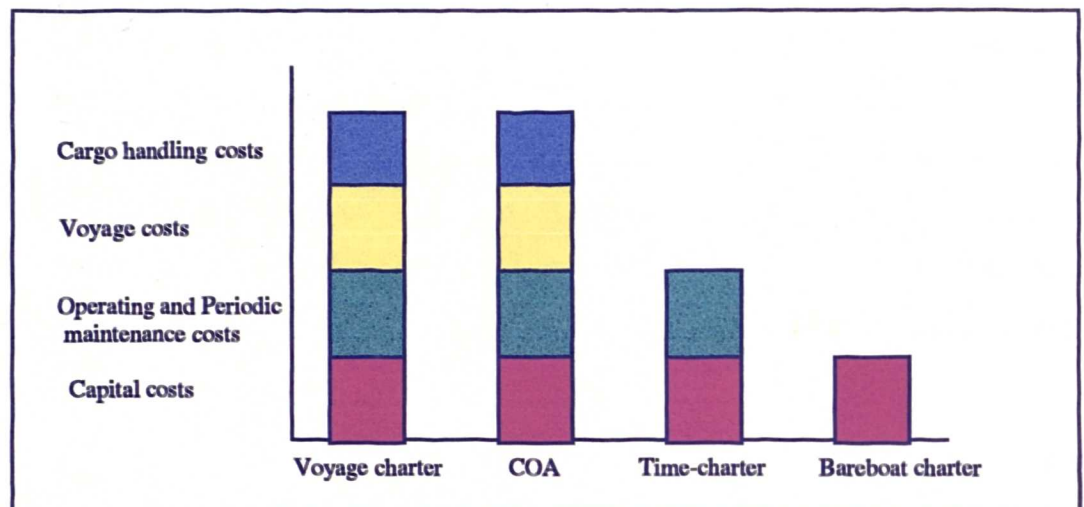
⁵ These are tonnage measurements, provided by the shipyard when the ship is constructed, for calculation of canal tolls, which are derived from the Net Register Tonnage of the vessels multiplied by certain factors (see Lloyd's Register of Shipping).

1.5.4 Cargo handling costs

Cargo handling costs are those costs involved in loading, stowage, lightering and discharging of the cargo. Again these costs depend on the type, size and age of vessel and normally are the shipowners' responsibility unless it is specified otherwise in the contract.

Figure 1.2 graphically summarises the allocation of costs under different shipping contracts. For example, in voyage charter contracts, the shipowner is responsible for the voyage cost whereas in time-charter contracts, the charterer is responsible for the voyage costs.

Figure 1.2: Shipowner's cost allocations under different charter contracts



Source: Stopford (1997)

1.6 Shipping Data Collection, Processing and Report

Over the years the City of London has been the focal point for those involved in the business of shipping and its related activities. These related activities include; brokerage, chartering, management, financial, legal, consultancy and insurance businesses. Along these shipping related businesses, there are also firms that are involved in collecting information and shipping related news, in order to provide up to date periodic market reports and analysis. Among these are; Clarkson Research Studies (CRS), Simpson, Spence and Young Consultancy and Research Ltd. (SSY), Lloyds of London Press (Lloyds Shipping Economist, LSE), the Lloyds Register for classification, the Lloyds insurance company, the Baltic Exchange and the Lloyds Maritime Information Services (LMIS). There are also other well known institutes outside the UK which collect and publish shipping data market reports, for example, the Institute of Shipping Economics and Logistics (ISL) in Bremen (Germany) and Fearnleys (Norway).

All the above named institutes collect data from a variety of sources and sometimes their own brokering departments (e.g. CRS and SSY) and process them to produce market analyses and reports. LSE and Lloyds Ship Manager (LSM) use the LMIS database which contains information on almost every fixture, sale and purchase, new order and delivery, demolition and loss, and vessel movements in both wet and dry bulk markets.

Once relevant information on different aspects of the market (sale and purchase prices, freight rates, etc.) are collected, they are organised (divided) by size and aggregated over time (weekly, monthly etc.) to construct price or freight indices for different size vessels with different frequencies. For example, LSE reports supply, demand and freight rates as well as newbuilding, second-hand and scrap prices for different size tankers, dry bulk carriers and other types of vessels on a monthly basis. CRS produces similar reports on a weekly, monthly and semi-annual basis.

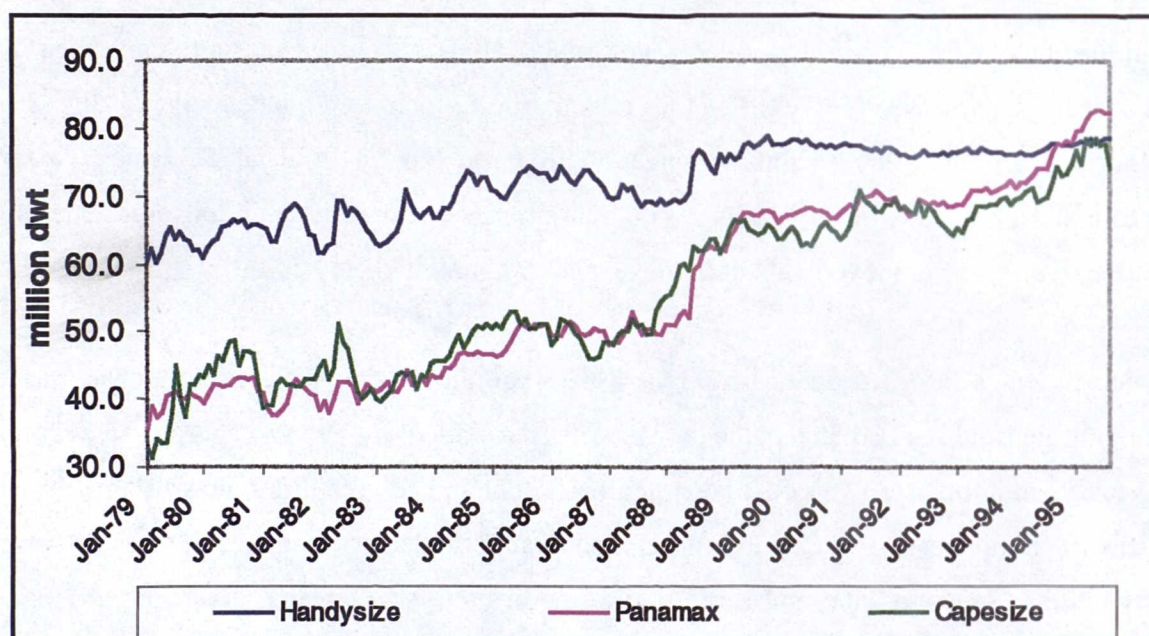
The following sections are devoted to describing sources, periodicity and duration of data sets used throughout this thesis and present methods of transformation of freight rate data, which are used by some publishers and research institutes.

1.6.1 Supply and demand for different segments of dry bulk shipping

The demand for shipping service is a derived demand which depends on several factors such as the world's economic activity, international seaborne trade, seasonal and cyclical changes for different commodities transported by sea, the distance between sources of production and consumption of commodities (see Stopford 1997).

Following the discussion on size disaggregation in the dry bulk market, it can be argued that the demand for each size dry bulk carrier is driven by the trade and transportation characteristics of certain types of commodities and is different across vessel sizes. The demand levels for different size dry bulk carriers are shown in Figure 1.3 for the period January 1979 to July 1995. The demand data, compiled by Lloyds Shipping Economist (LSE), is defined as the difference between supply and surplus tonnage. The surplus tonnage is defined as the laid up tonnage plus the proportion of the fleet running at slow speed.

Figure 1.3: Demand for 3 size dry bulk carriers 1979-1995⁶

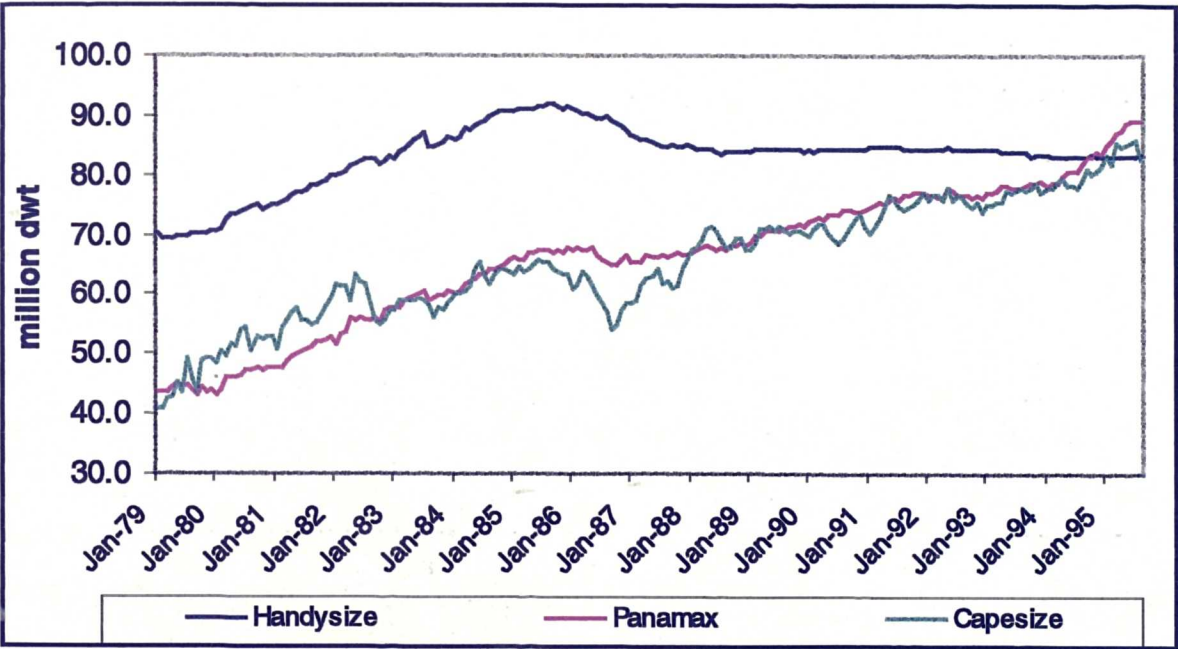


Source: Lloyd's Shipping Economist

⁶ LSE data on supply and demand for handysize (10,000-40,000dwt), panamax (40,000-80,000dwt) and capesize (+80,000dwt) dry bulk carriers is available until September 1995. Since September 1995, LSE has changed these size ranges to handysize (10,000-50,000dwt), panamax (50,000-80,000dwt) and capesize (80,000-140,000dwt and +140,000). Supply and demand series over the period 1980 to 1995 are used here for expositional purposes only.

Figure 1.3 clearly illustrates that the demand series behave differently across different size categories. Demand for Handy-size vessels is higher than the other two size categories in the late 70's standing just above 60 million tons dwt (mdwt). While the demand for Capesize vessels was about 35 mdwt and for Panamax vessels around 45 mdwt. During this period the demand for all weight categories evolved differently, which is an indication of different driving forces for each demand series. Demand for panamax and capesize vessels seem to move close together over time. This is because demand for these vessels are related through the demand for transportation of two major industrial commodities, coal and iron ore, which are used in conjunction for steel production. In addition, it seems that the growth in demand for capesize and panamax vessels is higher than the growth in demand for handysize vessels during the sample period. The fact that demand series show different behaviour over time is in line with the argument of market segmentation. Hence it is important to consider such segmentation in analysis of the market, as differences in the behaviour of demand in each dry bulk sub-sector has implications on both modelling and forecasting of related variables (e.g. freight rates and prices) as well as operational and managerial decisions (e.g. diversification and risk return optimisation).

Figure 1.4: Supply for 3 size dry bulk carriers 1979-1995



Source: *Lloyd's Shipping Economist*

Figure 1.4 presents the supply series for three different classes of dry bulk carriers for the same period as the demand figure, According to the LSE data, the supply of shipping services

is defined as the tonnage effectively engaged in seaborne transportation plus the tonnage readily available for this purpose. This also includes the proportion of Combined carrier vessels engaged in commodity transportation in each dry bulk sector, at any point in time. Again, a difference can be observed in the behaviour of the supply series for different classes. Although all the supply series for all size categories seem to move together in the long-run (Figure 1.3 and Figure 1.4), the supply for the larger size dry bulk carriers show higher growth rates and variations than the small size ones.

1.6.2 Freight rates

Freight rates at any point in time, reflect the balance between supply and demand for shipping services, which in turn depend on factors such as world economic activities, the stock of fleet, political events, international commodity trade, etc. (see, Stopford 1997). In other words, freight rates are formed through the interaction between shipping supply and demand schedules.

In the market, shipowners and charterers, assumed to be fully informed about the market conditions, negotiate through their brokers until both parties agree on a price. Once the deal is fixed, whether a spot or a time-charter, the broker prepares the necessary documents (charter party) and sends them to both parties for approval and confirmation. Brokers normally keep a record of their fixtures and report them to the LMIS or the Baltic Exchange.

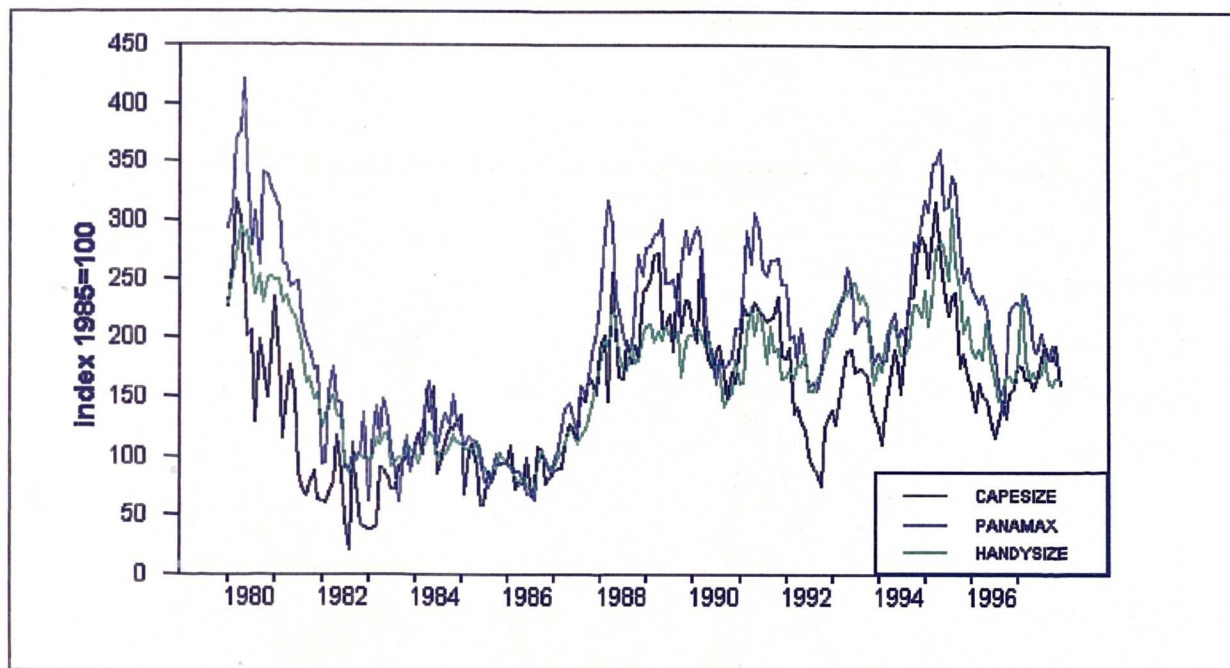
Monthly trip-charter (spot freight) rate indices for three size dry bulk carriers are obtained from the ISL (Bremen). The dry cargo indices are based on the LSE database for tramp trip-charters (1985=100). ISL and LSE report monthly trip-charter rate indices for 5 different size categories of dry cargo vessels since 1980. These size categories are; small (12,000 to 19,999) dwt, handysize (20,000 to 34,999 dwt), handymax (35,000 to 49,999 dwt), panamax (50,000 to 79,999 dwt), and capesize (80,000 dwt and over) vessels. The index for larger categories mainly represents trip-charter rates for dry bulk carriers.

Monthly one-year and three-year time-charter rates for the same sizes of dry bulk carriers (handysize, panamax and capesize vessels) are obtained from CRS (London). Time-charter

rates are based on the average of daily reported fixtures over the month and cover the period from January 1977 to December 1998⁷.

Figure 1.5 plots monthly spot freight rate series reported by LSE for three different sizes of dry bulk carriers (handysize, panamax and capesize). It can be seen that, while there are co-movements between the series in the long run, short-run movements are quite different across these freight rate series. The existence of co-movements between the series in the long run can be explained by the fact that these rates are driven by the same common factor; that is the aggregate demand for international commodity transport. Differences between the behaviour of freight rates in the short term are thought to be due to some distinct factors such as trade in commodities, which each type of vessel is engaged in.

Figure 1.5: Spot freight rates for 3 size dry bulk carriers.



Source: *Lloyd's Shipping Economist and ISL (Bremen)*

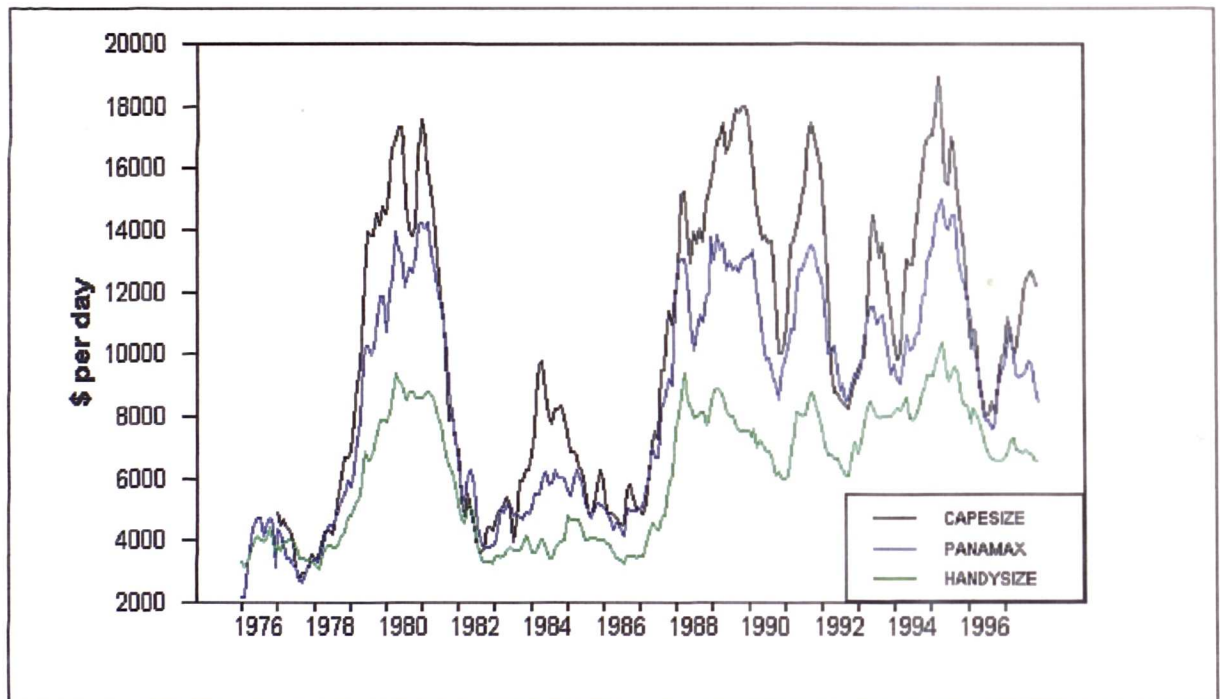
Figures 1.6 and 1.7 plot one-year and three-year time-charter rates reported by CRS for three categories of dry bulk carriers, respectively. Time-charter rates seem to show less short-run fluctuations compared to spot rates. This is expected as long-term charter contracts have been argued in the literature (see, for example Zannetos, 1966 and Glen et al, 1981) to be a weighted average of expected spot rates over the life span of the long term contract.

⁷ Since the complete data set required for our analysis is not available from a single source, data from different sources

Therefore, fluctuations in period rates spot rates are expected to be smoothen through the aggregation of expected values, which is thought to be the underlying assumption in the formation of period rates.

Moreover, time-charter contracts are normally used by industrial and trading firms for the transportation of industrial commodities such as iron ore and minerals, which more or less follow regular trading patterns over the year. In contrast to time-charter contracts, voyage charter contracts are generally used for transportation of commodities with irregular and cyclical patterns such as grain (see Stopford 1997 page 122). It is also well known that industrial charterers use time-charter contracts in order to meet most of their long term transportation requirements and use spot contracts for their extra needs, which might be seasonal or cyclical. This type of chartering behaviour is reflected in the patterns observed in contracts of different duration. It seems that the longer the duration of the contract the smoother the rates, see Kavussanos (1996a) for a formal comparison of this.

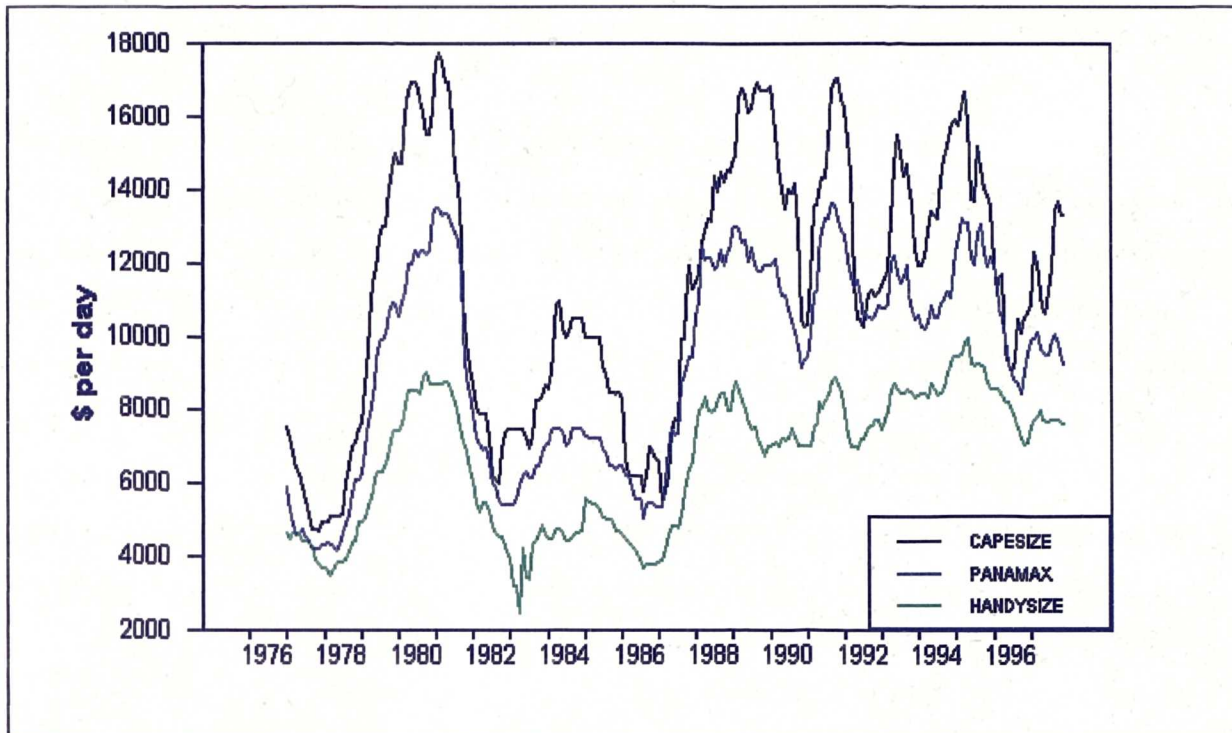
Figure 1.6: 1-year time-charter rates for different size dry bulk carriers



Source: Clarkson Research Studies

(CRS, ISL and LSE) are obtained and matched to ensure consistency.

Figure 1.7: 3-year time-charter rates for different size dry bulk carriers



Source: Clarkson Research Studies

1.6.3 Methods of converting freight rates

It has been mentioned earlier that methods of payment, freight calculations and cost allocations vary depending on the type of charter contract. When studying the relationship between different charter contracts, namely spot and time-charters, such differences in units of measurement can cause inconsistencies in results and difficulties in interpreting them. This is because of two reasons. First, as mentioned before, in contrast to time-charter rates, spot contracts contain voyage costs, while time-charter contracts are exclusive of voyage costs. This may affect the result of analysis performed between these rates, especially when the aim is to investigate the relationship between these types of contracts. This is because fluctuations in voyage costs (e.g. bunker prices), which are mainly reflected in voyage charter and not time-charter contracts, may cause short term divergence or convergence between the earnings from the two charter contracts. Second, although using voyage and time-charter rates directly in regression analysis allows one to investigate the co-movement of rates, the difference between units of measurement (\$/ton and \$/day) does not allow direct comparison between

the profitability of one type of operation to the other. This has been the case in some studies in the past, for instance, Vergottis (1988) and Beenstock and Vergottis (1989a and b).

Thus, it is necessary for spot and time-charter rates to be expressed in the same units of measurement; that is, both should be in dollar per ton (\$/ton) or dollar per day (\$/day), before investigating the relationship between the two types of charter contracts. There are two ways to make spot and time-charter rates comparable. The first method, which has been used in the literature by Zannetos (1966), Glen et al (1981), Hale and Vanags (1992) and Veenstra (1999), is to convert time-charter rates into their spot rate equivalents. For such a conversion, it is assumed that the chartered vessel is employed in a particular route. Then respective voyage costs are estimated, using vessel particulars (speed and consumption, etc), and added to time-charter rates. Finally, the total expense is divided by the amount of cargo (in tons) to obtain spot equivalent of time-charter rates on a dollar per ton (\$/ton) basis. In that sense, such a conversion adds voyage costs fluctuations to time-charter rates. LSE reports voyage or the spot equivalents of time-charter rates for three different size dry bulk carriers. Three routes, one for each size vessel, are chosen, which are the same as those for which voyage charter rates are reported. These routes, which are supposed to be market representative for each size vessel include: Morocco to India for handysize vessels (25,000dwt) carrying phosphate; US Gulf to Japan for panamax vessels (55,000dwt) carrying grain; and Brazil to North West Europe for capesize vessels (120,000dwt) carrying iron ore.

The second conversion method, which is used by Strandenes (1984) converts spot rates into their time-charter equivalents (TCE). In this method, a spot rate fixture (\$/t) for a vessel in a particular voyage (route) is used to calculate the total freight payment by multiplying it by the amount of cargo. The voyage costs for that particular voyage (port charges, canal dues and bunker costs) are then deducted from the total freight payment and the result is divided by the number of days for a round trip, in that route, based on vessel's particulars. The resulting figure is known as time-charter equivalents of spot rates, which is reported on a \$/day basis. CRS uses this method to calculate and report TCE's for each fixture in major routes⁸ under

⁸ The routes used for capesize rate conversion are; Narvik-Rotterdam, Tubarao-Rotterdam, Tubarao-Japan, Nouadhibou-Rotterdam, W. Australia-Rotterdam, W.Australia-Japan for iron ore; Hampton Roads/Richards Bay-Japan, Hampton Roads-Rotterdam, Bolivar-Rotterdam, Queensland-Rotterdam, Queensland-Japan and Richard's Bay-Japan for coal. The routes for panamax rate conversion include; US Gulf-Rotterdam, US Gulf-Japan, North-Pacific-Japan in grain trade; Hampton Roads-Rotterdam, Roberts Bank-Japan, NSW-Continent, Newcastle-Japan, Richards Bay-Spanish Med in coal trade. Finally, the routes for handymax rate conversion include; Continent-Far East, Transpacific round voyage, Far-East continent, Transatlantic round voyage.

certain assumptions, based on standard ship types⁹. Once TCE or earnings per day for each fixture are obtained, they are aggregated over time and reported for each size category.

The example in Table 1.3 shows the method used for converting a voyage charter rate to TCE or earnings per day. Vessel's particulars, bunker prices and port costs are known and a round trip is used to relocate the vessel in the loading area. The fixture is for a voyage from New Orleans to Rotterdam for 54,500 tons of grain, which takes 3 days to load and 3 days to discharge. Port disbursements and canal dues are \$37,000 and \$50,000 at New Orleans and Rotterdam, respectively. The distance for each leg of the voyage (laden and ballast back to the US Gulf) is 4854 nautical miles, and the fuel consumption of the vessel is 33 tons/day laden and 27.8 tons/day ballast. It is also assumed that the vessel consumes an extra ton of diesel oil per day at sea and 3 tons of diesel oil per day in port or when awaiting at port.

Once all the necessary information regarding vessel and voyage specifications, port costs and disbursements are fed to the voyage-estimator, it is not difficult to work out the total voyage expenses. Also, the freight rate (\$/ton) multiplied by the amount of cargo (tons) results in the gross freight, which can be converted to net freight by deducting the brokerage fee from the gross freight. The difference between the net freight and the total voyage expenses is known as the gross voyage surplus, which can be converted to the gross daily surplus once divided by the total number of days for the round voyage. In order to derive the TCE, one should add back the commission to the daily voyage surplus. The resultant figure represents the daily earnings of the ship during the round trip (\$14,745/day in this case). Once all fixtures in major shipping routes are converted to TCE, it is not difficult to find the average TCE for each size vessel and over the month by aggregating figures.

⁹ For example, for panamax fixtures, CRS uses a standard mid 1980's built vessel, which has a dead weight capacity of 65,282 dwt, speed of 14 knots and 13.5 knots during the laden and ballast legs, respectively. The standard vessel's fuel consumption is also assumed to be 33 tons/day for laden voyage and 27.8 for a ballast voyage, with a port consumption of 3 and 2 tons/day of fuel oil and marine diesel oil, respectively (see CRS Shipping Intelligence Weekly for more details).

Table 1.3: An illustrative example of converting voyage charter rates to time-charter equivalents (TCE) on a round trip basis

Vessel:	Panamax	Speed in Knts	Daily Dist. in n.miles				
		Laden: 14	Laden: 336	Daily Bunker Consumption			
		Ballast: 13.5	Ballast: 324	Fuel Oil		Diesel Oil	
Cargo Details:				Laden	Ballast	Working	Idle
54,500 MT Grain, US Gulf / Rotterdam, 3 d/3 d, \$13, FIO				33	27.8	1	3
VOYAGE LEGS				Miles	Days	Fuel Oil	Diesel Oil
US Gulf / Rotterdam				4854	14.45	477	14
Rotterdam / US Gulf				4854	14.98	416	15
Canal Transit:							
Port Time:	Loading:	3	Discharging:	3	6.00		18
CARGO CAPACITY CALCULATIONS				TOTALS:	35.43	893	47
Dwt:	65,000						
Less:	Bunkers:	2000					
	Cons.Weights:	200	= 2200				
	Total Cargo Capacity:	62800	Tons				
VOYAGE EXPENSES							
BUNKERS:							
Fuel Oil	900	tons in	US Gulf	@ \$ 96.00	= \$	86400	
Diesel Oil	50	tons in	US Gulf	@ \$ 179.00	= \$	9000	
		tons in		@ \$	= \$	0	= \$ 95400
			Loading Port Disbursements		= \$	37000	
			Discharging Port Disbursements		= \$	50000	
			Canal Transit Expenses		= \$		
			Other Expenses		= \$		= \$ 87000
GROSS VOYAGE EXPENSES:						= \$	182400
Cargo	Rate		Gross Freight	Commissions		Net Freight	
54,500	\$/ton	13.00	\$708,500	2.00%	\$14,170	\$694,330.0	
Gross Voy. Surplus	Gross Daily		Running Cost	Net Daily		T/C Equiv.	
\$511,930	\$14,450		\$5,800	\$8,650		\$14,745	

1.6.4 Newbuilding, second-hand and scrap prices

The market for ships is segmented into three different sub-markets depending on the age of vessels dealt with, namely; the Newbuilding market, the Second-hand market and the Scrap market. Almost all ship sales and purchases are carried out through brokers, with the exception of newbuildings, which are ordered by investors to shipyards directly. The sale and purchase of ships is a lengthy process, which can take anything between a few weeks and several months to complete, depending on different factors such as the market condition. This process involves different stages of placing the ship in the market, the negotiation of price

and conditions of contract, preparing the memorandum of agreement, inspections and final closing of the deal, after which the ship is delivered to the buyer.

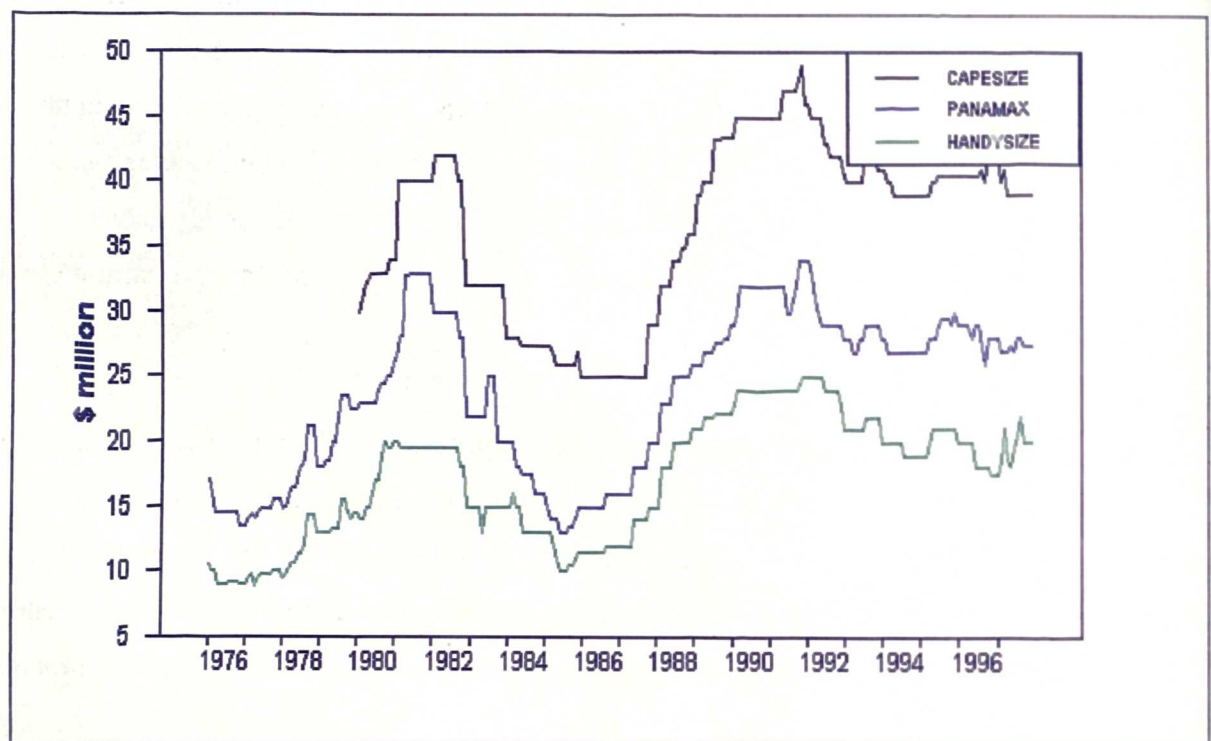
As the name suggests, the newbuilding market is the market for newly built ships or ships which are ordered by shipping companies, shipowners and investors to be delivered after the construction period, which takes between several months and a few years. The perfect market condition also holds for this market as not only international shipowners take several quotations from various shipyards before placing orders, but also there are no barriers for shipyards to market their products internationally and compete with other shipyards. Newbuilding prices are also determined through supply and demand factors for new ships and are generally negotiated and settled between investors and shipyards. In general, Newbuilding prices depend on the market condition and other determinants such as steel prices, the level of freight rates, the backlog of the shipyard (or the shipbuilding industry), terms of contract, etc. For example, in a good market, when freight rates are high and shipyards' orderbooks are full, newbuilding prices may rise considerably, whereas when the freight market is depressed and shipbuilding activity is low, newbuilding prices may fall rapidly. This is because shipyards are willing to accept orders at very low prices in order to survive and avoid down sizing.

Figure 1.8 plots monthly newbuilding prices for the three sizes of dry bulk carriers over the period January 1976 to December 1997, except capesize prices, which are available from January 1980. Newbuilding prices are obtained from different issues of LSE. For each size category, newbuilding prices represent the aggregate of reported new building contracts in the Far East shipyards to the Lloyd's Maritime Information Services (LMIS) over the month.

It can be seen that newbuilding prices vary by vessel size but show similar behaviour over time. In fact, it can be argued that these series follow similar patterns and move together in the long run; that is, price levels follow a similar cyclical pattern. For example, price levels for all size vessels show peaks between 1980 to 1982, and 1989 to 1992, whilst there are troughs in price levels between 1976 to 1979, 1983 to 1988 and 1992 to 1997. The cyclical behaviour of newbuilding prices is argued in the literature to be the combined result of the fluctuations in world economic activity (international seaborne trade) and the investment (ordering) behaviour of shipowners (see, for example Tinbergen, 1934, Vergottis, 1988, and Stopford, 1997). More precisely, when investors expect the freight market to rise, they place

new orders to take advantage of the market prospects. Therefore, there is excess demand for new vessels, orderbooks grow and prices will rise. By the time, the new vessels are delivered: 1) there might be an excess tonnage in the market due to excessive orders; 2) the freight market may collapse due to excess supply, both from reduction in scrapping old vessels and the arrival of new deliveries; 3) or even the demand for shipping services may collapse due to the drop in the world economic activity. This effect is then transmitted back to the shipbuilding market through investment decisions of agents, reducing the demand for newbuildings and prices for new ships. Shipbuilding cycles, which are caused by the mismatch of investors' expectations to the world's economic activity, have been repeatedly observed in the shipping industry.

Figure 1.8: Newbuilding prices for different size dry bulk carriers



Source: Lloyd's Shipping Economist

The second-hand market, better known as the sale and purchase market, is the market for vessels, which are ready for trade and are aged anything between a year and 20 years or more. In terms of liquidity, about 1000 vessels are bought and sold in the sale and purchase market every year, out of which about 30% are dry bulk vessels (Stopford 1997); that is, at least one vessel every day. The sale and purchase market is known as one of the most

competitive markets in the world as it is an open market, and buyers and sellers are under no obligation to follow any sort of price restrictions. Therefore, prices are determined through supply and demand conditions in the market, which in turn depend on the current and expected world economic activity, the current and expected freight market, the current and expected bunker prices, and the current and expected ship prices. In other words, second-hand prices directly depend on the profitability of the market¹⁰.

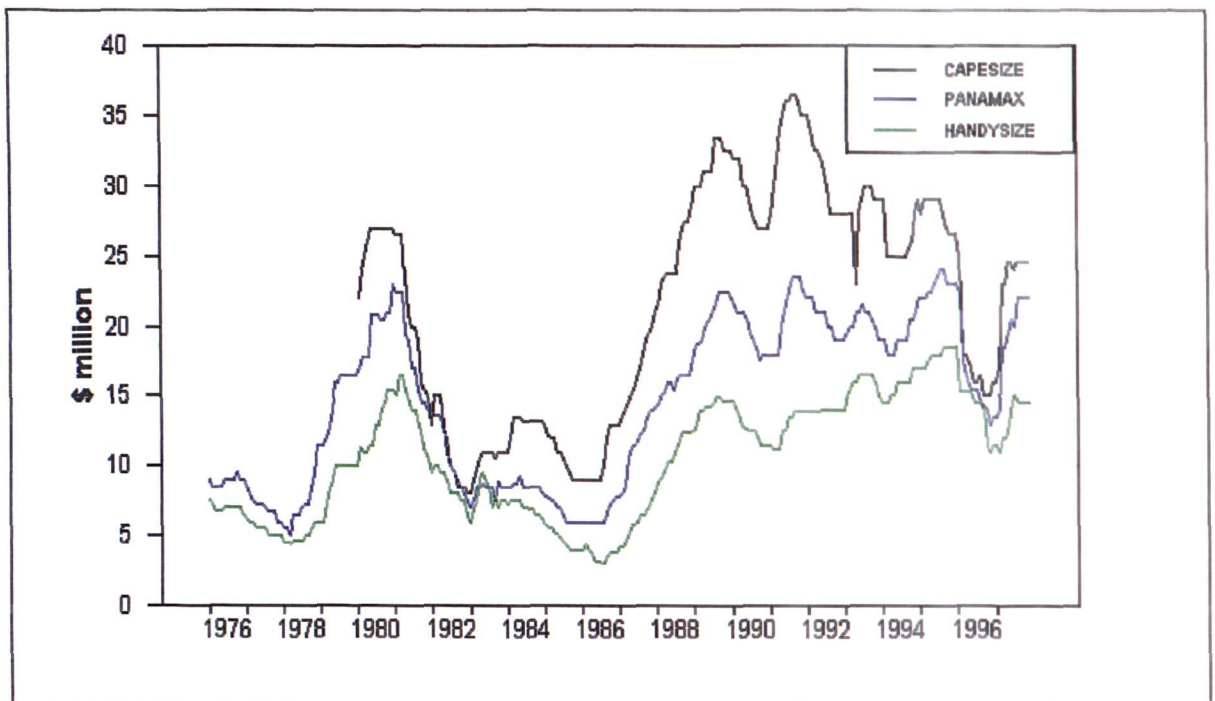
Figure 1.9 illustrates monthly prices for 5-years old second-hand prices for three different sizes of dry bulk carriers over the period January 1976 to December 1997, except capesize prices, which are available from January 1979. Second-hand prices are obtained from different issues of LSE. For each size category, prices represent the aggregate of reported sale and purchase contracts to the Lloyd's Maritime Information Services (LMIS) over the month. For those months that no second-hand sale and purchase or newbuilding contracts are reported, LMIS collects estimates of these values from different brokers. These estimates are then refined by eliminating outliers and aggregated to represent the closest market values.

A visual inspection of Figure 1.9 reveals that second-hand prices for different size bulk carriers move together in the long run. This is the case as the price series are thought to be linked through a common stochastic trend; i.e. the world economic activity and the volume of international seaborne trade (see Glen 1997). However, short run dynamics of second-hand prices do not seem to be identical. These differences are due to variations in the demand for different size vessels and the profitability of the freight market for each size as the current and expected freight rate levels are argued to be major determinants of second-hand prices. An interesting point which can be observed from the evolution of price series is that when the market is in recession (i.e. prices are at lowest levels), the three price series converge and the difference between prices reduces compared to when the market is good. For example, during 1982-1986 recession, prices for handysize, panamax and capesize vessels seem to converge. The price difference between a second-hand capesize and second-hand handysize during this period is less than \$8m. On the other hand, when the market is in expansion phase, second-hand prices diverge as larger vessels become relatively more expensive than smaller ones. For example, between 1988 to 1994 the difference between second-hand prices for capesize handysize vessels is between of \$15m and \$20m. Since it is the operational profitability that

¹⁰ See, for example Beenstock (1985), Beenstock and Vergottis (1989a) and Stranden (1984).

determines second-hand prices, the divergence and convergence of prices can be explained by relative profitability of these vessels under different market conditions. For example, larger vessels generate more revenue during expansion periods due to their economies of scale, whilst they carry higher risk of unemployment during recessions due to their operational inflexibility. In contrast to larger vessels, smaller bulk carriers are not as profitable as larger ones during a market expansion, but they are more flexible and can switch between trades during recessions. Therefore, smaller vessels are more likely to be employed in tight markets in comparison to larger vessels.

Figure 1.9: Second-hand prices for different size dry bulk carriers



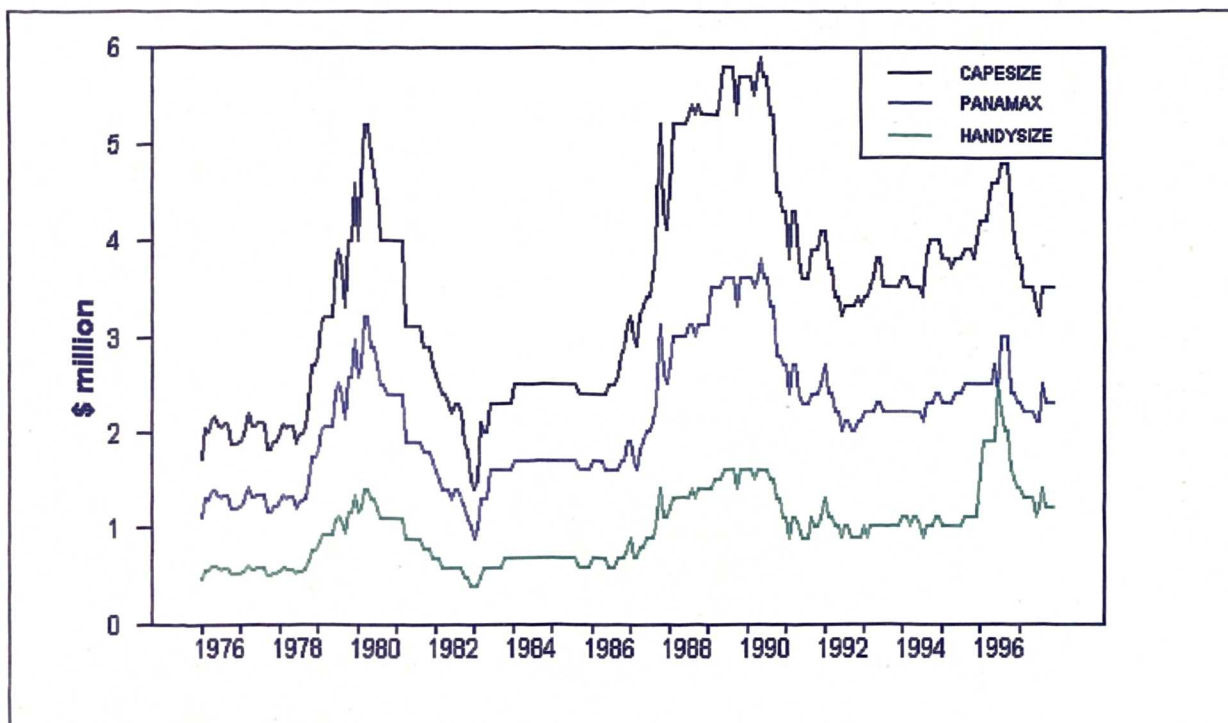
Source: *Lloyd's Shipping Economist*

The third market for ships is the market where ships are sold for scrap, better known as the demolition market. In this market, ships which are not economical to run or operate, are sold to ship-breakers for their scrap metal on a \$/ldt¹¹ basis. The age at which ships are sold for scrap varies over time and largely depends on the condition of the freight market as well as the second-hand, newbuilding and scrap markets. For example, when freight rates are low

¹¹ ldt stands for light displacement, which is in fact the actual weight of the ship in tons, without any cargo, bunkers and fresh water on board.

and the expectations for future market improvements is low, owners of relatively inefficient vessels, which have been forced to lay up, may be forced to sell their vessels to avoid further losses. Consequently the increase in supply of scrap vessels causes the scrap price to fall. On the other hand, when freight rates are relatively high and there is a shortage in the supply of shipping services, even operating less efficient and old vessels is considered profitable, therefore, there is no pressure to scrap old and inefficient vessels. As a result, there will be a shortage of supply in the scrap market, which causes the scrap price to rise.

Figure 1.10: Scrap prices for different size dry bulk carriers



Source: Lloyd's Shipping Economist

Figure 1.10 plots the monthly scrap prices for different sizes of dry bulk carriers over the period January 1976 to December 1997. Scrap prices, on a \$/ldt basis, are collected from different issues of LSE. For each size category, scrap prices are the average of prices reported to the LMIS, over the month.

1.6.5 Operating costs

Operating costs are those costs involved in the day to day running of the vessel, which consist of crew wages, stores and lubricants, management, technical and maintenance costs as well as provisions for dry-docking. In contrast to voyage costs, operating costs do not fluctuate over time, but they grow at a constant rate, which is normally in line with inflation. As mentioned earlier, the level of operating costs varies from vessel to vessel and depends, among other factors, on the age of the vessel, as well as the flag under which the vessel is sailing and the maintenance strategy of the owners or operators. The age of the ship is also important as older vessels require more repair and maintenance and a larger crew. The flag of the vessel affects operating costs as crew wages for vessels under flags of convenience are lower than those registered elsewhere (see Stopford 1997, page 164). Finally, maintenance costs depend largely on owners' strategies; some owners prefer a well-maintained vessel or fleet, which involves a high level of maintenance costs, whilst others may prefer a low level of maintenance and expenditures¹². Despite these uncertainties over operating costs, LSE collects and reports operating costs figures for three different types of vessels on a quarterly basis since 1987. These operating costs data are based on certain assumptions and age profiles¹³ for which information and estimates are provided by some ship management companies.

Unlike voyage costs, which may vary across vessel sizes due to their fuel consumption, port charges and canal tolls, operating costs for different size vessels, vary only by a small percentage. The difference between operating costs for different size vessels is mainly due to dry-docking expenses. Nowadays vessels, whether tanker or dry bulk, large or small, are manned with more or less the same number of personnel; spend relatively similar amounts on

¹² The choice of the maintenance level, amongst other factors, depends on the age of the vessel and the owner's maintenance policy. For example, owners who operate preventive maintenance policies may incur lower costs, whilst owners with no preventive maintenance policies may incur higher costs (see Stopford 1997).

¹³ The three types of vessels for which operating costs are reported are; 10-12 year-old 100,000 dwt tanker, 10-year-old panamax bulk carrier and 5-10 year old 20-30,000 dwt containership (all manned under an open flag by Indian officers and Korean ratings). Since operating cost data for capesize and handysize vessels are not available, we assume that such costs for capesize bulk carriers are equal to those for a 100,000dwt tanker and for a handysize bulk carrier is equal to those for a 25,000 dwt containership. These assumptions are not far from reality, since cost structures for these vessels are similar. For example, they require similar crew, spend similar amounts on maintenance and management, and spend the same amount on dry dock expenses. However, quotes obtained from a dry bulk shipowner show that such operating costs for capesize and handysize vessels are almost 10% higher and 10% lower than the costs for panamax dry bulk carriers, respectively. Estimated operating costs obtained (assumed) here for capesize and handysize vessels are also found to be within the 10% range of those for panamax vessels.

repairs; require almost the same management fees. Therefore, it is not far from reality to assume that operating costs for a capesize bulk carrier are roughly equal to those of a 100,000 dwt tanker reported in LSE, and for a handysize bulk carrier to be equal to the cost of running a 30,000 dwt container carrier.

We convert these operating costs to monthly observations by dividing the quarterly figures by 3. This yields three monthly operating cost series for the period 1987 to 1997. As operating costs do not fluctuate over time and increase at an inflationary rate, a non-linear exponential growth model is used to fit the data and backcast them to 1976.

The exponential growth model used to fit to operating costs series has the form, $OC_t = ae^{\beta t} + u_t$, where, OC_t represents operating costs and t is the time trend. The above exponential growth model is estimated over the period January 1987 to December 1997, using nonlinear least squares methods. Other models such as AR, ARMA and polynomial models are also examined, however, the exponential growth model was found to have the best fit; that is, the highest \bar{R}^2 and reasonable growth rate over the sample period. The \bar{R}^2 's of exponential growth rate models for operating costs are found to be above 97%, 91% and 96% for handysize, panamax and capesize, respectively, indicating a high degree of accuracy.

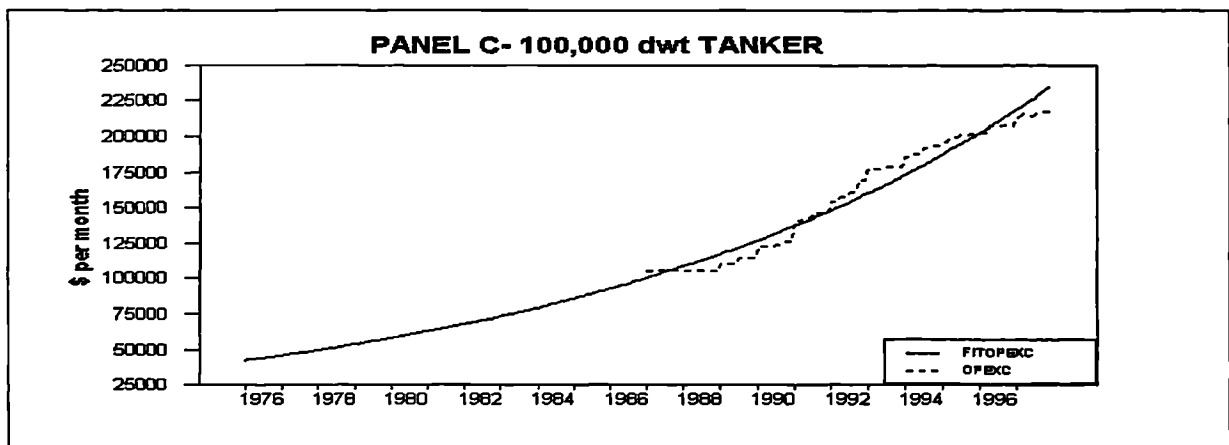
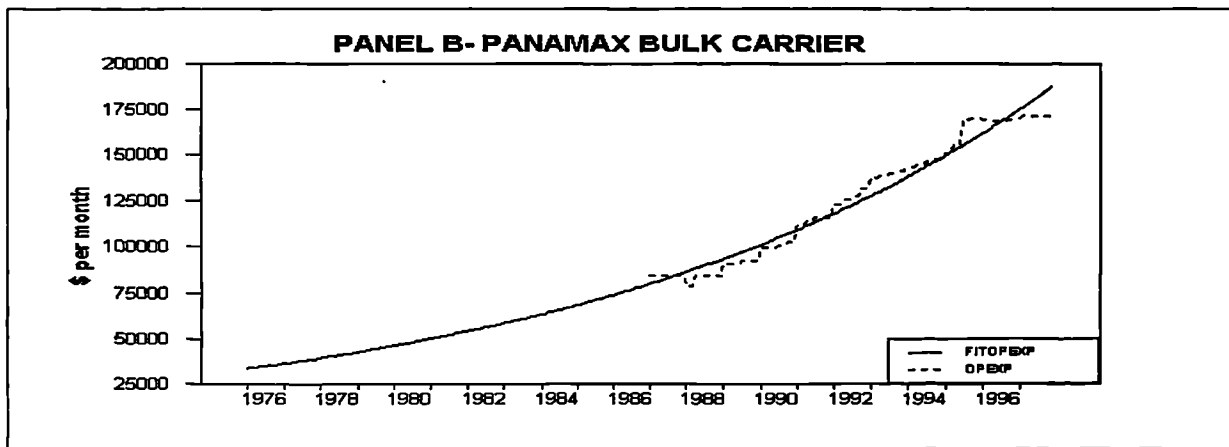
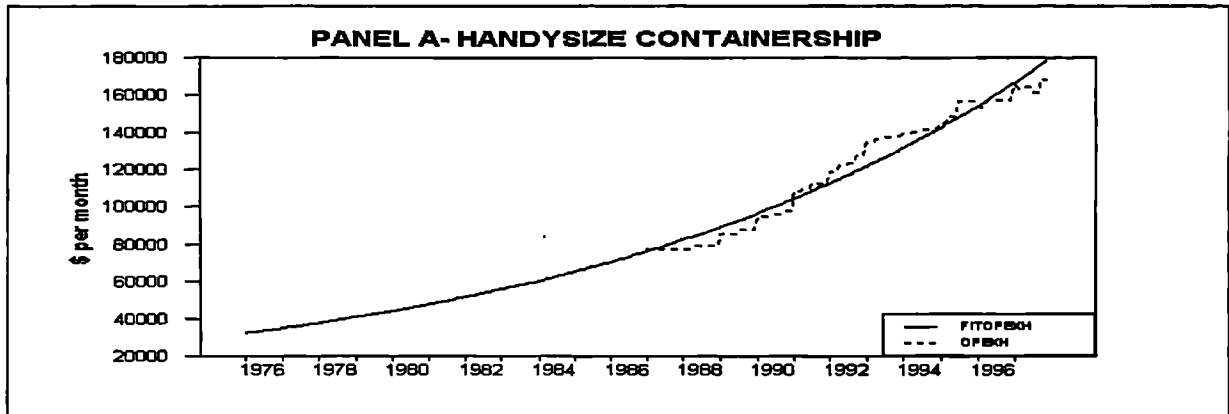
Table 1.4: Estimates of exponential growth models of operating costs for three size ships

$OC_t = ae^{\beta t} + u_t$									
	100,000dwt tanker			Panamax dry bulk carrier			Handysize containership		
α	42371.12	(1159.41)	[36.545]	39855.03	(1391.48)	[28.642]	29258.98	(773.795)	[37.813]
β	0.006481	(0.000125)	[51.971]	0.005554	(0.000161)	[34.548]	0.007044	(0.000120)	[58.804]
\bar{R}^2	0.96			0.91			0.97		

• Sample 1987:1 to 1997:12. Figures in (.) and [.] are standard errors and t statistics, respectively.

Panels A, B and C of Figure 1.11 plot estimated and actual operating costs for three types of vessels. It can be seen that fitted values closely track the actual values and there is a constant exponential growth in the series. The process of backcasting is used to elongate our data for operating costs. The operating costs series obtained using the exponential growth model will be used as an aggregate level of costs incurred by shipowners on the day to day running of the vessels. We then use the series to calculate operating profits for each size vessel in chapter 7, when investigating the efficiency of pricing in the dry bulk shipping industry.

Figure 1.11: Estimated monthly operating costs for different size vessels



- FITOPEXH, FITOPEXP and FITOPEXC represent fitted operating expenses for handysize, panamax and capesize vessels, respectively. OPEXH, OPEXP and OPEXC represent actual operating expenses for handysize, panamax and capesize vessels, respectively.

1.7 The Efficient Market Hypothesis

The concept of market efficiency has been used in several contexts to characterise a market in which rational investors use all the relevant information to evaluate and price assets traded in that market and arbitrage away any excess profit making opportunities. This definition of the efficient market implies that prices fully and instantaneously reflect all the relevant information. As a result, there is no opportunity for agents to make profits in excess of what the rational investors expect to make, considering the level of risk and transaction costs involved.

Since the efficient market hypothesis (EMH) is directly related to investors' expectations, Roberts (1967) and Fama (1970) classify the EMH according to the level of information used by investors to form their expectations regarding prices, returns and their trading strategies. They distinguish three levels of market efficiency: i) *Weak form efficiency*, in which the information set includes only the historical prices or returns; ii) *Semi-strong form efficiency*, in which the information set includes all publicly available information; and iii) *strong form efficiency*, in which the information set includes all information, public or private. The definition of the information set in classifying the EMH is important because it is directly related to the model, which determines expected prices or returns. This is because in testing the EMH, expected (theoretical) prices or returns are compared to actual prices or returns, to test whether there are no significant and consistent deviations between them.

According to the theory, in an efficient market, participants are rational, prices adjust to the arrival of new information instantaneously, and there is no riskless opportunity to arbitrage any excess profitability. Based on these assumptions and characteristics of the market, different tests are proposed in the financial economics literature to investigate the validity of the EMH. Market characteristics are important as the EMH implies different hypotheses in different markets and may be interpreted differently. Nevertheless, testing the theory requires investigating whether there is any riskless opportunity to make excess profit through taking advantage of mispricing in the market. For example, in the bond market, where investors have the option to invest in long term or short term bonds, the EMH requires the Expectations Hypothesis of the Term Structure (EHTS) to hold. The EHTS posits that the return on a long

term bond is equal to the average of the returns on a series of short term bonds within the life of the long term bond (see chapter 5 for more details). If the EHTS fails, in the absence of risk premia, there might exist instances where investors may exploit to make excess profit.

In the market for commodities and freight futures, one form of the EMH implies the unbiasedness hypothesis. The unbiasedness hypothesis posits that futures prices are unbiased predictors of spot prices at the expiry of the futures contracts. Therefore, in order to test the unbiasedness hypothesis in commodity futures or freight futures markets, one needs to investigate whether futures prices are statistically equal to spot prices at expiry (see Kavussanos and Nomikos 1999).

In stock markets, one implication of the EMH is that abnormal returns on securities are unpredictable (see chapter 7 for more details). Tests of pricing efficiency therefore investigate whether it is possible to generate abnormal returns (profits). Abnormal returns are defined as the difference between actual returns and expected returns on investments. The expected profit or return used in empirical tests is the one, which is assumed to be generated from the investors' pricing model. The most commonly used models in empirical studies are the Capital Asset Pricing Models (CAPM) or the market model, in which the excess return on an asset over a risk free investment is assumed to be related to the associated risk of holding that asset.

An alternative implication of the EMH requires that security prices reflect their fundamental values, where the fundamental or theoretical value is defined as the discounted present value of expected profitability of the asset. Therefore, in order to test the EMH, one needs to investigate whether the actual and theoretical prices are statistically equal over time.

It is important to investigate whether markets are efficient and if agents price assets rationally and efficiently, as failure of the EMH, in the absence of time-varying risk premia, signals riskless arbitrage opportunities. This means that if a market is consistently inefficient and prices deviate from their rational values for relatively long periods, then trading strategies can be devised to exploit excess profit making opportunities. For example, when prices are lower

than their fundamental values¹⁴, then holding these assets might be profitable as they are under-priced in comparison to their future profitability. On the other hand, when prices are higher than their corresponding rational values it might be profitable to short the asset since they might be overpriced in comparison to their future profitability.

Although there is a large body of literature on testing different implications of the EMH in various financial and commodity markets¹⁵, little work has been done in investigating the validity of the EMH in shipping freight and in the markets for ships (newbuilding and second-hand).

The aim of the following sections is to identify and discuss the objectives of this thesis, which include testing the validity of the EMH in the formation of period rates and newbuilding and second-hand prices for dry bulk vessels, among other issues.

¹⁴ Here by fundamental or rational value of assets, we mean the discounted present value of the expected stream of income that they generate over their lifetime.

¹⁵ See, for example Fama (1991) and Scott (1990) for a detailed survey.

1.8 Aims, Objectives and Contributions of the Thesis

The aim of this thesis is to provide further evidence, which will enhance our understanding of how the freight and ship markets move in the dry bulk sector of the shipping industry by examining four important areas. These areas include: i) seasonality of freight rates; ii) the efficient market hypothesis and its implications on the freight market and the market for ships; iii) the existence of time-varying risk premia in the formation of period rates and ship prices; iv) finally, the dynamic interrelationships between freight rates and freight volatilities. In this section we briefly discuss the motivation for further research in each area and highlight the contributions of this thesis to the existing literature.

After presenting the relevant literature for the above areas of research in shipping economics in the next chapter, the econometric methodologies used for analyses in the thesis are presented in the third chapter. Chapter 4 examines the univariate and stochastic properties of shipping freight rates such as unit roots and seasonality. Examining the univariate characteristics of the data is important since such properties determine and justify methodologies utilised for multivariate analysis of variables in later chapters. Chapter 5 examines the term structure relationship between long term and short term freight contracts. Having failed to find support for the expectations hypothesis, failure is explained/modelled in terms of the agents' perception of the relative risks involved in operating in the spot or time-charter markets. In chapter 6, the dynamic interrelationships between freight rate levels and the spillover effects between freight rate volatilities for different size vessels in the spot, 1-year and 3-year time-charter markets are examined. Multivariate time series models and impulse response analysis are used to investigate causality and spillover effects in levels and volatilities of spot, 1-year and 3-year time charter rates. Finally, chapter 7 investigates the efficiency of the newbuilding and second-hand markets using different approaches. In particular, following Campbell and Shiller (1987 and 1988) a present value model is used to investigate the rational valuation formula and the EMH for determination of newbuilding and second-hand prices. Having failed to find support for the EMH in the newbuilding and second-hand market for ships, chapter 7 utilises a GARCH-M model to model the risk return relationship in the market for dry bulk vessels. The following sections present the motive and contribution of each study in more detail.

1.8.1 Stochastic properties of dry bulk freight rates; Stationarity and Seasonality

The direct relationship between international commodity trade and shipping markets implies that both short and long term fluctuations in the trade in commodities may be transmitted to freight markets. Such fluctuations can be cyclical, seasonal or random. One would expect similar stochastic and deterministic behaviour in shipping freight rates, as in the markets where demand for sea transportation emanates.

Furthermore, a lot of attention has been paid to the univariate and stochastic properties of shipping freight rates and prices in recent years. For example, Hale and Vanags (1992) and Glen (1997) find that dry bulk prices are nonstationary, while Kavussanos (1996c) shows that tanker prices are nonstationary. Berg Andreassen (1996) and Veenstra and Franses (1997) draw similar conclusions on the stochastic behaviour of dry bulk freight rates in Baltic routes. All these studies consider the behaviour of freight rates and prices as a side issue to their own investigations. In that sense, they do not consider the possibility of different forms of stochastic behaviour in the series such as seasonality and seasonal unit roots. The only exception is Kavussanos (1997) who rejects the existence of seasonal unit roots in dry bulk carrier prices.

Investigating the seasonal behaviour of data is important and has both economic and econometric implications. From the economic point of view, revealing the nature and true behaviour of seasonal fluctuations of freight rates can be of interest to shipowners and charterers in their chartering strategies, tactical operations and budgeting. From the econometric point of view, it is important to determine the true nature of seasonality in the series as the existence of stochastic seasonality and seasonal unit roots leads to spurious regression results and can invalidate inferences if ignored; see Hylleberg et al (1990) and Franses (1991).

Therefore, in chapter 4, for the first time, the nature of seasonality (deterministic and/or stochastic) in dry bulk freight rates is investigated by utilising the Beaulieu and Miron (1993) seasonal unit root. The test is an extension of the Hylleberg et al (1990), HEGY, seasonal unit root test for quarterly data to monthly data. Once the existence of stochastic seasonality is

rejected, we measure and compare the deterministic seasonal behaviour of freight rates across vessel sizes and contract durations. We then focus on the seasonal behaviour of freight series under different market conditions; that is, periods of market expansion and contraction.

It is well established in the literature that the elasticity of shipping supply, in a market equilibrium framework, depends on the state of the market. This implies that a change in the demand function during a market expansion, when the supply curve is inelastic, has a greater impact on freight rates compared to periods of market downturn, when the supply function is elastic. We test this property of the shipping supply curve by distinguishing between the two market conditions and comparing the seasonal fluctuations of freight rates under these two market conditions.

1.8.2 The efficient market hypothesis in dry bulk freight markets

The relationship between spot and period (time-charter) rates has always been problematic in modelling shipping freight markets. Several studies in the literature are devoted to examining this relationship utilising different theories, methodologies and various data sets. The studies on the relationship between long and short term rates can be classified into two categories. On the one hand, there are attempts to model long term rates assuming that some form of expectations mechanism relates long term to short term rates and the efficient market hypothesis holds (e.g. Zannetos, 1966, Beenstock and Vergottis, 1989a and b, Glen et al, 1981, and Strandenæs, 1984). On the other hand, a number of studies test the efficient market hypothesis and investigate the validity of the expectations hypothesis in the relationship between short and long term rates (e.g. Hale and Vanags, 1989 and Veenstra, 1999).

The notable work of Zannetos (1966) was the first attempt to study the relationship between long and short term tanker rates. He provides comprehensive theoretical arguments and analyses to establish the relationship between long and short term tanker freight rates during the 1950's. Zannetos points out the similarities between money markets and freight markets and argues that period rates should represent a weighted average of future spot rates. He also proposes the "elastic expectations" theory in the formation of long term rates, but fails to provide supporting evidence.

Glen et al (1981) propose a present value model for the relationship between spot and time-charter rates in the tanker market, and transform the relationship to estimate an autoregressive distributed lag model which relates period rates to lagged spot rates. They find a different lag structure to those proposed by Zannetos, and conclude that the expectations in the formation of period rates might not be elastic¹⁶.

Strandenæs (1984) argues that period rates are formed through agents' "semi-rational expectations". She finds that current spot and long run equilibrium rates are both important determinants of time-charter rates for panamax dry bulk carriers, medium and large tankers. However, her estimation results show that current spot and long run equilibrium rates have different impacts on formation of long term rates across different types of vessels; that is, results are not consistent across sizes.

Beenstock and Vergottis (1989a and b) assume that rational expectations and the EMH in the formation of time-charter rates are valid and based their integrated shipping industry model on these assumptions. They find that current and expected spot rates are significant determinants of time-charter rates. However, they do not attempt to investigate the validity of EMH and rational expectations in the formation of period rates.

Hale and Vanags (1989) test the EMH and rational expectations in the formation of freight rates using disaggregated dry bulk market series and find no support for the theory. Recently, Veenstra (1999) reports further results on the expectations hypothesis and the term structure relationship of dry bulk voyage and time-charter rates. Although his study suffers from methodological issues (see chapter 2 for more details), he concludes that the results support the expectations hypothesis of the term structure for three size dry bulk carriers.

The above review suggests that not only evidence on the relationship between spot and long term rates in shipping is mixed, but also the results of tests on the efficiency of the freight market are inconclusive. This mixed evidence might be due to the following reasons. First, statistical issues regarding the nonstationary nature of data (e.g. freight rates) is not investigated in some of the studies such as Zannetos (1966), Glen et al (1981) and Strandenæs

¹⁶ See chapter 2 of this thesis for more details on Zannetos (1966) and Glen et al (1981) models.

(1984)¹⁷. It is well established in the literature that failure of considering the stochastic behaviour of the data in investigating the relationship between long term and short term contracts yields invalid results and inferences (Campbell and Shiller 1987). In addition, the authors assume that some form of expectations relates the long and short term rates and attempt to find the best model or fit for the relationship as implied by the expectations presumed (e.g. Glen et al, 1981 and Strandenæs, 1984) rather than testing the validity of the hypothesis. Second, studies such as Hale and Vanags (1989) and Veenstra (1999) consider the stochastic properties of freight rates in testing the expectations hypothesis that relates long and short term rates, but fail to define the appropriate formulation of the test¹⁸. Finally, most of the models and tests proposed in the literature fail to allow for factors such as agents' perceptions of market risk at each point in time (time-varying risk), which are important in relating long and short term rates.

In chapter 5, using the present value relationship between long term and short term rates, we perform several tests to investigate the validity of the EHTS in the formation of long term rates for three different size dry bulk carriers. These tests include; the perfect foresight spread test, restrictions on the VAR model, variance ratio and cointegration tests, for spot and 1-year, and spot and 3-year time-charter rates. These tests take directly into account the nonstationary property of freight rate series, a fact that has been ignored in some of the previous studies.

Once the expectations hypothesis in the formation of long term rates is rejected across different sub-sectors and contracts with different times to maturity, a model is proposed which relates spot and long term time-charter rates and takes into account the risks associated with the spot market. This model uses an Exponential Generalised Autoregressive Heteroscedasticity in the Mean, EGARCH-M (Nelson 1991) framework¹⁹. We find that, in contrast to money markets, the time-varying risk premia have negative coefficients (discounts). This means that shipowners are prepared to offer a discount, which varies over time, in order to fix charter contracts with longer terms to maturity. This finding is in line with the structure of shipping markets and freight rate formation in the literature.

¹⁷ This is because the econometric techniques, which take into account non-stationarity behaviour of time series were not established at the time.

¹⁸ See chapter 2 for a detailed review of these criticisms.

¹⁹ More details of ARCH, GARCH and EGARCH-M models are given in chapter three.

1.8.3 Interrelationships and spillover effects between freight rate levels and volatilities

It has been argued earlier, as well as in the literature (e.g. Stopford, 1997, Kavussanos 1996a and 1997), that the dry bulk market is disaggregated by size, and each size vessel is involved in the transportation of certain commodities with a low degree of substitution between vessels of different sizes. This implies an idiosyncrasy in the behaviour of freight rate levels and volatilities. However, sometimes vessels of adjacent size categories are used as substitutes; for instance, panamax instead of handysize, capesize instead of panamax and vice versa. Such substitutions become more significant when the demand in one market is relatively higher than the other market and is enough to attract, say, larger vessels to accept part cargoes and make a profit. On the other hand, there might be occasions when charterers prefer to hire smaller vessels for the transportation of commodities, which are conventionally carried by larger vessels; for example by splitting the large consignment into two or three shipments. This is usually the case when importers prefer or switch to “just in time” inventory management techniques, or try to top up their seasonal requirements, which might be less than a large shipment.

The above argument suggests that although different size dry bulk carriers are not perfect substitutes, they may overlap in their cargo transportation capabilities or even be linked through intermediate size vessels. Therefore, one would expect that shocks to any sub-sector might be transmitted to other sub-sectors. For instance, if there is an increase in demand and subsequently freight rates for handysize vessels, other size categories such as panamax vessels may react by participating in the handysize market by accepting part cargoes, if it is found to be more profitable. This shift from one market to the other will cause an over supply in the handysize market and a shortage of supply in the panamax market, as a result, handysize rates will drop and panamax rates will rise. This process will continue until both markets stabilise; that is, until supply equals demand in each market and there is no opportunity to make extra profit by switching between markets.

Investigating the form of interrelationships among these sub-markets in shipping itself is another interesting dimension of this thesis. This type of analysis can be of interest to agents in the shipping industry, as well as academics interested in uncovering the dynamic

interaction between first and second moments of these freight series and the possible spillover effects between them in the spot and period markets. Furthermore, this type of analysis can provide information on the degree of substitutions between different dry bulk sub-sectors and the speed of stabilisation of freight rates in each market.

This type of investigation is similar to the one by Beenstock and Vergottis (1993) on spillover effects between tanker and dry bulk markets. However, Beenstock and Vergottis (1993) trace the spillover effects between the markets through the market for combined carriers, shipbuilding and scrapping markets using dynamic econometric models and simulation techniques. The difference here is that, the spillover effects between different segments are analysed within the dry bulk sector using recently developed time series techniques such as VAR, cointegration and impulse response analysis instead of dynamic structural models. Cointegration and error correction models, provided the series are nonstationary and cointegrated, can reveal information on long-run relationships as well as short-run dynamics among freight rates for different size vessels. Impulse response analysis enables us to trace the response of freight rates in different sub-sectors to shocks to other sub-sectors. Analyses are carried out on charter contracts with different terms to maturity, i.e. spot, 1-year and 3-year time-charter rates, and comparisons are made to highlight differences in spillover effects within spot markets in comparison to those of time-charter markets.

We also investigate the possibility of transmission of freight rate volatilities from one sub-sector to other sub-sectors within the spot and time-charter markets. This is done through a multivariate VECM-GARCH model, which has a vector error correction specification in the mean, and a multivariate generalised autoregressive variance specification. These types of models have been used in the financial economics literature to assess the integration as well as the transmission of information between the capital, interest or bond markets in different geographical locations. For example, Koutmos and Booth (1995) find volatility spillover effects between international capital markets using a multivariate EGARCH model and Koutmos and Tucker (1996) report dynamic interactions between spot and future stock markets using a multivariate GARCH model.

1.8.4 Efficiency of newbuilding and second-hand markets for dry bulk carriers

One of the most important and interesting areas in the shipping economics literature is the determination of ship prices. Many studies have been devoted to modelling, evaluating and forecasting ship prices and their volatilities in the past, among these are: Strandenes (1984), Beenstock (1985), Beenstock and Vergottis (1989a and b), Charmeza and Gronicki (1980), and Kavussanos (1996b and 1997). Studies on the determination of ship prices, e.g. Strandenes (1984) and Beenstock and Vergottis (1989a and b), consider ships as capital assets and share the same theoretical framework. Present value models, which posit that the price of an asset should reflect the discounted present value of expected income that the asset may generate over its life, are used extensively in modelling ship prices. The major difference among the studies on ship price determination, is the way they deal with the expectations about the future income generated by ships. More precisely, they assume that the EMH is valid and utilise different forms of expectations hypothesis in their pricing models. For example, Strandenes (1984) assumes that expectations are semi-rational, while Beenstock (1985), Beenstock and Vergottis (1989a and 1989b) assume rational expectations in price formation.

Hale and Vanags (1992) dispute the assumption of rational expectations and the EMH in models for ship prices, and argue that such assumptions should be investigated and their validity must be verified prior to any modelling and forecasting. This is because rejection of these hypotheses may have serious consequences on results. They argue that for the EMH to be valid, prices for different size vessels should incorporate all the available information; that is, given past prices, no other information should improve the predictability of prices. They propose a test based on the cointegration approach and Granger- causality between prices for the three sizes of bulk carriers. Based on the Engle-Granger cointegration technique, they find that not only there are cointegrating relationships between the price series, but also prices Granger-cause each other. They conclude that their results cast doubt on the validity of the EMH and RE in price formation in the dry bulk sector.

Glen (1997) re-examines the informational efficiency in dry bulk carriers price determination using Johansen's multivariate cointegration test, which is more powerful compared to the Engle-Granger test, and reports similar results as Hale and Vanags. However, he attributes

the link between prices for different size vessels to the existence of common stochastic trends rather than the failure of the EMH.

Wright (1993) attempts to examine different forms of expectations in the formation of second hand prices for small dry bulk carriers for the period 1980 to 1990 using quarterly data. He tests three different hypotheses, namely, rational, static and adaptive expectations hypotheses. Apart from statistical issues, such as the direct use of nonstationary variables, his tests also suffer from theoretical shortcomings, so not much reliance can be placed on these results. For the sake of completeness, therefore, we report here that he finds mixed results and concludes that ship prices are formed under a mixture of expectations depending on market conditions.

There is also a large body of literature on the present value models and the EMH in asset pricing in capital markets, especially following Campbell and Shiller's (1987 and 1988) seminal papers in which the VAR methodology and cointegration were used to test the EMH for the first time. Different markets, sample periods and various discount rates (constant, time varying) have been used to examine the EMH. For example, Mills (1992) examines monthly data for the UK stock market using a constant discount rate and finds similar results to Campbell and Shiller (1987); that is, rejection of the EMH. Cuthbertson et al (1999) argue that failure of the EMH in the UK market might be due to sectoral aggregation and re-examine the UK market using industry disaggregated quarterly data. They find that disaggregation may improve the results in some sectoral portfolios and conclude that divergence in the tests of the EMH using aggregate data, may improve when sectoral data are used and hold that as evidence in favour of the market segmentation. In this study, we distinguish between markets for different size dry bulk carriers and therefore take into account the segmentation in the dry bulk sector.

The above review suggests that, despite several attempts in the literature on testing the efficiency of the market for ships and investigating the nature of the expectations in the formation of ship prices, the evidence on these issues still remains inconclusive. Therefore, the aim of the seventh chapter of this thesis is to use advance techniques, in particular, cointegration and nonlinear tests on the VAR model proposed by Campbell and Shiller (1987) to examine the present value model and the EMH in the determination of newbuilding and second-hand prices in the dry bulk sector. One advantage of the VAR approach is that stochastic properties of variables are explicitly considered. In addition, the bivariate model of

Campbell and Shiller is extended to a trivariate model, which incorporates the residual (scrap) values as the third variable in the model.

We use a present value model, which relates the price of a ship (either newbuilding or second-hand) to the discounted present value of expected profits, generated through chartering operations plus the discounted present value of her expected residual value. This can be written in the following mathematical form

$$P_t = \sum_{i=1}^n \left(\prod_{j=1}^i (1 + E_t R_{t+j})^{-1} \right) E_t \Pi_{t+i} + \left(\prod_{j=1}^n (1 + E_t R_{t+j})^{-1} \right) E_t P_{t+n}^{sc} \quad (1.1)$$

Where P_t is the price of the vessel, E_t is the expectations operator (expectations formed at time t), $E_t \Pi_{t+i}$ represents expected profit in period $t+i$, $E_t R_{t+j}$ is the expected discount rate and $E_t P_{t+n}^{sc}$ is the expected terminal value of the vessel. Variables in (1.1) can be nonstationary, a fact which would invalidate direct tests for EMH. However, the Campbell and Shiller (1987) transformation can be used to re-parameterise (1.1) to obtain a model with stationary variables (see chapter 7 for more details).

Two cases are considered for testing the price efficiency of newbuilding vessels. In the first case, the expected terminal value is considered to be the price of a second-hand vessel, assuming the vessel operates for 5 years and its value after 5 years reflects the price of a 5-year old second-hand vessel. In the second case, we assume that the newbuilding vessel will be used for her entire economic life, therefore, the residual value is her scrap price. A limited economic life of 20 years is assumed for a newbuilding and 15 years for a 5 year old second-hand vessel.

We also investigate another implication of the EMH, which requires unpredictability of excess one period returns or *abnormal returns*. Therefore, one period excess returns on a shipping investment can be written as

$$exr_{t+1} = r_{t+1} - r_t^m \quad (1.2)$$

Where, Exr_{t+1} is the excess (abnormal) return at time $t+1$, r_{t+1} is the return on shipping investments and r_t^m is the market return (e.g. one month London Inter-Bank Offer Rate, LIBOR, plus a margin, e.g. 1%). The EMH implies that one period excess returns on shipping investments over market returns should be independent of information available at time t . In other words, in an efficient market abnormal returns should be unpredictable, otherwise, excess profit making opportunities may be identified and exploited by a group of investors. Depending on the information set used, from the most restricted to the least restricted information set, the EMH can be classified as weak, semi-strong and strong form efficiency, respectively. In chapter 7, we attempt to test the weak form efficiency in the market for second-hand dry bulk carriers, using lagged abnormal returns or excess return forecast errors as information set.

1.9 Structure of The Thesis

Having described our research objectives, we now turn to explain the outline of this thesis, which has eight chapters including this one. Chapter 2 reviews studies in the literature. This critical review is carried out in a structured way in order to fulfil two main objectives. The first objective is to present a general overview of past studies investigating the relationships of different variables in the tramp shipping industry, and in particular, studies on modelling shipping freight rates and ship prices are analysed. Our second objective is to identify shortcomings in those studies and distinguish certain areas, which need further investigation. The review of the literature covers early econometric studies of the shipping industry, recent complex and detailed industry models, and other empirical research on market efficiency and its related issues in shipping markets. Recent research on time series models, used to investigate the dynamics of freight rate and price volatilities, are also discussed.

The third chapter discusses details of different econometric and time series techniques, which are used throughout the thesis. Models for investigating univariate properties of time series, including stationarity and unit root tests, seasonality and seasonal unit roots, are explained. Topics on multivariate analysis of time series such as VAR models, cointegration techniques and impulse response analysis are also presented. Finally, recently developed ARCH and GARCH models, which are used to estimate time-varying volatilities of time series along with some important specification and estimation issues, are discussed.

Chapter four deals with univariate properties of dry bulk freight series such as stationarity, unit roots and seasonality. The existence of different forms of seasonality (stochastic and deterministic seasonality) is investigated, using Beaulieu and Miron (1993) tests. The magnitude and pattern of deterministic seasonality is then measured and compared across freight rates for different size vessels as well as contract durations. Moreover, seasonal behaviour of freight rates for dry bulk carriers are examined under different market conditions.

Chapter five investigates the term structure relationship between long and short term rates for different sizes of dry bulk carriers. A present value model is used to relate long term and short term rates. Different testing methods are used to test the validity of the expectations

hypothesis, these include: perfect foresight spread test, cointegration, Granger-causality, non-linear restrictions on the VAR model and variance ratio tests. The rejection of the expectations hypothesis of the term structure is then explained by a model, which takes into account the time-varying perception of the risk of the agents involved in the market.

Chapter six is devoted to studying the interrelationships between levels and spillover effects between freight rate volatilities for different size dry bulk carriers within the spot, 1-year and 3-year time-charter markets. The study is carried out in two steps. In the first step, once cointegrating relationships between freight rates in each market (spot, 1-year and 3-year time-charter) are established, VECM models are specified to model both long and short term relationships between freight rates within each market. Generalised Impulse Response analyses are then performed on VECM models to trace the impact of shocks on freight rates for each size to others. The speed of adjustment in spot and time-charter markets are also measured and compared using impulse response analysis on the cointegrating vectors. In the second step, VECM models are extended to VECM-GARCH models to investigate any spillover effects among freight rate volatilities in spot and time-charter markets.

Chapter 7 investigates the validity of the efficient market hypothesis in the determination of newbuilding and second-hand prices for different size dry bulk carriers. In particular, we test two different but interrelated implications of the EMH in the market for ships. It is hypothesised that the price of a vessel at any point in time, equals the discounted expected value of operational profits earned during the economic life of the vessels, plus the discounted present value of her residual price. Since price and profit series are found to be nonstationary, cointegration and VAR methodologies are used to tests the validity of the EMH and the present value relationships.

The final chapter presents the summary and main conclusions of the study. The implications of the findings of each empirical study are then discussed further. The last section in chapter 8 is devoted to highlighting the limitations of empirical investigations along with suggestions for future research.

1.10 Concluding Remarks

The aim of this chapter was to introduce the dry bulk shipping sector in order to provide background information needed for the non-specialists and to motivate the need for the topics analysed in this thesis. In particular, we discussed the disaggregation of the dry bulk market in different sub-sectors which arise, due to different physical and economic factors such as commodity parcel size, the route and ports of load and discharge characteristics as well as the vessel design features. It is mentioned that supply, demand, freight rates and prices for different size dry bulk carriers vary due to idiosyncratic factors, which distinguish these sub-sectors in the dry bulk market.

We also discussed different forms of shipping contracts, the differences between them and the cost allocations between shipowners and charterers under different types of contracts. Since a necessary condition for market efficiency is the existence of a competitive market, the conditions under which the dry bulk market can be categorised as a perfect market were highlighted and discussed.

Sources of shipping data, such as historical prices, freight rates and operating costs, which are used throughout this thesis, were introduced and data collection and processing methods by different institutions were discussed.

After a brief description of the efficient market hypothesis and its interpretations in different markets, we identified four main research areas covered in this thesis and highlighted our contributions to the existing literature. These areas include: **i)** investigating the seasonal behaviour of the freight market; **ii)** testing the expectations hypothesis of the term structure and modelling time-varying risk premia in the formation of long term rates; **iii)** examining the dynamic interrelationships between freight rate levels and volatilities for different size vessels in the spot, and period markets; **iv)** finally, investigating the EMH and the existence of time-varying risk premia in the market for newbuilding and second-hand vessels. It is hoped that investigations and answers provided in the thesis will promote our understanding of the freight and the ship price microstructure in the dry bulk sector.

2. CHAPTER TWO

REVIEW OF THE LITERATURE

2.1. Introduction

Despite the importance of the role of international shipping in linking the sources of supply and demand for commodities around the world, the number of studies in the literature on exploring the complex nature of this industry is limited compared to other areas of financial and industrial economics. This is mainly due to two reasons; i) the lack of existence of consistent data on the shipping industry, ii) the complex structure of this industry in terms of the interrelationship between its constituent markets such as shipbuilding and second-hand markets, the scrap market and the freight market. However, availability of shipping data compiled by different research institutes¹, advances in econometric analysis and modern time series techniques, coupled with the increasing necessity to understand the dynamics of the shipping industry for investment and operational purposes, have encouraged researchers to pay more attention to this sector of the economy in recent years.

The aim of this chapter is to present a comprehensive review of previous studies in modelling and analysing shipping markets. This critical review is carried out in a structured way in order to fulfil two main objectives. The first objective is to present a general overview of past studies investigating the relationships of different variables in the tramp shipping industry. In particular, studies on investigating the validity of expectations in the formation of shipping freight rates and ship prices, the validity of the EMH in each market and modelling time varying risk in both the freight market and the market for ships are presented and discussed. Our second objective is to identify shortcomings in those studies and distinguish certain areas, which need further investigation, in order to support our research theme in the rest of the thesis.

The structure of this chapter is as follows. Section 2.2, as the starting point, reviews the early studies of Tinbergen (1931 and 1934) in explaining the shipbuilding and freight markets and Koopmans (1939), in explaining the determinants of freight rate markets in a supply-demand framework. Section 2.3 discusses models used by Beenstock (1985) and Beenstock and Vergottis (1989a) to explain the formation of ship prices and period rates, respectively.

¹ For example, Clarkson Research Studies, Lloyd's Maritime Information Services, Lloyd's Shipping Economist, Fearnleys and Simpson, Spence & Young.

Section 2.4 reviews the pioneering work of Zannetos (1966) on the formation of expectations and long term freight rate formation in the tanker market as well as recent studies, such as Glen et al (1981), Stranden (1984), Hale and Vanags (1989) and Veenstra (1999) on testing the expectations theories and the term structure relationship in the formation of period rates. Section 2.5 presents recent studies on the interrelationship between shipping freight rates in different routes. Review of studies on expectations hypothesis, ship price formation and efficiency of the market for ships, such as Stranden (1984), Hale and Vanags (1992), Wright (1993) and Glen (1997), are the subject of section 2.6. Section 2.7 presents studies on modelling risk in shipping markets and the market for ships by Kavussanos (1996a, and 1997). The last section presents the summary of the review of the literature and conclusions.

2.2. Early Econometric Models of the Shipping Industry

Despite the rapid growth in international seaborne trade in the early 1900's and the increasing importance of the shipping industry in connecting sources of supply and demand for different types of commodities, it was not until the 1930's when the pioneering studies of Tinbergen (1931 and 1934) and Koopmans (1939) that the foundations in analysis of the shipping industry were set. Tinbergen (1934) investigated, for the first time, the formation of shipping freight rates through a supply-demand framework (market equilibrium). In particular, he examined the sensitivity of freight rates to changes in factors affecting supply and demand for shipping such as bunker prices, stock of fleet and an inelastic demand for shipping services. In a different study, Tinbergen (1931) provided the first quantitative analysis of the dynamic behaviour of the shipbuilding market, empirically identifying important variables related to this market. Koopmans (1939) was the first attempt to analyse the shipping freight market, in which the behaviour of shipping supply and demand schedules under different market conditions are distinguished. These two studies provided the foundation for subsequent studies in the literature on shipping and shipbuilding markets.

2.2.1. Tinbergen (1931) "A dynamic shipbuilding model"

The pioneering work of Tinbergen (1931) was the first of its kind to study the cyclical behaviour of the shipbuilding industry using a series of mathematical equations. This model, which forms the basis for subsequent studies in the literature, relates shipping freight rates and shipbuilding activities through the fleet size, K_t . Tinbergen first assumes that an expansion (contraction) in the fleet size at time t , K_t , should have a negative (positive) effect on freight rates, FR_t .

$$FR_t = f_1(\bar{K}_t) \quad (2.1)$$

He also argues that a change in the fleet size at time t , ΔK_t , adjusted for losses and scrapping, is proportional to the orders placed k periods earlier, OR_{t-k} .

$$\Delta K_t = f_2^+(\text{OR}_{t-k}) \quad (2.2)$$

where k is the time taken for an order to be completed. New orders at period t , OR_{t-k} , are then assumed to be positively related to the level of freight rates at that period, FR_{t-k} :

$$\text{OR}_{t-k} = f_3^+(\text{FR}_{t-k}) \quad (2.3)$$

Through substituting (2.3) in (2.2), Tinbergen (1931) derives a model, which relates freight rate levels at $t-k$ to the expansion or contraction of the fleet size at period t . Tinbergen estimates the model using data for the period of 1870 to 1913, and concludes that the shipbuilding industry follows a cyclical pattern, with approximately eight-year duration from peak to peak.

2.2.2. Tinbergen (1934) “Shipping freight rate model”

In a subsequent study, Tinbergen (1934) suggests, for the first time, the study of shipping freight rates in a supply-demand framework. In this framework he investigates the sensitivity of the freight rate to the determinants of supply, Q^S , and demand, Q^D . He considers fuel prices, BP , the fleet size, K , and freight rates, FR , as important determinants of shipping market supply. On the demand side, he assumes a perfectly inelastic demand for shipping services with respect to freight rates, since changes in freight rates do not seem to influence the demand very much. Therefore, he proposes the following market clearing equations for shipping supply and demand.

$$Q^S = f(K^+, BP^-, FR^+) \quad (2.4)$$

$$Q^D = \text{inelastic demand} \quad (2.5)$$

where signs above the variables are the signs of partial derivatives. Tinbergen argues that supply, measured in ton-miles, is negatively related to fuel prices because an increase in fuel price forces shipowners to adjust (reduce) the speed of their vessels in order to optimise their

fuel costs. Supply is also positively related to the fleet size, K (dead weight tons) and freight rates, FR . This is because the fleet size directly increases supply. Also, an increase in freight rates, FR , will increase the supply for shipping services since shipping operations become more profitable and activate idle ships as well as increase the speed of the fleet in operation.

Tinbergen (1934) suggests that, under the market clearing assumption, freight rates move instantaneously in order to bring the supply in equilibrium with demand, $Q_t^D = Q_t^S$. Therefore, the freight rate equation can be obtained by solving the above system of equations ((2.4) and (2.5)) as follows:

$$FR_t = f(Q_t^{+D}, K_t, BP_t) \quad (2.6)$$

Using an annual data set from 1870 to 1913, he estimates Equation (2.6) in the following log-linear form in order to determine the significance of the variables in his model and their elasticities.

$$\ln FR_t = \alpha \ln Q_t^D + \beta \ln K_t + \gamma \ln BP_t \quad (2.7)$$

Tinbergen reports estimated parameters with correct signs; that is $\alpha > 0$, $\beta < 0$ and $\gamma > 0$, and therefore, he establishes the important influence of demand, supply and bunker prices in the determination of freight rates.

2.2.3. Koopmans (1939) “Tanker freight rates and tankship building”

Koopmans (1939) is the first attempt in the literature of shipping markets that distinguishes between the dry cargo and tanker sectors. Koopmans studies the tanker freight market in a detailed supply-demand framework. Most of the theory proposed by Tinbergen (1931 and 1934) is examined using tanker market data for the 1920 to mid 1930's. The most interesting contribution in this work, apart from treating the tanker market separately, is the distinction in the analysis between periods of prosperity and depression in the tanker market. Therefore, Koopmans could explain a supply schedule for tanker shipping in which the supply is relatively elastic when the freight rates are low and inelastic when freight rates are high and almost all the fleet is employed.

2.3. Structural Models of the Shipping Industry

2.3.1. Beenstock (1985) “An econometric model of ship prices”

Beenstock (1985) is the first attempt to incorporate future market expectations in the determination of ship prices and model them in a forward-looking way, by considering ships as capital assets generating wealth for shipowners not only through freight revenues but also through capital gains (or losses). He argues that agents in the shipping industry form rational expectations on future prices and profitability of the market and act accordingly to maximise their profit through operations and capital asset speculation.

Beenstock assumes that the market for ships and freight services are interrelated. Therefore, he uses the conventional supply-demand framework to determine spot freight rates. Demand for shipping services is assumed to be positively related to world trade (WT), and negatively related to freight rates. Supply for shipping services is assumed to be a function of freight rates, bunker prices and the size of the fleet, in a similar fashion to Tinbergen (1934) and Hawdon (1978).

Beenstock models the market for ships as a set of equations, which relate the stock of the fleet to newbuilding and scrap markets, using changes in the stock of fleet as its central link. The change in the fleet size each period is defined as the difference between new deliveries (NB) and the percentage of the fleet sent for scrap (SC) in that particular period. Since activities in the newbuilding and scrap market are closely related to ship prices (P), scrap prices (P^{SC}) and the size of the fleet, he could then write the changes in the fleet size, ΔK , as a function of these variables

$$\Delta K = f(\bar{P}^+, \bar{P}^{SC}, \bar{K}) \quad (2.8)$$

A prominent part of this model is the way RE is incorporated in explaining the relation between the demand for ships and the return on shipping investment. In this respect, a present value model is used to explain agents' expected return on investment. Beenstock argues that

the expected return on a shipping investment is the sum of the discounted return from operations and the discounted return from capital gains. The present value model is then rearranged in the following form in which expected return on shipping investment is defined as a function of expected price of the vessel and operating profit

$$E_t R = \frac{[a(FR_t - OC_t) - (1-a)OPC_t]}{P_t} + \frac{E_t P_{t+1} - P_t}{P_t} \quad (2.9)$$

where:

$E_t R$ = the expected return on the investment,
 OC = the cost of ship operations,
 OPC = represents the opportunity cost in lay up,
 $E_t P_{t+1}$ = the expected future value of the ship, one period ahead,
 FR_t and P_t = represent freight rate and ship prices for the current period respectively,
 a = the probability of the ship being operational

The first term on the RHS is the proportion of the expected return due to revenues from shipping operations. This is assumed to be the difference between the probability of the ship being employed (a) times the operational profit and the probability of the ship being unemployed ($1-a$) times the opportunity costs when the vessel is laid up. The second term on the right hand side is the proportion of the expected return due to the expected capital gains or losses from shipping investments in that period, measured as the discounted expected future returns on the capital investment, (P_t).

Beenstock also considers the investor's portfolio selection behaviour with respect to the wealth of the investor, since profit maximising investors adjust their investment portfolios according to associated risks and returns to maximise wealth. Therefore, he hypothesises that the proportion of the investors' wealth held on ships depends on the return on shipping investments and the return on other investments through the following equation:

$$K^D P / W = f(\bar{R}^+, \bar{R}^*) \quad (2.10)$$

where $K^D P$ is the investors' wealth held on ships, W is the total wealth of these investors, and R and R^* are the returns on shipping investments and the return on other investment opportunities, respectively. This means that the proportion of the wealth of the investor invested in shipping ($K^D P / W$) is directly related to returns on shipping investments, R , and negatively related to the returns on other business activities, R^* . Substituting equations (2.8

and (2.9) in (2.10) and solving for K^D , Beenstock derives the following relationship between demand for ships and variables such as ship prices, freight rates, costs and investors' wealth.

$$K^d = f(a^+, FR_t^+, BP^-, OC^-, E_t P_{t+1}^+, \bar{P}_t, R^*, \bar{W}) \quad (2.11)$$

The sign of partial derivatives above the variables indicate the direction of their impact. In the equilibrium condition, the demand for ships, K^d , must be equal to the current stock of the fleet, K , therefore the stock of the fleet can be explained through the same equation.

Having established the necessary relationships for determination of freight rates, ship prices and the stock of fleet, Beenstock argues that simultaneous determination of ship prices and freight rates can be done in two ways. First, in a static situation where changes in prices and the stock of the fleet are zero ($\Delta K=0, \Delta P=0$, the stationary state). This implies that prices and freight rates change instantaneously. Second, in a dynamic situation where prices and freight rates evolve over time from one equilibrium state to another.

In the first case, where prices and rates are assumed to be constant, the stationary state, Beenstock derives the analytical solutions of the relationships through the following reduced system of equations

$$\begin{aligned} FR &= \lambda_1 WT + \lambda_2 P_{sc} + \lambda_3 BP - \lambda_4 W + \lambda_5 R^* + \lambda_6 OC \\ P &= \lambda_7 WT + \lambda_8 P_{sc} + \lambda_9 BP + \lambda_{10} W + \lambda_{11} R^* - \lambda_{12} OC \\ K &= \lambda_{13} WT - \lambda_{14} P_{sc} + \lambda_{15} BP + \lambda_{16} W + \lambda_{17} R^* - \lambda_{18} OC \end{aligned} \quad (2.12)$$

This system of simultaneous equations is used to determine freight rates, prices and the stock of fleet at any point in time in a stationary equilibrium state.

In order to derive the dynamic behaviour of ship prices and freight rates over time, Beenstock argues that the ship-owners' views of the future are important in the sense that they behave rationally and try to maximise wealth. In other words, they use all the available information to predict the future with a minimum error in order to maximise profit and minimise risk, as expected for any rational investor. Based on this assumption, he captures the behaviour of

ship prices over time by adding a time subscript to equations defined for the freight market, ship prices and fleet size. After some algebraic manipulations and simplifications, he derives the following dynamic equation for ship prices, which incorporates RE:

$$P_t = r_1 P_{t-1} + \theta_4 WT_t + \theta_4 (\delta_2 - 1) WT_{t-1} - \left(\frac{\theta_4 \gamma_s}{r_2} \sum_{i=0}^{\infty} r_2^{-i} [E_t(WT_{t+i+1}) + (\delta_2 - 1)E_t(WT_{t+i}) + (\delta_2 - 1)(E_{t-1}(WT_{t+i}) + (\delta_2 - 1)E_{t-1}(WT_{t+i-1}))] \right) \quad (2.13)$$

The above equation implies that, assuming RE in the market for ships, current ship prices depend on the prices of ships last period, the current and last period world trade activities, and a weighted average of the expected future world trade. It can be noted that if the world trade (or the expected world trade) does not change and remains constant, then ship prices will only depend on the current level of world trade as well as lagged world trade and ship prices. Determination of ship prices through equation (2.13) also allows for revision of the expectations and imperfect foresight through expected world trade.

The assumption of RE allows Beenstock to simulate ship prices under two distinct assumptions of anticipated and unanticipated shocks to the system. This is the main advantage of Beenstock's model compared to the one in Hawdon (1978), since there was no distinction between expected and unexpected shock in the market in the latter. Simulations performed clearly show the difference between the behaviour of the prices when the shocks are expected and when they could not be foreseen. He reports simulation results for a permanent 10% increase in world trade and its effects on ship prices under the two different assumptions of anticipated and unanticipated shocks. The reported results are quite interesting since they reveal that adjustment towards equilibrium is smoother and starts earlier when the shock is anticipated, although over shooting effect of the prices is greater than unanticipated shocks. Both markets will settle to equilibrium in the long run. Another table also reports the results of a simulation when the shock is assumed to be temporary. The reported results for the temporary shock also indicate similar smooth adjustments and over-shooting effects for anticipated shocks.

Despite his pioneering and innovative study, there are a number of issues, which remain unresolved in this model. First, the RE and efficient market hypothesis (EMH) in ship price formation are imposed and not tested explicitly. Secondly, the Beenstock (1985) model is a

highly aggregated model of the shipping industry in which shipping sectors and sub-markets are not distinguished. The market disaggregation is quite important since the assumption of RE may hold for some sub-markets or sectors and not the others. Also, aggregation over time, although it reflects the behaviour of variables in the long run, it does not capture the short run dynamics of ship prices which, as argued by the author, might be very important for speculative asset play. Finally, simulation methods in Beenstock (1985), although they reveal important information on the long run dynamics of ship prices, are sensitive to estimated coefficients and simulation period. This is particularly important when the stochastic behaviour of variables and model specifications are not taken into account.

In chapter 7, several tests are proposed and utilised to investigate the validity of the EMH in the formation of newbuilding and second-hand dry bulk prices, which take into account the stochastic properties of price series and other variables involved. In addition, the use of monthly size disaggregated data in the analyses in chapter 7 ensures that short run dynamics of variables are considered in the formation of ship prices. Furthermore, recently developed ARCH and GARCH techniques for modelling time-varying volatility are utilised to investigate the risk-return relationship in ship price formation.

2.3.2. Beenstock and Vergottis (1989a) “An econometric model of dry bulk shipping”

Beenstock and Vergottis (1989a) based on the Beenstock's theory of ship price formation, develop a disaggregated (tanker versus dry bulk) and interrelated model for world shipping in which freight rates, lay up tonnage, new and second hand prices and the size of the fleet are jointly and dynamically determined. In fact, this model can be deemed as an extension of the Beenstock (1985) model and is based on the same assumptions regarding the RE the EMH.

The framework consists of two main blocks, the shipping freight market and the market for ships, which are assumed to be in constant interaction with each other as well as the newbuilding and the scrap markets. The market for ships is further assumed to consist of three submarkets; namely, the newbuilding, the second-hand and the scrap markets. It is argued that these market are in constant interaction through variables such as freight rates, ship prices, etc. The RE and the EMH have been utilised in the two main blocks of the model. In particular, the authors hypothesise that time charter rates reflect RE of freight rates and

costs in the spot market. In the ship-building market, they treat ships as capital assets and assume that quoted prices to build new vessels reflect the RE of the price of a comparable vessel prevailing at the time of delivery adjusted for its condition and age characteristics. Finally, the demand to own vessels is hypothesised to depend upon the RE of the future price of second -hand vessels in the market.

One major difference between the Beenstock and Vergottis (1989a) model and previous studies such as Hawdon (1978) is the incorporation of the relation between spot and time charter rates in the industry model and the treatment of this relationship through RE. In this respect, the authors argue that time-charter rates, in contrast to spot rates, give the risk-averse shipowners the opportunity to hedge their position against adverse movements in the spot market through long term commitments. Second, in contrast to voyage contracts, in time-charter contracts the charterer incurs voyage costs, including bunker costs. Therefore, the ship-owner's profit in time charter contracts will be determined differently from his profit when operating in the spot market. The authors suggest that the relationship between time-charter and spot rates also lies in these two differences. Using the RE assumption, they argue that the first difference implies that future spot rates will influence the current time-charter rates. The second difference implies that future voyage costs (bunker prices) are also important factors in determining current time-charter rates. Therefore, they propose the following forward-looking relationship for spot rates, time charter rates and bunker prices:

$$TC_t = f(E_t \overset{+}{FR}_{t+1}, E_t \overset{-}{BP}_{t+1}, \overset{-}{LU}_t) \quad (2.14)$$

where TC_t are assumed to be one-year time charter rates², $E_t \overset{+}{FR}_{t+1}$ and $E_t \overset{-}{BP}_{t+1}$ are expected spot rates and fuel prices for next period, respectively. LU_t , which represents the lay up rate, is assumed to be a proxy for the time-varying risk premia. The authors find that estimated coefficients have the right sign, but the coefficient the lay up rate, LU_t , is not significant.

It can be argued that once again, in the above formulation of the relationship between spot and period rates, not only the stochastic properties of the series are not taken into account, the model fails to explain the spot and period rates appropriately (see chapter 5 for details of the

² Since the authors use annual data, one period ahead means next year and time charter rates are annual.

correct relationship between spot and time-charter rates). Furthermore, the use of lay up rates as a proxy for time-varying risk in the relationship is debatable since lay up rate only represent the risk of unemployment and not other differences that exist between spot and time-charter contracts such as fluctuations in bunker prices, relocation costs, etc.

2.4. The Expectations Hypothesis and the EMH in Freight Markets

One of the most important and interesting areas in shipping economics is the relationship between short and long term charter rates. Uncovering the true nature of the relationship between short and long term rates and the determination of period rates have important implications both for practitioners and academics. Such implications include chartering, operational and investment strategies as well as modelling freight rate movements and risk return relationships in shipping operations. Different forms of expectations hypothesis are proposed and tested for in the literature to explain and model long term freight rates. The following section aims to discuss these studies in a chronological order and highlight their shortcomings.

2.4.1. Zannetos (1966) “Theory of oil tank shipping rate”

In his seminal work on the tanker shipping industry Zannetos (1966) extensively analyses the tanker freight rate formation and distinguishes between the determination of spot and time charter rates, for the first time. He initially investigates the ownership structure of the world tanker fleet. He finds that tanker ownership has undergone a transition during the 1950's. This was due to the fact that major oil companies reduced their proportion of ownership of the world fleet following the nationalisation of oil fields and production in oil producing states, while individual shipowners were attracted more and more to this market. Zannetos shows that the chartering strategies of the oil companies changed statistically, from long-term charter contracts to short-term or spot contracts during the period 1950-1959 as a result of the uncertainty surrounding the petroleum market and the associated tanker industry. He then argues that the transition in the tanker business changed the oligopolistic structure of the market to a market with a large number of participants, which implied moving towards conditions of perfect competition.

Once conditions of perfect competition in the market for ocean petroleum transportation are discussed and established, Zannetos focuses on the theory of “*elastic expectations*” in freight formation. The main argument behind this theory is based on the behaviour of the owner and charterers once there is a change in freight rates. Zannetos’ (1966) “*elastic expectations*”

theory of freight rate formation states that, once the market shows a slight increase in freight rates, charterers try to fix their tonnage requirement as quickly as possible in order to avoid further freight rate increases, while shipowners are reluctant to hire their vessels because they expect freight rates to increase further. Therefore, the increase in demand coupled with the reduction in supply will cause a further surge in the market. Similarly if there is a slight decrease in freight rates shipowners try to fix their vessels as soon as possible to avoid lower freight rates, while charterers are reluctant to commit themselves since they wait for rates to drop more; as a result, freight rates decrease further.

Zannetos (1966) also points out the similarities and differences between money markets and tanker shipping markets in terms of the relationship between contracts with different terms to maturity. He argues that long term shipping rates should be equal to the arithmetic average of the current spot rate and the expected spot rate over the life of the long term contract, provided that there is no uncertainty in the market. The fact that long term rates are a weighted average of current and future spot rates implies less fluctuations in long term rates compared to short term rates. He also mentions that if the latter assumption (uncertainty in the market) is relaxed, long term rates might differ from the arithmetic average of the series of spot rates for the following reasons. First, the risk involved in spot market operation is higher compared to time-charter operation as there is always a risk that the vessel does not find employment for a period of time or need to be relocated for commencement of the next contract. Second, there are higher costs, paperwork and administration involved in negotiating and fixing frequent and successive short term contracts compared to long term contracts. Finally, the mortgage value of long term contracts, from the financiers' point of view, is considered to be an important factor in explaining the difference between spot and long term time-charter rates. This is because financiers prefer to see the security of shipowners' revenue when negotiating a loan. As a result, shipowners might accept lower rates for longer term time-charter contracts compared to prevailing short term spot contracts in order to fulfil this requirement to finance a new purchase.

Despite the correct theoretical argument on the relationship between spot and time-charter rates, Zannetos (1966) did not formulate such a relationship in an appropriate statistical framework. He assumes that time-charter rates are formed through a series of expected spot rates, but he does not explicitly and statistically test the validity of such assumption. In fact,

he investigates the formation of time-charter rates under the “*elastic expectations*” assumption by relating spot and time charter rates using the following equation;

$$TC = f(FR, dTC, LTC, VS, LU, OR, E\Delta FR, TY, CAR) \quad (2.15)$$

where

FR = current spot rates, (monthly index)	dTC = duration of time-charter contract,
VS = vessel size,	LU = laid up tonnage,
OR = tonnage on order,	TY = vessels' propulsion type,
CAR = and the type of cargo,	LTC = lead time to the commencement of
EΔFR = expected value of the index of short term rate adjustment,	the time-charter contract.

In order to make the long term and short term rates comparable, Zannetos converts time charter rates to spot rate equivalents³. He also assumes that variables such as the laid up tonnage and order book are proxies for future market risk. In order to construct the index of short term adjustment, he uses a weighted average (with geometrically declining weights) of changes in spot rates as a representative of the expectations in the market.

$$E_t \Delta FR_{t+1} = \frac{1}{2} \Delta FR_t + \frac{1}{4} \Delta FR_{t-1} + \frac{1}{8} \Delta FR_{t-2} + \frac{1}{16} \Delta FR_{t-3} \quad (2.16)$$

Using OLS and pooled cross section and time series data for the period 1950 to 1959, Zannetos estimates equation (2.15) over different time periods within the sample at which freight rate levels were above and below the average freight rate over the sample period.

The regression results show that long term rates are positively related to the current spot rates, the size of the vessel and the size of the orderbook. However, the coefficient of the index representing expected changes in spot rates is negative, indicating that long term rates, under both high and low market conditions, are negatively related to expected changes in spot rates. This finding is not consistent with the elastic expectations theory, as they suggest that an expected positive (negative) change in spot rates will result in a drop (rise) in long term rates. Zannetos does not provide an explanation for this inconsistency between his theory and results.

³ Zannetos converts time charter rates which are normally expressed in \$/month into spot rate equivalents (\$/ton-mile) under certain assumptions such as distance, speed, fuel consumption and other vessels specifications.

This might be due to the following reasons. First, including variables such as vessel size, time-charter duration, the orderbook and laid up tonnage, which may pick up the effect of market conditions, distort the results and obscure the true relationship between spot and time-charter rates. Furthermore, the relationship between long and short term rates for smaller vessels might not be the same as the relationship between the rates in the market for larger vessels. This can also affect the results since different relationships between period and spot rates for small and large vessels may offset each other. One way to overcome this problem is to differentiate data according to size and duration of contract, as in this thesis.

Second, Zannetos finds a positive relationship between the level of period rates and the orderbook, which is not in line with economic theory. According to the theory, high order book levels suggest an increase in supply of shipping services in the near future, which in turn suggests that there will be an over supply and freight rates may decrease. Thus, time-charter rates should decrease since they reflect future profitability in the spot market.

Finally, the term structure relationship between short term and long term rates is not specified appropriately in the regression equation. More precisely, according to Zannetos' own argument of the term structure relationship, long term rates should represent a weighted average of the current and expected spot rates over the life of the long term rates. Despite his correct theoretical argument, he includes the expected one-period ahead change in spot rates in the regression model rather than a series of them.

Nevertheless, Zannetos' results are consistent with the elasticity variant supply schedule model of Koopmans presented earlier. For example, his results suggest that the response of time-charter rates to expected changes in the spot market is greater during market recovery compared to periods of market downturn. Therefore, it can be argued that the availability of tonnage during periods of prosperity and depression could be mixed with the "*elastic expectations*" theory. In other words, asymmetric responses of time-charter rates to its determinant under different market conditions might be due to the shape of the supply curve for shipping services and not due to the "*elastic expectations*" theory.

2.4.2. Glen, Owen and Van der Meer (1981) “Spot and time charter rates for tankers”

This study investigates the relationship between spot and time charter rates in the tanker market. The authors first investigate the trend in the tanker market towards shorter time charter contracts during the 1970's and the fact that charterers were becoming more and more interested in short term contracts (a sign of uncertainty in the tanker market). It is also noticed that the lay up rate had increased substantially in that period. They document that the charter rates and time series behaviour of time charter rates are quite different across vessel sizes (a sign of market differentiation by size). Glen et al derive a present value relationship between spot and time charter rates using the revenue and cost relationships in different types of contracts. This is based on the assumption that the owner should be indifferent in operating under a time-charter contract or a series of voyage charters with the same duration as the time-charter contract subject to a constant risk premium as follows;

$$TC_t = \sum_{i=t}^T \alpha_i [E_t FR_i - E_t VC_i] + \phi \quad (2.17)$$

where TC_t = time charter revenue for period t to T ϕ = constant risk premium
 $E_t FR_i$ = expected spot rate for voyage i at time t α_i = coefficient determined by the discount rate
 $E_t VC_i$ = expected voyage cost for voyage i at time t

They assume that expectations are based on the past behaviour of variables (i.e. the information available to agents) and suggest the following equations for the formation of expected freight rates and voyage costs,

$$E_t FR_{t+m} = \sum_{i=0}^{\infty} (\beta_{1,i}^{(m)} FR_{t-i} + \beta_{2,i}^{(m)} VC_{t-i} + \beta_{3,i}^{(m)} OC_{t-i} + \beta_{4,i}^{(m)} CC_{t-i}) + v_t \quad ; \quad v_t \sim iid(0, \sigma_v^2) \quad (2.18)$$

$$E_t VC_{t+m} = \sum_{i=0}^{\infty} (\delta_i^{(m)} VC_{t-i}) + w_t \quad ; \quad w_t \sim iid(0, \sigma_w^2) \quad (2.19)$$

where VC_t , OC_t and CC_t , are the voyage, operation and capital costs, respectively⁴, and FR_t represents spot rates. It can be seen that an important source of information, i.e. the history of time-charter rates, in the formation of expected spot rates is missing. This is important since

⁴ There are mainly three types of costs involved in shipping operation. i- Capital costs are considered as the repayments of the loan with which the ship is purchased. ii- Operation costs are those costs for the day to day operation of the ship whether the ship is idle or active (crew wages, maintenance, etc.). iii- Voyage costs are those costs which are incurred in a certain voyage such as canal and port dues, bunker costs, etc. [for more details, see chapter 1 of this thesis or Stopford (1997)].

spot and time-charter rates are related (see chapter 5 for more details), which means that time-charter rates can be used in predicting future spot rates. This implies that the information set, which is used to form expectations on future spot rates, is not fully utilised and therefore the expectations are not rational. Glen et al (1981) propose the following equation for investigating the relationship between spot and time charter rates;

$$TC_t = \sum_{i=0}^{\infty} (\delta_{1,i}FR_t + \delta_{2,i}VC_{t-i} + \delta_{3,i}OC_{t-i} + \delta_{4,i}CC_{t-i}) + \phi + u_t \quad ; \quad u_t \sim iid(0, \sigma_u^2) \quad (2.20)$$

However, instead of estimating the above equation, they use a more simplified version due to unavailability of data on cost components. In fact, they estimate equation (2.21) using spot rates, which are reported on Worldscale basis, and Worldscale equivalents of time-charter rates.

$$TC_t = \sum_{i=0}^{\infty} \mu_i FR_{t-i} + \phi + u_t \quad u_t \sim iid(0, \sigma_u^2) \quad (2.21)$$

They report the results of estimating the above equation using quarterly data for a short period (1970 to 1977). Handysize tanker rates are used and the number of lags in each equation is adjusted to improve the goodness of fit in the model.

Table 2.1: Results of Glen et al (1981) model

		$TC_t = \sum_{i=0}^{\infty} \mu_i FR_{t-i} + \phi + u_t \quad u_t \sim iid(0, \sigma_u^2)$		
Degree of Polynomial		2	3	3
Constant ϕ		5.2622	-13.99	-13.96
μ_0	r_t	0.3803**	0.3791**	0.3341**
μ_1	r_{t-1}	0.2625**	0.2762**	0.2842**
μ_2	r_{t-2}	0.1693**	0.1912**	0.2172**
μ_3	r_{t-3}	0.1007**	0.1240**	0.1445**
μ_4	r_{t-4}	0.0567**	0.0746**	0.0774**
μ_5	r_{t-5}	0.0373**	0.043**	0.0274*
μ_6	r_{t-6}	0.0425	0.0295**	0.0057
μ_7	r_{t-7}		0.0337*	0.0237
μ_8	r_{t-8}		0.0558*	0.0929**
R-bar squared		0.92	0.96	0.9621
Durbin-Watson test		1.025	1.66	1.91
Standard error of regression		15.561	11.29	10.98

• Source: Glen et al (1981);

• * and ** indicate significance at the 10% and 5% levels, respectively.

Their estimation results reveal that the risk premium is negative but not significant in two out of three of regressions. They attribute this to the fact that shipowners might prefer secure long-term contracts to short-term risky contracts. The authors also argue that the negative sign of the risk premium might be due to the prevailing market conditions in the 1970's (estimation period). This does not seem to be the correct interpretation since when the tanker market is expected to improve (during oil crises in the 1970's), optimistic owners are not willing to commit themselves to long-term contracts. As a result, there will be a short supply in the time-charter market, while charterers' rush to fix long term contracts increases the demand for long term contracts, which in turn causes time-charter rates to increase and get closer to spot rates.

Glen et al (1981) also mention that data restrictions and turbulent markets during the 1970's were obstacles in their investigations since abnormal behaviour of the market during this period may have affected the results. This suggests that more insight to the relationship between spot and time charter rates can be obtained by using disaggregated and longer data series.

In addition to statistical issues regarding the use of nonstationary variables in regression models there are also other theoretical issues, which remained unresolved in this study. For instance, the validity of the expectations hypothesis of the term structure (EHTS) which relates the spot and time-charter rates, equation (2.17), in this context is another subject for debate. This is because the authors do not attempt to test the validity of the EHTS explicitly. Instead, they assume that the EHTS is valid and try to find the best fit (lag structure) for the model, which is proposed to explain the relationship and infer on the form of the expectations through the shape of the lag structure. The lag structure observed by Glen et al (1981) is argued to be different from what is suggested by Zannetos' (1966) elastic expectations hypothesis. In Zannetos' model, the elastic expectations suggests that at least the first lagged freight rate coefficient should be positive and greater than one, while Glen et al (1981) find coefficients of the lagged structure to be less than one. In fact, empirical results of Glen et al (1981) reject the elastic expectations theory of Zannetos in the formation of period rates and suggest that some form of exponentially declining weights provide a reasonable explanation of the formation of expectations.

2.4.3. Binkley and Bessler (1983) “Expectations in bulk ocean shipping; An application of autoregressive modelling”

Binkley and Bessler (1983) analyse the role of expectations of shipping agents in ocean freight rate determination. They compare charter contracts of different duration (voyage charters versus time charters) and hypothesise that the effect of expectations on rate determination would vary with the duration of employment. In other words, their main argument is that as the duration of the charter contracts increases, more weight will be put on the expected future market conditions (rates and costs) than the current market conditions. Following Zannetos’ suggestions on the “*elastic expectations*”⁵ in the tanker market, Binkley and Bessler define an autoregressive equation for monthly dry cargo time charter and voyage charter rates, for the period 1973 to 1981, to test and compare the effect of expectations on freight rate determination. Binkley and Bessler try to find the optimum lag length in each case and report the following regression results using aggregate dry bulk time-charter (less than one year) and single voyage charter rates series for the period of January 1973 to October 1981 on a monthly basis.

$$\begin{array}{l}
 \text{t-stat} \quad FR_t = 11.89 + 0.946 FR_{t-1} + 0.165 FR_{t-5} - 0.185 FR_{t-8} \quad R^2=0.953 \\
 \quad \quad \quad (2.82) \quad (19.63) \quad (2.65) \quad (-4.31) \quad (2.22)
 \end{array}$$

$$\begin{array}{l}
 \text{t-stat} \quad TC_t = 12.29 + 1.550 TC_{t-1} - 0.846 TC_{t-2} + 0.352 TC_{t-3} - 0.069 TC_{t-13} \quad R^2=0.976 \\
 \quad \quad \quad (2.46) \quad (15.53) \quad (-5.14) \quad (3.15) \quad (-2.77) \quad (2.23)
 \end{array}$$

where figures in brackets are t statistics. Estimation of the above autoregressive models revealed that there is a significant difference between the dynamics of these two types of freight contracts in terms of their dependence on their past values. In fact, the authors find that both spot and time-charter rates are dependent on the recent past values, but the effect of past spot rates on current spot rates dies out more smoothly than the effect of past time-charter rates on current time-charter rates. In fact, the response of time-charter rates to their lagged values is characterised by sharp oscillations; that is, a positive first lagged coefficient, which is greater than one followed by a negative second lagged coefficient, which is close to one. Although, there are statistical issues regarding the use of nonstationary time series in

⁵ Zannetos argued that if the rates are rising, then charterers try to fix their tonnage requirement to avoid higher rates which itself helps the market to rise further. On the other hand when the rates are dropping shipowners try to hire their vessels to avoid future drops while charters are waiting for lower rates. This will lower the rates even further.

estimating AR models in this study, Binkley and Bessler conclude that the results are consistent with Zannetos' "*elastic expectation*" hypothesis. This is because the coefficient of the first autoregressive term in the time-charter equation is found to be greater than one, which means that participants in this market overreact to recent developments in the market.

They also argue that their results provide an explanation for the existence of high instability (volatility) in the time-charter market, which again is not consistent with the term structure relationship in the formation of time-charter rates and the evidence in the literature (e.g. Kavussanos, 1996a). According to the term structure relationship, time-charter rates are a weighted average of current and expected future spot rates, therefore, they are bound to be smoother than spot rates. The authors left the question of which type of expectations, i.e. adaptive or rational expectations, is appropriate in formation of freight rates, as a suggestion for further research.

The Binkley and Bessler (1983) study suffers from a number of shortcomings. First, they do not consider the univariate properties of shipping freight rate series, in terms of stationarity and periodicity in order to avoid issues such as spurious regression results, incorrect model specifications and misleading inferences. Secondly, they use size aggregated data, which may distort the results and affect the conclusions about the role and nature of the expectations in the shipping markets, since freight rates in the disaggregated markets may behave differently⁶. Third, they do not consider the dynamic interrelationship between spot and time-charter rates. This means that they use a limited information set (history of time-charter (spot) rates for time-charter (spot) rate determination) which may result in biases due to omitted variables in the regressions. Finally, their sample period covers a short and turbulent period (1973 to 1981) in which the shipping industry was affected by two major oil crises and other political events such as the Iranian revolution and the Iran-Iraq war. Such external factors can influence shipowners' and charterers' expectations, decisions and pricing strategies outside the normal market behaviour.

⁶ See, for example Kavussanos (1996), Berg-Andreassen (1997) and Chapter 4 of this thesis for more details on univariate behaviour of freight rates for different size dry bulk carriers.

2.4.4. Strandenes (1984) “Price determination in the time-charter and second-hand markets”

Strandenes (1984) investigates the relationship between spot and time charter rates in the dry bulk (panamax) and tanker markets (medium and large tankers) for the period 1968 to 1981 using annual data. Utilising a present value relationship between long and short term rates and semi-rational expectations, the author proposes a model for the determination of period rates.

Semi-rational expectations implies that agents believe that period rates adjust towards the long run equilibrium rates at a rate which depends on the current market conditions and trend. Therefore, agents are expected to use a weighted average of expected long term equilibrium and current rates in determining period rates, where these weights may change depending on how far the current rates are from the long term equilibrium rates.

Strandenes (1984) derives a linear relationship between period rates and levels of current spot and long run equilibrium rates. She defines long run equilibrium rates as the level of freight rates, which provide a reasonable return on a shipping investment at any point in time. These are freight rates necessary to obtain a normal profit on newbuilding vessels, where this is assumed to be 5%.

$$TC_t^n = \phi(\alpha FR_t + \beta LFR_t) + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon) \quad (2.24)$$

where LFR_t are long run equilibrium rates and ϕ is a risk premium. She also mentions that there should be a negative relationship between the duration of the contract, n , and the importance of current freight rates, α , in the formation of long term rates. This means that as the duration of the period contract increases, current spot rates become less important in determining long term rates. Another point made by Strandenes (1984) is that, if there is perfect foresight about the market, then the coefficients in (2.24) should sum to one as agents can accurately price time-charter rates. A sum of coefficients less than unity indicates the existence of a risk premium, which forces period rates below the weighted average of current and long run equilibrium rates. She also points out that the risk premium should increase with the duration of the contract. This is because as plans stretch further into the future,

uncertainty increases. Therefore, the sum of coefficients should be negatively related to the duration of period rates.

In order to make freight rates comparable for estimation, Stranden (1984) transforms spot rates for panamax dry bulk carriers, and medium and large tankers into their time-charter equivalents. She then calculates the long run equilibrium rates and estimates the model using 1 to 12 months, 13-36 months and more than 36 months charter rates for each size category. The following table presents her estimation results.

Table 2.2: Results of the Stranden (1984) model of the term structure relationship

Duration in months	Panamax Time-charter rates			Medium Tankers time-charter rates			Large Tankers Time-charter rates		
	1-12	13-36	36+	1-12	13-36	36+	1-12	13-36	36+
FR _t α'	0.5644 (0.053)	0.3066 (0.063)	0.1609 (0.087)	0.5969 (0.211)	0.4655 (0.112)	0.2564 (0.0658)	0.7090 (0.085)	0.5341 (0.087)	0.2077 (0.074)
LFR _t β'	0.3779 (0.060)	0.5385 (0.072)	0.4303 (0.149)	0.4357** (0.318)	0.5112 (0.169)	0.6955 (0.099)	0.3090* (0.139)	0.4108 (0.142)	0.6762 (0.121)
\bar{R}^2	0.93	0.80	0.71	0.51	0.73	0.77	0.92	0.87	0.68

- Source: Stranden (1984)
- Figures in () are standard errors,
- $\alpha' = \phi\alpha$ and $\beta' = \phi\beta$,
- ** and * indicate that coefficients are not significant at the 5% and 2.5% level, respectively.
- Estimation period; Panamax bulk carriers 1968-1981, Medium size tankers 1969-1981, Large tankers 1970-1980.

She finds that as the duration of the contract increases, the importance of current freight rates decreases, while the impact of long run equilibrium rates increase. Also, the sum of the coefficients appear to be less than unity in each case, which is an indication of the existence of a risk premium, which decreases as the duration of the charter contracts increase. That is, time-charter rates decrease as contracts become longer, which in turn means that shipowners are prepared to accept longer charter rates at lower rates because of their security. Stranden (1984) also finds a negative relationship between the duration of charter contracts and the sum of the coefficients in the panamax market, which is in line with the existence of risk premia in formation of period rates. However, such relationship is found to be positive in the case of medium and large tanker markets (considering the significance of estimated coefficients); that is, the sum of the estimated coefficients increases with the duration of charter contract. However, this inconsistency is not explained.

Strandenes' study is interesting in the way that time-charter rates are related to spot rates through the specification of current and long run equilibrium rates. However, shortcomings of this study are as follows. First, the stochastic properties of freight rate series are not considered and the dynamic interrelationship between long term and short term contracts has not been incorporated in the model⁷. This is important since, as it will be shown in chapter 5, time charter and spot rates are both nonstationary series which interact with each other both in the short and the long run. Therefore, an appropriate approach is to use cointegration techniques to analyse the relationship between these two types of freight contracts. Second, use of annual data may eliminate the short term dynamics of freight rates in the model, which are thought to be important in the determination of short to medium term time-charter rates. Third, the investigation is performed over a short sample period (1969-1981) during which the tanker market experienced a turbulent period due to the two oil crises and other political events. This may affect the results as expectations are formed according to the prevailing turbulent market conditions. Finally, the existence of the risk premium in the formation of time-charter rates is considered in an indirect way and is assumed to be constant, which restricts the relationship between the two freight rates.

In chapter 5, in addition to formally testing the term structure relationship between spot and period rates using appropriate statistical tests, we show a more complete approach to investigating the existence of time-varying risk premia in the formation of period rates, using the recently developed EGARCH-M models.

2.4.5. Vergottis (1988) "An econometric analysis of world shipping"

Vergottis (1988. Ch.7) argues that if expectations are rational, then time-charter rates should reflect future spot rates, measured as time-charter equivalents (weighted average of a series of spot rates converted to their time-charter equivalents). He then uses the above argument to investigate the validity of RE and the EMH in the formation of time-charter rates in the dry cargo sector. For this purpose, he estimates the present value of excess earnings from an n

⁷ This is because the econometric techniques, which take into account the stochastic properties of variables, were not established at that time.

period time-charter contract over the present value of expected earnings from a series of one period spot contracts which span over the life of the time-charter contract. Mathematically

$$u_t = \sum_{i=0}^{n-1} \frac{TC_t^n}{d_{t,i}} - \sum_{i=0}^{n-1} \frac{E_t FR_{t+i}}{d_{t,i}} \quad , \quad d_{t,i} = \prod_{j=0}^i (1 + r_{t+j}) \quad (2.25)$$

or

$$u_t = \sum_{i=0}^{n-1} \frac{TC_t^n - E_t FR_{t+i}}{d_{t,i}} \quad (2.26)$$

where TC_t^n represents n period charter rates at time t , $E_t FR_{t+i}$ is the expected voyage charter rate for period $(t+i)$ at time t . Vergottis (1988) argues that since u_t is a weighted average of forecast errors of future earnings from the short term (spot) contracts, according to the RE and the EMH, u_t should be orthogonal to the information set available at time t .

He defines a test based on the equality of terms on the RHS of (2.25), which assumes that agents have a perfect foresight of how rates are formed. The following regression is estimated using quarterly rates for four size categories of dry cargo vessels (10,000-20,000 dwt, 20,000-35,000 dwt, 35,000-50,000 dwt and 50,000-85,000 dwt).

$$V_t^{FR} = a + bV_t^{TC} + u_t \quad (2.27)$$

where V_t^{FR} is the discounted present value of earnings from a series of short term contracts and V_t^{TC} is the discounted present value of earnings from time-charter contracts. Therefore, for the joint hypothesis of RE plus EMH to hold, $a=0$ and $b=1$.

Table 2.3: Results of the Vergottis (1988) model of the term structure relationship in the dry bulk sector

$V_t^{FR} = a + bV_t^{TC} + u_t$				
Vessel Size	10,000-20,000 dwt	20,000-35,000 dwt	35,000-50,000 dwt	50,000-85,000 dwt
a	0.71 (0.45)	0.52 (0.29)	0.77 (0.25)	0.47 (0.45)
b	0.81 (0.13)	0.85 (0.10)	0.75 (0.09)	0.83 (0.10)
<i>Wald test</i>	5.891	7.465	16.383	5.592
$H_0: a=0, b=1$	[0.053]	[0.024]	[0.000]	[0.061]
<i>t-test</i>	1.446	1.558	2.705	1.628

$H_0: b=1$	[0.155]	[0.126]	[0.009]	[0.110]
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- Source: Vergottis (1988)
- Figures in () are standard errors.
- Wald test is the test for the restriction of $a=0$, $b=1$ on parameter estimates with a $\chi^2(2)$ distribution.

Table 2.3 shows the estimation results. They do not seem to support the joint hypothesis of RE plus EMH at the 10% level in the case of small dry cargo carriers and capesize bulk carriers, and at the 5% level in the case of handysize dry cargo carriers and panamax bulk carriers. Vergottis suggests that failure of the RE+EMH might be due to the existence of non-zero risk premia; i.e. $a \neq 0$, and examines a weaker hypothesis by testing whether b equals one when a is unrestricted using a t-test. Results of the t-test seem to support the weaker form of the RE+EMH, under the assumption of constant risk premia, in every case except for the panamax sector. He also finds that the residuals are not serially correlated, providing further support for the weak form of the EMH.

Although, Vergottis (1988) provides the correct framework to investigate the expectations hypothesis of the term structure in the determination of period rates, he does not consider the stochastic properties of these freight rate series. As a result, inferences on regression results may not be valid. Moreover, he argues that the risk premium, which relates spot to period rates in equation (2.27), is constant. This seems to be restrictive since shipping markets are known to be volatile and the volatility of shipping markets, on which the risk premia might depend, has been documented in the literature to be time-varying (see Kavussanos 1996).

2.4.6. Hale and Vanags (1989) “Spot and period rates in the dry bulk market”

Hale and Vanags (1989) question the validity of the assumption of RE and EMH in the formation of long term shipping rates, imposed in the earlier studies such as Beenstock and Vergottis (1989a and b). Using the analogy of the spot and time-charter rates in shipping markets to short and long term bonds, Hale and Vanags also propose a present value model, initially used in financial markets analysis⁸, to formulate the relationship between spot and time charter rates in the following way

$$TC_t^n = \theta \sum_{i=0}^{n-1} \delta_i E_t FR_{t+i} + \phi \quad (2.28)$$

where ϕ represents a constant risk premium, and δ_i and θ are a constant discount factor and a constant factor of proportionality, respectively. Similar to Vergottis (1988), the above equation postulates that a risk neutral shipowner should be indifferent between accepting a time charter contract with n period duration and a series of voyage charters during that period. This arises from the assumption that in international shipping, rational shipowners try to arbitrage away any profitable opportunities that may exist between these two types of contracts. For example, if operating the vessel in the time-charter market is more profitable than the spot market, then shipowners with open vessels switch to the time-charter market, creating a shortage of supply in the spot market and an increase of supply in the time-charter market. As a result, spot rates rise while time-charter rates fall. This process can be reversed when operating in the spot market is more profitable than the period market. This means that both spot and time-charter freight rates are in constant interaction and move towards an equilibrium condition in which there is no arbitrage opportunity.

Hale and Vanags (1989) reparameterise the spot-time-charter relationship of equation (2.28), based on the study by Mankiw and Summers (1984) on interest rates, to obtain the following equation, which can be estimated by imposing RE,

$$\Delta TC_t^a = \alpha_0 + \alpha_1 S_{t-1} + \alpha_2 (FR_{t-1} - E_{t-1} FR_{t+n-1}) + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.29)$$

where $\alpha_1 = (1-\delta)/\delta$ is the coefficient of the spread term, $\delta = 1/(1+r)$ is the discount factor, r is the constant discount rate and S_{t-1} represents the spread between voyage and time-charter rates. Hale and Vanags (1989) use the spot equivalent of time charter rates⁹ and argue that for the joint hypothesis of RE and the term structure relationship to hold, the coefficient of the spread, α_1 , should be positive and different from zero. This is because, based on the Mankiw and Summers (1984) argument on interest rates, time-charter (long term) rates should respond positively to any disequilibrium between spot (short term) and time-charter (long term) rates.

⁸ See chapter 5 of this thesis for more details on present value models of long term and short term rates.

⁹ Spot equivalent of time charter rates could be obtained by adjusting the time charter rates for the voyage costs in certain routes for the duration of time charter. Hale and Vanags (1989) obtained the spot equivalents from Lloyds Shipping Economist unpublished data (see chapter 1 for more details).

Since the expected values of $E_{t-1}FR_{t+n-1}$ are not readily available, the authors use three different methods to estimate equation (2.29). First, they assume that agents have perfect foresight knowledge on how the rates will behave, and therefore, actual freight rate values (FR_{t+n-1}) are used instead of expected values ($E_{t-1}FR_{t+n-1}$), equation (2.29a). Second, an autoregressive model, which incorporates the full information set (lagged values of FR_{t-i} , and TC_{t-i}), is used to predict the expected voyage charter rates, denoted FR^*_{t+n-1} , which are then used equation (2.29b). Finally, a random walk model, which asserts that the best forecast for future spot rates is the last period spot rates ($E_{t-1}FR_{t+n-1}=FR_{t-1}$), is used to predict future freight rate levels. This leads to elimination of the last term, and therefore they estimate equation (2.29) using only the spread as the independent variable, equation (2.29c).

Hale and Vanags (1989) use monthly spot equivalents of time charter rates in order to make the units of measurements of the variable in equations (2.29a), (2.29b) and (2.29c) comparable and estimate the following regression for 3 size categories of dry bulk carriers.

$$\Delta TC_t^{12} = \alpha_0 + \alpha_1 S_{t-1} + \alpha_2 (FR_{t-1} - FR_{t+1}) + \varepsilon_{1,t} \quad ; \quad \varepsilon_{1,t} \sim iid(0, \sigma_{\varepsilon_1}^2) \quad (2.29a)$$

$$\Delta TC_t^{12} = \alpha_0 + \alpha_1 S_{t-1} + \alpha_2 (FR_{t-1} - FR^*_{t+1}) + \varepsilon_{2,t} \quad ; \quad \varepsilon_{2,t} \sim iid(0, \sigma_{\varepsilon_2}^2) \quad (2.29b)$$

$$\Delta TC_t^{12} = \alpha_0 + \alpha_1 S_{t-1} + \varepsilon_{3,t} \quad ; \quad \varepsilon_{3,t} \sim iid(0, \sigma_{\varepsilon_3}^2) \quad (2.29c)$$

Estimates of these models are reported in Table 2.4.

Table 2.4: Results of the Hale and Vanags (1989) model of the EHTS

	Model (2.29a)			Model (2.29b)			Model (2.29c)	
Coefficients	α_0	α_1	α_2	α_0	α_1	α_2	α_0	α_1
Handysize	1.797 (2.893)	-0.315 (-3.752)	-0.095 (-0.935)	1.980 (3.173)	-0.339 (-3.986)	-0.177 (-2.123)	0.738 (3.073)	-0.193 (-4.654)
Panamax	0.035 (1.374)	-0.077 (-1.620)	-0.095 (-0.935)	0.348 (0.987)	-0.094 (-1.822)	-0.005 (-0.078)	0.328 (1.412)	-0.110 (-2.590)
Capesize	-0.035 (-0.242)	0.032 (0.416)	-0.117 (-0.117)	-0.136 (-1.157)	0.052 (0.739)	-0.080 (-2.755)	-0.111 (-0.908)	0.012 (0.170)

- Source: Hale and Vanags (1989).
- Figures in () are standard errors.
- Estimation period; October 1980 to December 1986.

It can be seen that the results are mixed and in general do not support the joint hypothesis of term structure and RE for small and medium size dry bulk carriers during their sample period (1980 to 1987). For example, the estimated coefficient of the spread, α_1 , which is argued to be positive for the joint hypothesis of RE and the term structure relationship to hold¹⁰, is negative in every handysize and panamax model and not significantly different from zero in all capesize regressions. The authors conclude that this failure might be due to one of the following reasons. First, inadequacy of the term structure relationship model in explaining the relationship between spot and time-charter rates. Second, they state that since in the joint hypothesis testing the RE in freight rate formation is set a priori, the failure might be due to the existence of time-varying risk premia, which they do not attempt to model.

Although, Hale and Vanags (1989) implicitly consider the stochastic properties of freight rates¹¹, their term structure model of equation (2.29) does not seem to be appropriately re-parameterised to investigate the validity of the hypothesis using appropriate parameter restrictions. In addition, the authors base their testing methodology on the present value relationship between spot and time-charter rates, but fail to provide an intuitive as well as a mathematical link between the hypothesis that they test ($\alpha_1 > 0$) and the validity of the EMH in the formation of period rates.

A correct re-parameterisation of the term structure model in the formation of period rates is given in chapter 5 (see appendix 5.A and 5B), which allows testing of the theory through the imposition of parameter restrictions. It can also be argued that the results of Hale and Vanags (1989) might be subject to some period specific bias, since their sample period covers only a short period in which the shipping industry was experiencing one of the worst recessions (1982 to 1986).

¹⁰ The restriction on the coefficient of the spread ($\alpha_1 > 0$) is implied by the fact that this coefficient is related to the discount factor since $\alpha_1 = (1-\delta)/\delta$ and $\delta = 1/(1+r)$. Therefore, an estimate of $\alpha_1 < 0$ implies an implausible discount factor, which in turn rejects the validity of the theory.

¹¹ Hale and Vanags (1989) use first difference of time-charter rates as the dependent variable and spread between time-charter and spot rates, and differences of spot rates as independent variables. If time-charter and spot rates are $I(1)$ variables (see chapter 4 and 5), then first difference of these variables are $I(0)$, and the spread between the two series might be $I(0)$, provided that they are cointegrated. However, they do not present any formal test for the degree of integration and cointegration between spot and time-charter series they use.

2.4.7. Berg-Andreassen (1997a) “The relationship between period and spot rates in international maritime markets”

In a recent study, Berg-Andreassen (1997a) investigates the validity of a number of hypotheses proposed in the literature for the relationship between spot and period rates. He argues that in order for an expectations hypothesis in the formation of the time-charter rates (elastic, adaptive, rational, etc.) to be valid, the variables in the equation which determines the period rates should be cointegrated. He presents the following formulations for all the hypotheses proposed in the literature for the formation of period rates and tests the validity of each using the Johansen (1988) cointegration technique.

- 1) Zannetos’ “elastic expectations” hypothesis, which assumes that time-charter rates on a \$/dwt/month basis is a function of current spot rates and changes in spot rates

$$TC^*_t = a_0 + a_1 FR_t + a_2 \Delta FR_t + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.30)$$

where, TC^*_t represents time-charter rates in \$/dwt/month.

- 2) the lagged elastic expectations hypothesis, in which variables on the RHS of (2.30) are lagged one period, as in equation (2.31), to test whether such specification improves the validity of Zannetos’ theory.

$$TC^*_t = a_0 + a_1 FR_{t-1} + a_2 \Delta FR_{t-1} + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.31)$$

- 3) the Koyck-lag structure for formation of period rates, in which the author assumes that time-charter rates are a function of lagged spot rates, which can be written in the form of one period lagged time-charter rates, and current voyage costs, VC_t ,

$$TC_t = a_0 + a_1 TC_{t-1} + a_2 VC_t + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.32)$$

- 4) the rational expectations hypothesis of Beenstock and Vergottis (1989a) and Hale and Vanags (1989), which relates time-charter rates to the spread between the time-charter and spot rates as well as the lagged level of spot rates,

$$TC_t = a_0 + a_1(TC_{t-1} - TCE_{t-1}) + a_2TCE_{t-1} + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.33)$$

where TCE_t represent time-charter equivalent of spot rates on a \$/day basis.

- 5) finally, the conventional wisdom hypothesis, which relates the changes in spot rates to levels of period rates.

$$TC_t = a_0 + a_1\Delta FR_{t-1} + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad (2.34)$$

Berg-Andreassen (1997a) first establishes that spot and period rates (or their transformations in terms of units of measurement) are nonstationary, $I(1)$. In the second stage, he investigates the existence of cointegrating relationships between variables in the regression model, which is argued to explain each hypothesis. Surprisingly, he rejects all hypotheses in the formation of time-charter rates except the last one; that is, the conventional wisdom hypothesis, and concludes that expectations on the formation of period rates are based on developments (changes) in the spot market.

Berg-Andreassen's results do not seem to be valid and conclusive due to following shortcomings. First, a major problem with this study is that the author fails to recognise that the existence of cointegrating relationships between two freight rates only means that they are in long run relationship and not that any expectations hypothesis regarding the formation of period rates is valid. In fact, the existence of a cointegrating relationship between variables (spot and time-charter rates) might be a necessary condition for the validity of the expectations hypothesis but is not a sufficient condition. For the expectations hypothesis to hold, certain restrictions on the estimated coefficients of the theoretical relationship between spot and time-charter rates should be derived and examined. Second, according to his unit root test results, TC_t and FR_t are $I(1)$, and ΔFR_t is stationary, $I(0)$. Therefore, theoretically,

the residual from the last regression (2.34) cannot be stationary to support the conventional wisdom hypothesis, which is claimed to be the valid hypothesis among other alternatives. This is because the linear combination of an I(1) series, the dependent variable, with an I(0) series, the independent variable, is an I(1) series.

2.4.8. Veenstra (1999) “The term structure of ocean freight rates”

Veenstra (1999) attempts to test the expectations hypothesis of the term structure (EHTS) in the formation of 12-month time-charter rates for three size dry bulk carriers for the period 1980 to 1995, using the VAR methodology of Campbell and Shiller (1987). For this purpose, he uses a present value relationship similar to the one of Hale and Vanags (1989) ((2.28) above) to set the discounted present value, DPV, of earnings in the time-charter market equal to the expected DPV of earnings from a series of voyage charter contracts, over the life of the time-charter contract. Using the Campbell and Shiller (1987) transformation (see chapter 5, appendix 5.A for more details), he derives the following model, which explains the spread between time-charter and spot rates in terms of expected changes in spot rates

$$S_t^{(k,1)} = TC_t^k - FR_t = \frac{1}{(1-\delta^k)} \sum_{i=1}^{k-1} \delta^i E_t(\Delta FR_{t+i}) + \phi \quad (2.35)$$

where k represents the duration of a time-charter contract in months, δ is the discount factor ($\delta=1/(1+r)$) and it is assumed that the duration of spot contracts is one month. Equation (2.35) can be tested for the validity of the EHTS in different ways. The value of the term on the RHS; that is, the weighted average of the expected changes in spot rates is known as the “theoretical spread”, while the term on the LHS is the actual spread. Thus, one way of testing the validity of the EHTS is to test whether the ratio of the variance of the actual and the theoretical spread series is not significantly different from unity (Campbell and Shiller, 1987). An alternative approach suggested by Campbell and Shiller (1987 and 1991) involves estimating a VAR model to predict the expected changes in spot rates and testing restrictions implied by the EHTS on parameters of the VAR model in its companion form¹².

¹² See Appendix 5.A and 5.B for more details on the companion form of the VAR model and restrictions implied by the EHTS on the VAR.

Veenstra (1999) estimates two different versions of (2.35), assuming $k=12$ and $k \rightarrow \infty$, and formulates the respective restrictions to be tested in each case. The first assumption implies that the duration of the time-charter contract is 12 months, while the second assumption known as the transversality condition¹³, implies that time-charter contracts are infinite.

With respect to the first assumption, $k=12$, he derives the following set of nonlinear restrictions on the companion form of the VAR model, which is used to model the spread and changes in spot rates for predicting expected changes in spot rates in equation (2.35)

$$e1 = e2' \delta A \left[I - \frac{1}{12} (I - \delta A^{12}) (I - \delta A)^{-1} \right] (I - \delta A)^{-1} \quad (2.36)$$

where A is the companion matrix and $e1$ and $e2$ are selection vectors containing zero and one elements¹⁴. The second assumption, $k \rightarrow \infty$, yields the following set of nonlinear restrictions on the companion form of the VAR model (utilising the fact that as $k \rightarrow \infty$, the square bracket in (2.36) becomes I).

$$e1 = e2' \delta A (I - \delta A)^{-1} \quad (2.37)$$

Results of both sets of nonlinear restrictions, (2.36) and (2.37), reject the EHTS in the formation of period rates across three size dry bulk carriers. However, he finds that the theoretical and the actual spread series move close together and shows that while variance ratio tests reject the EHTS, the actual and theoretical spreads are highly correlated in each case.

There are major problems with this study, which make the results unreliable. First, the transformation of the present value relationship to explain the spread between time-charter and spot rates in terms of the expected changes in spot rates is incorrect. The correct transformation, as shown in chapter 5 (Appendix 5.A), yields

¹³ The transversality condition assumes that the discount factor approaches zero as the horizon gets longer.

¹⁴ See chapter 5 and Appendices 5.A and 5.B of this thesis for more details on selection vectors and derivation of nonlinear restrictions on the VAR model for testing the validity of the expectations hypothesis of the term structure.

$$S_t^{(12,1)} = TC_t^{12} - FR_t = \frac{1}{(1-\delta^{12})} \sum_{i=1}^{11} (\delta^i - \delta^{12}) E_t(\Delta FR_{t+i}) \quad (2.38)$$

Second, both sets of nonlinear restrictions derived by Veenstra (1999) are not appropriate since they are not derived from the correct relationship between the spread and expected changes in spot rates; that is, equation (2.38).

Third, in the second version of the model for the EHTS, he assumes that the transversality condition holds and simplifies the set of restrictions. This seems to be inappropriate and may cause biases in the results because a 12-month horizon is a relatively short period for the transversality condition to be a valid assumption.

Finally, in the conclusions, the author argues despite mixed statistical results on the validity of the EHTS between spot and time-charter rates, the present value model and the term structure relationship might be a valid ground for investigating the relationship between short and long term freight rates. In this respect, one should investigate whether deviations from the term structure relationship are due to existence of time-varying risk premia, which the author fails to take into account when investigating the relationship between short and long term rates.

2.5. Interrelationship between shipping freight rates

The disaggregation of the dry bulk shipping market into different sectors has been a combined result of the trend in the international commodity trade, developments in the shipbuilding industry and the realisation of economies and diseconomies of scale in sea transportation. Nowadays, bulk carrier vessels ranging from 10,000 to over 150,000 dwt provide the link between sources of supply and demand for raw materials around the globe.

Different trading routes have been established over the years as a result of the tremendous growth in seaborne transportation in connecting exporting and importing regions. Freight rates in these routes are believed to be determined through the interaction between supply and demand schedules, which are themselves explained by different variables.

Despite the importance of the issue from the operational as well as the academic point of views, only two studies in the literature attempt to investigate the relationship between freight rates paid in different shipping routes for each vessel size. These are Veenstra and Franses (1997) and Berg-Andreassen (1997b). Both studies investigate the interrelationships between freight rates in different Baltic routes. The following section aims to review these studies in order to highlight their shortcomings and identify the gap in the literature to support the need for further investigation in this area.

2.5.1. Veenstra and Franses (1997) “A cointegrated model of dry bulk freight rates”

Veenstra and Franses (1997) propose a multivariate cointegration model for dry bulk spot rates for six major Baltic Exchange routes to test both the forecasting performance of the model and the efficiency of the spot market. They argue that if the market is efficient then freight forecasts in any route should not be improved using past information on freight movements in other routes. Their pair-wise cointegration tests show that freight rates are nonstationary and cointegrated. Further, using a multivariate cointegration test, they suggest that there are five cointegrating relations between the series despite the actual outcome of the test, which suggests that there are less than 5 cointegrating relations. Veenstra and Franses

(1997) use a Vector Error Correction model to explain the long run relationships and short run dynamics of freight series in one-step in the following form

$$\Delta \mathbf{FR}_t = \mathbf{c} + \alpha \beta' \mathbf{FR}_{t-1} + \sum_{i=1}^p \Gamma_i \Delta \mathbf{FR}_{t-i} + \varepsilon_t \quad \varepsilon_t \sim iid(0, \Sigma) \quad (2.39)$$

where \mathbf{FR}_t is a (6 x 1) vector of freight rates (6 Baltic routes¹⁵), \mathbf{c} is (6 x 1) vector of constant terms, Γ_i are (6 x 6) matrices of parameters, and α and β are (6 x 5) matrices of speed of adjustment to long-run equilibrium relationship and cointegrating vectors, respectively. Equation (2.39) is estimated using Johansen's reduced rank approach¹⁶.

Veenstra and Franses (1997) assume that there are 5 cointegration vectors ($r=5$ and $n=6$), despite the results of likelihood ratio test statistics (λ_{\max} and λ_{trace}), indicating $r=3$ cointegration vectors. They justify the selection of the number of cointegration vectors in the VECM model by pointing out to the power and limitations of the test with respect to the sample size, according to Cheung and Lai (1993) as well as the results obtained from pairwise cointegration tests. Veenstra and Franses (1997) show that the test for stochastic common trends indicates that the series are driven by a single common stochastic trend. The final model is therefore specified as a vector error correction model, VECM, which has first differences of freight rate series in 6 routes as dependent variables and lagged values of the differences between freight rates (spread) as independent variables.

They use this VECM model to forecast freight rates in these dry bulk routes up to 18 months ahead for the period 1993:9 to 1995:2. They find that the performance of long run forecasts, once deterministic relations between freight rate series are removed, is not promising. This is attributed to the large proportion of the variation in freight rate series being due to the common stochastic trend, which is not predictable.

Veenstra and Franses (1997) conclude that freight rates in these routes are linked and move together in the long run, following a common stochastic trend, while there are short run fluctuations in freight series, which could be explained by differences between these routes.

¹⁵ These routes are; 1) Tubarao-Rotterdam, 2) Rotterdam-Tubarao-Japan, 3) Hampton Roads/ Richards Bay- Japan, for capesize vessels, and 4) Roberts Bank-Japan, 5) Rotterdam-Hampton Roads and vice versa, and 6) Rotterdam-US Gulf vice versa for panamax vessels.

¹⁶ Details of the Johansen reduced rank estimation approach for cointegration analysis are given in chapter 3.

The authors also attribute the failure of the forecasting performance of their model to the validity of the EMH in the spot market for large vessels.

2.5.2. Berg-Andreassen (1997b) “Efficiency and interconnectivity in international shipping markets”

Berg-Andreassen (1997b) examines the interrelationship between daily freight rate series for 13 BIFFEX routes for the period May 8th 1986 to December 23rd 1988 using cointegration techniques. He argues that, if freight rates for these routes are non-stationary and integrated of first order, $I(1)$, then the existence of cointegration between the rates means that they move together in the long run. This, he argues, can be regarded as evidence of interconnectivity and efficiency of the dry bulk freight market, despite the fact that the existence of cointegrating relationships between freight rate series, although necessary, is not a sufficient condition for efficiency. The existence of cointegrating relationships between freight series on its own is not a sufficient condition for the EMH since it does not rule out the existence of any excess profit making opportunity, perhaps in the short run. Furthermore, the fact that freight rates are cointegrated means that they are linked; that is, causal relationships might exist between the series, which can be used to predict the movement of freight rates.

Berg-Andreassen (1997b) investigates the existence of cointegrating relationships between pairs of freight rate series using both the Engle-Granger two-step and Johansen's cointegration methods. He finds that out of 13 shipping routes, freight rates in 5 routes are not cointegrated with others in a bivariate framework, while the evidence supports the existence of cointegrating relationships between others. The co-movements of freight rates in shipping routes, for which cointegration is found, is attributed to the fact that different size ships are used as substitutes for transportation of commodities with different parcel sizes and over different routes. However, failure to find cointegration relationships between the mentioned five routes is explained by the fact that these routes are more distinct in terms of the size of the vessel employed. He states further that such distinctions or idiosyncratic behaviour in freight rates may provide niche markets for shipowners.

Berg-Andreassen (1997b) does not give a proper explanation of how and to what extent these markets (routes) are related, instead, he establishes that freight rates in different routes move

together over time due to the mobility and switching of vessels (perhaps of the same size) between different routes. Nevertheless, for shipowners (investors) it is more important to have insight into the movements and activities as well as the interaction between markets for different size vessels rather than routes. Therefore, in our analysis we use size disaggregated freight series.

Studies by Veenstra and Franses (1997) and Berg-Andreassen (1997b) on the interrelationship between freight rates in different routes provide some insight on the short and long run relationships between freight rates. However, the authors restrict their investigations to consider such interrelationships between freight series in a few shipping routes and not the whole market or across different size vessels, or even charter contract. We extend these studies in several dimensions. First, we investigate the relationship between freight rates for different size vessels as well as across contract duration by performing the analysis in the spot, 1-year and 3-year time-charter markets. Second, we use impulse response functions to trace the effect of shocks to freight rates for each size category on other sizes, again within spot and period markets. Third, we also examine the spillover effects between volatility of freight rates for different size vessels within both spot and period markets.

2.6. Expectations Hypothesis and the EMH in the Market for Ships

An important area in shipping economics, which has always been of interest to both academics and practitioners, is the determination of second-hand and newbuilding prices. Price determination in the shipping industry is important since it has direct implications for agents involved. Such implications include the timing of decisions such as; sale and purchase of second-hand vessels, placing orders, scrapping older vessels, shipping portfolio management (size selection, investment and finance) as well as company valuations.

There are a number of studies in the literature attempting to model ship prices and discover the underlying relationship between ship prices and freight rates. Different forms of expectations hypotheses are proposed in order to explain the formation of newbuilding and second-hand ship prices and a number of methods have been used to test the efficient market hypothesis in price formation. The aim of the following section is to review these studies critically for the purpose of this thesis.

2.6.1. Strandenes (1984) “Price determination in the time-charter and second-hand markets”

Strandenes (1984) investigates the price formation in the dry bulk and tanker sectors, over the period 1968 to 1981 using annual data. She argues that ship prices respond more to medium term (1 to 3-year) charter rates than to short term (less than 1-year) rates, because medium term charter rates reflect the future profitability of shipping operations better than the short term (current spot) rates¹⁷. She then suggests that since prices depend on medium and short term charter rates shipowners consider both charter rates when deciding whether to invest on ships and assessing the expected income from the investment. She assumes that expectations are formed semi-rationally¹⁸, and proposes a model, which explains the second-hand price of

¹⁷ She refers to Strandenes and Wergeland (1981) investigating the relationship between prices and freight contracts with different times to maturity.

¹⁸ Semi-rational expectations implies that agents believe that prices will adjust towards the long run equilibrium prices at a rate which depends on current market conditions and a trend. Therefore, agents are expected to use a weighted average of expected long term equilibrium and current prices in their pricing formula, where the weights may change depending on how far the current prices are from the long term equilibrium prices. For example, if current freight levels are lower than the long run equilibrium rate, then agents expect freight rates to rise in the future, and vice versa.

ships, adjusted for age, as a function of discounted earnings at the current market and of the market replacement value of the ship¹⁹. The theoretical relationship is then modified in order to relate the second-hand prices, adjusted for age, to the current and long term equilibrium earnings using the following model

$$P_t^a = a_s \Pi_t + a_e \bar{\Pi}_t + \varepsilon_t \quad (2.40)$$

where P_t^a is the age adjusted price, Π_t and $\bar{\Pi}_t$ are current and long run equilibrium²⁰ earnings, respectively, and a_s and a_e are parameters of interest measuring the impact of current and long run equilibrium earnings on the price level, respectively. The relationship is estimated for panamax as well as medium and large tankers for the period 1968 to 1981 using annual data.

Table 2.5: Results of Strandenæs (1984) model for second-hand price determination

Vessel type Period	Panamax 1968-1981	Medium Tankers 1969-1981	Large Tankers 1973-1981
Π_t α_s	22.990 (4.674)	17.138 (5.508)	34.313 (3.561)
Π_{t-1} α_{s1}			25.149 (3.536)
$\bar{\Pi}_t$ α_e	77.27 (6.199)	57.483 (15.83)	30.260 (5.838)
Impact of current earnings and market replacement value of the vessel on ship prices			
% impact of a change in current earnings on prices $\alpha_s / (\alpha_s + \alpha_e)$	23%	23%	66%
% impact in the first year	23%	23%	53%
% impact of a change in market replacement value on prices $1 - (\alpha_s / (\alpha_s + \alpha_e))$	77%	77%	34%

- Source: Strandenæs (1984)
- Figures in () are standard errors.

Her results suggest that prices are more influenced by changes in long term equilibrium profits than changes in current operating profits, however, prices for large tankers show the opposite relation. She suggests that the greater impact of current earnings on large tanker

¹⁹ The market replacement value of the ship is assumed to be equal to the newbuilding price of a similar vessel.

²⁰ Current operational earnings, Π_t , is defined as time-charter equivalent if spot rates minus operating costs. Long run equilibrium earnings, $\bar{\Pi}_t$, at any point in time is defined as the level of freight rates, at which a newbuilding investment is feasible for investors.

prices compared to long run equilibrium earnings might be due to the reaction of the agents to slower convergence of short term rates to long run equilibrium rates in this market compared to the other two markets.

Apart from statistical issues regarding the direct use of nonstationary series, the major problem with this study is the way equation (2.40) is formulated. This is mainly because the market replacement value of the vessel, which is a transformation of newbuilding prices (or long run equilibrium rates in the estimated equation), is used to explain the second-hand prices. In fact, the author finds that the long run equilibrium price, or operating profits derived from the newbuilding price, can explain second-hand ship prices. This is not surprising since newbuilding and second-hand vessels are close substitutes and their prices are bound to move together. The problem is that if second-hand prices are driven by agents' expectations, so are newbuilding prices. Therefore, regressing second-hand and transformation of newbuilding prices, although produces significant results and high R-bar-squared values, neither explains how price expectations are formed nor provides any evidence on the validity of the semi-rational expectations hypothesis in the formation of ship prices. Furthermore, the formulation of price expectations in this study does not take into account agents' perceptions of risk, which is an important part of asset pricing models.

We propose a model, which can be used to test the EMH in second-hand and newbuilding ship price formation directly, based on the cointegration and present value relationships of Campbell and Shiller (1987 and 1988) and the unpredictability of excess returns of Fama (1991) and Fama and French (1988). We also investigate the existence of time-varying risk in the formation of ship prices and model this using recently developed GARCH-M techniques.

2.6.2. Vergottis (1988) "An econometric analysis of world shipping"

Vergottis (1988, chapter 7) investigates the efficiency of the market for newbuilding vessels. He argues that since there is a time lag between the time the order is placed and the actual delivery time, newbuilding prices can be considered as future prices for second-hand vessels. Therefore, he postulates that the newbuilding price is equal to the price of a second-hand vessel in the market, and even if there is a difference due to vintage (age), technological advances and risk premia, it is assumed to be constant. Mathematically,

$$P_t^{NB} = E_t P_{t+d}^{SH} \quad (2.41)$$

where P_t^{NB} and $E_t P_{t+d}^{SH}$ represent newbuilding and the expected second-hand prices respectively, and d is the delivery time. Using quarterly data from 1960 to 1985, he tests the unbiasedness hypothesis, as well as weak and semi-strong forms of efficiency in the market for newbuilding vessels using the following regression.

$$P_t^{NB} = a + bP_{t+d}^{SH} + u_t \quad (2.42)$$

The unbiasedness hypothesis implies that $a=0$ and $b=1$, while weak form efficiency requires u_t to be independently and identically distributed with zero mean, $iid(0, \sigma^2)$. Semi-strong form efficiency requires that u_t is independent of the information set available at time t . Vergottis (1988) performs all three tests on aggregate ship prices for the period 1968 to 1985. Table 2.6 reports the results of Vergottis' tests of the EMH and RE in the market for ships.

Table 2.6: Results of Vergottis' (1988) tests of the EMH+RE in the market for ships

Unbiasedness Test									
$P_t^{NB} = a + bP_{t+d}^{SH} + u_t$									
a	b	SE of regression	DW test	F test	$H_0: b=1$				
0.811	0.737	0.329	1.332	4.971					
(0.444)	(0.118)			[0.035]					
Weak Form Efficiency Test									
$u_t = a + \sum_{i=1}^4 b_i u_{t-i} + v_t$									
a	b ₁	b ₂	b ₃	b ₄	F test				
-0.144	0.605	-0.561	0.247	-0.162	$H_0: b_1=b_2=b_3=b_4=0$				
(1.642)	(2.723)	(2.211)	(0.964)	(0.723)	2.223				
					[0.103]				
Strong Form Efficiency Test									
$u_t = a + \sum_{i=1}^2 b_i u_{t-i} + \sum_{i=1}^2 c_i WEA_{t-i} + \sum_{i=1}^2 d_i K_{t-i} + \sum_{i=1}^2 e_i TC_{t-i} + v_t$									
a	b ₁	b ₂	c ₁	c ₂	d ₁	d ₂	e ₁	e ₂	F test
-0.254	0.225	0.556	0.830	-0.792	8.562	-7.851	-0.900	-0.092	$H_0: b_1=c_1=d_1=e_1=0$
(0.077)	(0.890)	(0.803)	(0.129)	(0.145)	(0.877)	(1.082)	(1.859)	(0.324)	2.945
									[0.031]

- Source Vergottis (1988).
- Figures in () and [] are standard errors and p-values, respectively.
- WEA, K and TC represent world economic activity, size of the fleet and time-charter rates, respectively.

Vergottis (1988) finds that both the unbiasedness hypothesis test and the test for the strong form efficiency strongly reject the EMH+RE in formation of second hand prices, while the weak form of efficiency is rejected marginally.

There are a number of problems with this approach. First, the unbiasedness test and the test for strong form efficiency suffer from problems associated with the use of nonstationary series (e.g. P_t^{NB} and P_{t+d}^{SH}), which invalidate the results and inferences drawn on these tests. This is also evident by the low value of Durbin-Watson test. The other problem with this test is that error terms are serially correlated, a problem which arises when formulating multiperiod expectations, which results in inefficient coefficient estimates (see chapter 3, section 3.5 for details).

Second, the above setting can only be used to test the EMH in the market for newbuilding vessels and does not allow testing the efficiency of the second-hand market due to the way the tests is constructed. Third, in this approach, the difference between the current newbuilding price and second-hand price in the future is assumed to reflect the age difference and not the operational profit of the newbuilding (newly delivered) vessel over the age difference. In fact, equation (2.42) is a special case of the following present value model, used in this thesis to test the EMH under the framework of Campbell and Shiller (1988)

$$P_t^{NB} = \frac{E_t \Pi_{t+1}}{(1 + E_t R_{t+1})} + \frac{E_t \Pi_{t+2}}{(1 + E_t R_{t+1})(1 + E_t R_{t+2})} + \dots + \frac{E_t \Pi_{t+n} + E_t P_{t+n}^{SH}}{(1 + E_t R_{t+1}) \dots (1 + E_t R_{t+n})} \quad (2.43)$$

where, the sum of discounted operational earnings over the age difference is assumed to be constant. Operating profits, which Vergottis (1988) does not take into account, are important in setting up the model for testing the EMH. This is because discounted operating profits form part of the price of a newbuilding vessel or second-hand vessel, and rational investors consider the future profitability of an asset (operating profit in this case) when determining the price of the asset.

In chapter 7 we adapt the Campbell and Shiller (1987 and 1988) methodology, which has been used recently in the financial economic literature, to test the EMH and RE in formation of both newbuilding and second-hand prices for ships for different size dry bulk vessels. This

method uses the discounted present value of operating profits and the residual (resale) value of the vessel and compares this theoretical price to the actual value of the vessel. This method is shown to be superior to the Vergottis' approach since not only it takes into account the stochastic properties of price series, but also tests the EMH directly through a set of restrictions on the parameters of estimated models. In addition, we investigate the existence of time-varying risk premia in the formation of second-hand prices, using GARCH-M model which is use in the financial economics literature to explain the risk return relationship.

2.6.3. Wright (1993) "Expectations in the shipping sector"

Wright (1993) examines different forms of the expectations hypothesis in the formation of second hand prices for handysize dry bulk carriers for the period 1980 to 1990 using quarterly data. He proposes and tests three different hypotheses; namely, rational, static and adaptive expectations hypotheses. A random walk model is used to test the validity of rational expectations in the formation of ship prices. According to RE and the EMH, the price of the asset reflects the market's expectations about the future performance of that asset. This implies that the actual price of the asset at time $t+1$, P_{t+1} , and its expected value, $E_t P_{t+1}$, should differ by a forecast error, ε_{t+1} , which is assumed to be independent of the information set available at time t . In other words, the difference between the actual and the expected prices should only be due to the arrival of new information between time t and $t+1$. Wright also argues that, based on RE, if there are no substantial revisions in expectations, the best estimates of next period prices are current prices, P_t , and estimates the following equation in order to test the validity of RE in the formation of second-hand prices.

$$\ln P_{t+1}^{SH} = \beta \ln P_t^{SH} + \varepsilon_{t+1} \quad ; \quad \varepsilon_t \sim iid(0, \sigma^2) \quad (2.44)$$

The important parameter in equation (2.44) is β which needs to be equal to unity for the series to show random walk behaviour and RE and the weak form of the EMH to hold. Wright (1993) reports the following estimates using the Cochrane-Orcutt estimation method, with an MA(1) specification.

$$\ln P_{t+1}^{SH} = 0.9831 \ln P_t^{SH} + 0.5031 \varepsilon_t \quad (2.45)$$

t - stat (52.9) (3.3)

Although the results suggest that β is close to one, the residuals are highly correlated, which is not in line with the rational expectations hypothesis. However, this might be due to time aggregation of the price series, which induces a first order autocorrelation in the residuals (see Working, 1960).

In order to test the static expectations hypothesis in the formation of ship prices, Wright (1993) uses a present value model, $PV_t = \sum_{i=1}^{10} (FR_t - OC_t)/(1 + R_t)^i$, in which freight rates, FR_t , operating costs, OC_t , and discount rates, R_t , are considered to be constant over the life of the vessel (10 years in his case). Mathematically

$$P_t^{SH} = \beta PV_t + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma^2) \quad (2.46)$$

In this way, Wright finds that ship prices can be explained partially by the expected discounted present value of expected profits.

$$\begin{array}{ll} \ln P_{t+1}^{SH} = 0.3045 \ln PV_t + 0.9888 \varepsilon_t & (2.47) \\ \text{t-stat} \quad (4.2) \quad (8.7) & \end{array}$$

Apart from statistical issues in this tests, such as direct use of nonstationary variables in (2.47) and (2.45), which may invalidate inferences, there seem to be two major problems with this approach. First, the present value relationship which has been used to test the static expectations hypothesis is misspecified because of residual or resale value of the vessel, which is a substantial amount, is not included in the present value model. In addition, assuming a 10-year economic life for a 5 year old handysize dry bulk carrier might not be appropriate since handysize vessels tend to have an economic life of around 20 to 25 years.

Finally, he proposes the following model to test the adaptive expectations hypothesis in the formation of ship prices.

$$P_t^{SH} = \beta E_t PV_{t+1} + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma^2) \quad (2.48)$$

In this setting, expected present values, $E_t PV_{t+1}$, are assumed to be explained by a weighted average of lagged present values and an adjustment factor, which is a fraction of the difference between the actual and the predicted present values lagged; that is, $E_t PV_{t+1} = \eta E_{t-1} PV_t + (1-\eta)(PV_t - E_{t-1} PV_t)$. Using the Koyck lag transformation, Wright converts (2.48) to the following regression model, which is tested empirically.

$$P_t^{SH} = \alpha P_{t-1}^{SH} + \beta PV_t + \varepsilon_t \quad ; \quad \varepsilon_t \sim iid(0, \sigma^2) \quad (2.49)$$

$$\ln P_t^{SH} = 0.3067 \ln PV_t + 0.7045 \ln P_{t-1}^{SH}$$

t - stat (7.3) (17.8)

The results from this last model reveal that both PV's (expected profitability) and lagged ship prices contain information in explaining current ship prices. However, it can be seen that equation (2.49) is the same as equation (2.44) plus PV_t . Therefore, if equation (2.49) is assumed to be the correct model for explaining the expectations hypothesis, then the model in (2.44) is misspecified due to problems of omitted variable, which may invalidate inferences.

Wright (1993) argues that the results provide support for all three hypotheses tested and there is scope to accept all three hypotheses. He then concludes that because of the nature of shipping industry in terms of its exposure to many factors such as the world economy, political developments and changes in shipping environments, agents may use rational as well as non-rational expectations in their pricing, depending on their feeling about the market. This means that under some circumstances agents may consider adaptive expectations and try to follow the historical trends in the market, while under other circumstances they may well use a forward looking approach in their pricing mechanism.

Wright's results do not seem to be valid and conclusive, as there are three major problems with his approach. First, stochastic properties of variables are not taken into account. Second, in estimating present values the discounted present value of the residual price of the vessel are not considered. Finally, inferences on the validity of these hypotheses are not tested through parameter restriction.

2.6.4. Hale and Vanags (1992) “Market for second-hand ships; some results on efficiency using cointegration”

Hale and Vanags (1992) investigate the validity of the EMH in the formation of second-hand prices for three different size dry bulk carriers; namely, Handysize 30,000, Panamax 70,000 and Capesize 120,000 dwt vessels. The motivation for their study comes from the assumption of the EMH and RE in the determination of ship prices in Beenstock (1985) and Beenstock and Vergottis (1989a,b). They argue that the validity of such assumptions in price formation should be tested and base their testing method on the argument that in an efficient market ship price series for different size vessels should not be cointegrated (in the sense of Engle-Granger). This is because if price series are cointegrated, then according to the Granger Representation Theorem, at least one of them must Granger cause the other; that is, movements in one series can be used to predict the others (see, for example Macdonald and Taylor, 1988). This invalidates one of the basic implications of market efficiency, which posits that in an efficient market prices incorporate all currently available information and therefore no other variable should improve their forecast. Thus, after testing for stationarity of the price series, they perform a series of tests, based on the two-step Engle and Granger cointegration method, to establish whether a cointegration relationship between pairs of price series exists.

Hale and Vanags (1992) perform the Engle-Granger two-step test for each pair. This is carried out by testing the stationarity of the residuals in pair-wise OLS regressions of the non stationary price series, P_h , P_p , P_c in the following form

$$P_{i,t} = \alpha_0 + \beta_0 P_{j,t} + \varepsilon_{ij,t} \quad \varepsilon_{ij,t} \sim \text{iid}(0, \sigma_{i,j}^2) \quad ; \quad i \neq j, \quad i = h, p, c \quad (2.50)$$

where subscripts h, p and c stand for handysize, panamax and capesize series, respectively. The residuals from each regression equation, $\varepsilon_{ij,t}$, are then tested for stationarity using Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) unit root tests. Stationarity of the residuals of pair-wise regressions implies that the two prices are cointegrated. Hale and Vanags (1992) do not find any support for a cointegrating relation between any pairs of second-hand ship price series. However, when the third price series is included in the

regression equation, they find that a cointegrating relationship links these price series and there is evidence to support Granger-causality between some of the price series.

The results of Hale and Vanags (1992) cointegration analysis seem to be mixed and inconsistent, which led them to conclude that market efficiency in aggregated models for ship price determination should be considered cautiously. Based on the existence of a single cointegrating vector among the three price series, the authors also conclude that ship prices in the dry bulk sector are driven by one or two common stochastic factors such as world trade and bunker prices. This is regarded as a justification for the existence of a long run relationship between nonstationary price series.

Despite their interesting approach to investigate the EMH in ship price formation, which explicitly takes into account the stochastic properties of ship price series, there seem to be two major problems with the Hale and Vanags (1992) study, which may render the results unreliable. First, they use the Engle-Granger method to test for cointegration, which is argued to be less powerful than other multivariate cointegration techniques such as Johansen (1988)²¹. Second, the fact that price series are cointegrated and move together in the long run does not imply that the market is inefficient. This is because the existence of cointegrating relationship between price series is a necessary condition for the EMH but not the sufficient condition, as restrictions on parameters should be tested. Furthermore, existence of cointegrating relationships implies Granger-causality between price series. This in turn suggests that information in one market can be used to predict other series. Therefore, theoretically, the existence of long run relationships between price series does not rule out the existence of excess profit making opportunities in the short run or any mispricing of assets, which can be exploited by investors.

2.6.5. Glen (1997) “The market for second-hand ships; Further results on efficiency using cointegration”

Glen (1997) re-examines the informational efficiency in price determination in the dry bulk and tanker sectors using monthly data for the period 1980 to 1995 through a multivariate

²¹ See chapter 3 for discussion on cointegration tests and techniques.

cointegration analysis. In fact, he extends the Hale and Vanags (1992) study by arguing that a multivariate approach to establish cointegrating relationships between price series is more appropriate than the single equation approach of Engle-Granger (see chapter 3 for more details on cointegration tests). This is because of the fact that the multivariate approach of Johansen (1988), not only allows the investigation of the existence of more than one cointegrating relationships between the series, but it is also believed to be more powerful than the Engle-Granger method since it utilises the full information set.

In contrast to Hale and Vanags (1992) in the case of pair-wise cointegrating relations between price series in the dry bulk sector, Glen (1997) finds that the Johansen reduced rank cointegration method indicates that dry bulk carrier prices are cointegrated in pairs. Similar conclusions are also drawn in the case of a trivariate cointegration analysis, with the exception that the results indicate two cointegrating relationships between three price series. Using autoregressive models and Granger-causality tests, Glen (1997) finds that despite the existence of cointegration relationships between price series, including error correction terms do not improve predictive power of autoregressive model. On the other hand, the lagged price changes in some size categories are found to increase the predictability of prices both in the presence and the absence of the error correction terms. He then concludes that such relationship between price series is not in line with the EMH. He argues that failure of the EMH in the market for dry bulk vessels may be due to the existence of a common stochastic trend, which implies that price series are not predictable in the long run.

Although, Glen (1997) resolves the problem regarding the power of cointegration test observed in Hale and Vanags (1992) study, his test and argument regarding the failure of the EMH is not quite valid because of the following reasons. First, regarding the Granger causality tests performed in the presence of cointegration, it has to be mentioned that when two or more series are cointegrated, according to the “Granger Representation Theorem”, there is a causal relationship between the series. Therefore, the Granger-causality test should be performed on both lagged price changes as well as error correction terms. Second, as mentioned before while reviewing Hale and Vanags (1992), the existence of cointegration and causal relationships between price series by itself does not imply that markets are inefficient, that prices can be predicted and that there are opportunities to generate excess profits. In fact, prices in a market might be predictable and there might be opportunities to

make excess profit, but exploiting such informational inefficiency present in the market is costly or involves risks.

In chapter 7 we use a number of tests proposed by Campbell and Shiller (1987 and 1988) to test the EMH in the formation of ship prices. We also address the existence of such inefficiency in the market for second-hand dry bulk carriers using a recently developed econometric technique, which relates the risk and return in the market for ships.

2.7. Time-varying volatility of shipping freight rates and ship prices

One of the most interesting areas in time series analysis, which has been extensively developed in recent years, is modelling the behaviour of the second-order moment of time series and its interaction with the first moment (mean). This is an important area of financial economics since the second-order moment of time series is considered to be a measure of volatility or risk. This is of interest to investors for their decisions.

Freight markets and markets for ships are also characterised as volatile markets due to the uncertainty surrounding this industry. Such fluctuations are important to investors and operators in their decisions regarding sale and purchase as well as chartering activities. Despite the importance of the matter to the agents in the industry, it was not until recently that in a series of papers Kavussanos (1996a, b, c and 1997) models the dynamics of volatilities of freight rates and prices in dry bulk and tanker sectors.

Since the research theme set in this thesis includes investigating the existence of the time-varying risk premia in the formation of period rates and ship prices as well as investigating the spillover effects between freight rate volatilities, it is deemed necessary to review the existing literature on modelling dynamics of time-varying volatilities in shipping markets. Thus, the aim of the following sections is to discuss the studies on modelling time-varying volatilities of shipping freight rates and ship prices recently, in order to highlight the importance of the dynamics of risk in the shipping industry.

2.7.1. Kavussanos (1996a) “Volatility of dry cargo shipping freight rates”

Kavussanos (1996a) examines time-varying volatilities of the dry bulk freight rates across vessel sizes as well as their aggregate spot and time charter rates using ARCH and GARCH models²². He investigates the dynamic behaviour of freight rate volatilities, by first modelling the conditional mean of the series, and then the conditional variance of the error

²² See chapter 3 for more details on ARCH and GARCH models.

terms in the regression equations. Kavussanos (1996a) uses the following specification to condition the mean of monthly freight rates:

$$FR_t = f\left(IP_t^+, BP_t^+, \bar{K}_t\right) \quad (2.51)$$

where FR is freight rate, IP is an index for industrial production, BP is bunker prices, and K represents the size of the fleet. Time charter rates are also hypothesised to depend on the current expectations of future spot rates and bunker prices as follows

$$TC_t = f\left(E_t FR_{t+1}^+, E_t \bar{BP}_{t+1}\right) \quad (2.52)$$

Using monthly time series for freight rates (from January 1973 to December 1992) for three size categories of dry bulk carriers, he first estimates the model for the mean using OLS and then the conditional mean and variance using maximum likelihood methods. Comparison of the results between the two models indicates that not only ARCH and GARCH parameters are significant, but also the explanatory power of the model is increased when variances are modelled. In addition, he finds that risks in different sectors of the dry bulk freight market are time-dependent.

Furthermore, he finds that the pattern and magnitude of the time-varying volatilities in differentiated dry bulk freight markets are different across vessel sizes. In particular, freight rates for larger vessels tend to be more volatile than smaller ones. Kavussanos (1996a) also notes that time-charter rates are more volatile with wider fluctuations over time than the corresponding spot rates. He argues that this reflects Zannetos' "elastic expectations" hypothesis, which explains agents' behaviour when rates in the spot market are changing. However, this is puzzling since Zannetos (1966) also mentions that time-charter rates are considered to be a weighted average of spot rates, therefore, they are bound to be smoother than spot rates.

2.7.2. Kavussanos (1997) “Dynamics of time-varying volatilities in different size second-hand ship prices of the dry cargo sector”

In another study on time-varying volatilities of ship prices, Kavussanos (1997) examines the dynamics of volatilities of second-hand prices for different size dry bulk carriers using monthly data over the period 1976:1 to 1995:8. After testing price series for existence of unit roots at seasonal frequencies using the Beaulieu and Miron (1993) test, he concludes that price series are $I(1)$ variables, and uses an ARIMA-X/GARCH-X specification to model both the mean and the variance of dry bulk prices on a univariate basis.

Using structural variables in the mean and variance equations, he draws the following conclusions. First, changes in second-hand prices for handysize and panamax bulk carriers are positively related to changes in time-charter rates, while their time varying variances are positively related to the levels of interest rates. In the case of second-hand prices for capesize vessels, both level and volatilities are positively related to changes in time-charter rates. Second, in general, price volatilities in the dry bulk sector respond together and symmetrically to external shocks, however, there are differences, which are due to market segmentation and the fact that these vessels are employed in different routes and trades. Finally, price volatilities are also positively related to the size of vessel; that is, prices for larger vessels show higher volatilities compared to those of smaller ones. This is attributed to the fact that larger vessels are less flexible than smaller ones in terms of trading routes and commodities that they carry. As a result, responses of profitability and prices for larger vessels to any unexpected changes in the market are more drastic compared to smaller vessels.

2.8. Conclusions

The importance of economic analysis of the shipping industry has been recognised for a long time as it reveals valuable information for the decision making process of the agents involved. Perhaps one of the most interesting areas in shipping economics is modelling shipping freight rates and ship prices. A branch of the literature in shipping economics has been devoted to modelling the behaviour of prices and freight rates in tramp shipping markets and testing different theories on the formation of ship prices and freight rates.

A review of the above literature was presented in this chapter. The very early econometric studies on shipping markets by Tinbergen and Koopmans before the Second World War were discussed. More complex general equilibrium econometric models of the shipping industry, developed by Beenstock (1985) and Beenstock and Vergottis (1989a) were presented. These models assume that the market for ships and the shipping freight market are efficient and agents are rational. In fact, in these studies the formation of expectations and the efficient functioning of these markets have been taken for granted rather than explicitly investigated. A few studies investigated the formation of expectations in freight rates and price determination in different shipping sectors. These include: Zannetos (1966) on the tanker freight rate formation, Glen et al (1981) on the relationship between short and long term rates for handysize tankers, Strandenes (1984) on the formation of dry bulk and tanker period rates and prices and Wright (1993) on the formation of handysize prices. Later studies of Hale and Vanags (1989 and 1992), Glen (1997) and Veenstra (1999) question the validity of the EMH assumptions in the formation of period rates and ship prices in different sectors.

It is concluded that the results are mixed and inconclusive. This is attributed to three main deficiencies in the majority of studies. First, studies such as Zannetos (1966), Glen (1981), Binkley and Bessler (1983) Strandenes (1984) and Wright (1993), investigating the formation of expectations in freight and ship's markets, do not take into account the stochastic properties of the data. This is argued to have consequences on the validity of empirical models used and statistical tests performed. Second, studies such as Hale and Vanags (1989 and 1992), Glen (1997) and Veenstra (1999), although recognising the stochastic properties of the data in their models, do not use the appropriate techniques or methodologies to examine the EMH in shipping markets and the market for ships. This is because; a) they do

not use the correct frameworks and specifications, and b) they all fail to consider the importance of risk and its dynamics in the formation of long term shipping freight and prices. This is important since studies such as Kavussanos (1996a, b, c and 1997) document that volatilities of ship prices and shipping freight rates are time-varying and agents might take into account such dynamics in market risk in their expectations and pricing.

In the rest of this thesis we use recently developed econometric techniques, which are fully explained in chapter 3, to construct different tests to investigate four main areas in shipping economics in which the previous evidence is non-existent or mixed and inconclusive. These areas include; i) investigating the stochastic behaviour of freight rate series including seasonality, ii) testing the implication of the EMH in the formation of long term freight rates, i.e. the expectations hypothesis of the term structure and modelling time-varying risk premia, iii) examining the dynamic interrelationships between freight rate levels and freight volatilities for different size vessels in the spot and period markets, iv) and finally, investigating the EMH and the existence of time-varying risk premia in the market for newbuilding and second-hand vessels.

Having reviewed the relevant literature and identified those areas, which have to be investigated further, the next chapter presents different econometric methodologies, which are used as statistical tools to investigate these issues in the rest of this thesis.

3. CHAPTER THREE

ECONOMETRIC METHODOLOGY

3.1. Introduction

It has been argued in chapter 2 that most of studies in the literature investigating the formation of expectations and the validity of the EMH in the formation of period rates in freight markets and prices in the market for ship suffer from three major statistical issues. First, most of the studies fail to take into account the univariate properties of the variables including stationarity and seasonality. Second, they fail to incorporate the interrelationship between the variables, bearing in mind their stochastic properties. Third, some studies fail to consider the appropriate framework, in which the EMH has to be investigated, either in specifying the testable hypothesis or estimation techniques used.

This chapter presents and discusses different methodologies and econometric techniques used in later chapters of this thesis to; 1) study the univariate behaviour of shipping variables; 2) investigate the EMH in formation of rates and price; 3) examine the interrelationship between variables; and 4) model the risk return relationship in freight market and the market for ships.

Once the importance of recognising the univariate behaviour of time series data in model building and hypothesis testing is discussed, section 3.2 presents different testing procedures proposed in the literature to examine such properties in time series. Section 3.3 offers the discussion on different methodologies adapted in order to study the seasonal behaviour of time series data. Section 3.4 introduces a multivariate dynamic modelling approach, known as Vector Autoregression (VAR), and discusses different methodological issues of using this modelling technique in analysing time series as well as its advantages and disadvantages. Recent advances in estimating VAR models in the presence of nonstationary time series; i.e. cointegration techniques are also presented. Section 3.4.2 introduces the impulse response analysis along with new developments in performing such analysis on VAR and error correction models. Section 3.5 presents statistical issues in relation to rational expectations and estimation of models with non-orthogonal variables and serially correlated errors. The last section is devoted to autoregressive conditional heteroscedasticity (ARCH) and generalised autoregressive conditional heteroscedasticity (GARCH) models, developed to model the second moment of time series. Different methodological issues regarding the specification, estimation and interpretation of such models are also discussed.

3.2. Stochastic and Deterministic Trend

Stationarity is one of the most important properties of time series and received considerable attention in time series analysis over recent years. By definition, a stationary series has the property to return to its mean quite frequently, unlike a nonstationary series, which tends to depart from its mean for very long periods. Obviously these long departures from the mean will cause the mean not to be constant over time (different sub-samples). This is very important in econometrics and time series analysis and has to be investigated since regression results of nonstationary economic time series in univariate (AR, ARMA, etc.) or multivariate systems can be misleading and spurious. In fact, the results might falsely indicate significant relationships when stationarity does not exist. This phenomenon, which is known as “spurious regression” (see Granger and Newbold 1974), is basically due to two reasons. First, there is a possibility that the regression picks up the trend in the data generating process of the variables involved. The second reason is that the conventional statistical distributions do not hold in the presence of nonstationary series and inferences might be misleading. It is therefore imperative to test this important property of the series, before any attempt is made to model the series.

A series is said to be stationary if its mean and variance remain constant over time and its autocovariances depend only on the distance between the two observation points. In mathematical form these conditions for a time series y_t can be written as;

$$E(y_t) = \mu$$

$$E[(y_t - \mu)^2] = E[(y_{t-s} - \mu)^2] = \sigma^2$$

$$E[(y_t - \mu)(y_{t-s} - \mu)] = E[(y_{t-j} - \mu)(y_{t-j-s} - \mu)] = \gamma_s$$

where

$$\sigma^2 = \text{var}(y_t)$$

$$\gamma_s = \text{cov}(y_t, y_{t-s}) = \text{cov}(y_{t-j}, y_{t-j-s}) \quad \text{for } s=1, \dots, n$$

$$\rho_s = \text{cov}(y_t, y_{t-s}) / \text{var}(y_t) = \gamma_s / \sigma^2 \quad \text{for } s=1, \dots, n$$

where μ , σ^2 , γ_s , ρ_s are the mean, variance, autocovariance and autocorrelation of the series respectively.

By the same token, series that do not show constancy in their means and variances are known as nonstationary series. There are two types of nonstationary series, 1) trend stationary series and 2) difference stationary series. A trend stationary (TS) series is defined as a series, which is stationary around a constant linear trend and needs to be detrended to become stationary. A difference stationary series (DS) is a series, which contains a stochastic trend and has to be differenced at least once in order to become stationary.

A property of nonstationary series is that they retain the effect of shocks for a long period; that is, the effect of shocks persists in the series. This is because there is a high degree of dependence between successive observations. As a result, the autocorrelation function of the series, ρ_s , decays very slowly. The simplest form of a nonstationary series is a random walk (RW) process. By definition, a random walk is a data generating process in which the current value of the series, y_t , is equal to the value of the series last period, y_{t-1} , plus an identically and independently distributed error term with zero mean and constant variance, $u_t \sim \text{iid}(0, \sigma^2)$.

$$y_t = y_{t-1} + u_t \quad u_t \sim \text{iid}(0, \sigma^2) \quad (3.1)$$

The above RW model can be extended to include a drift or a trend or both simply by adding a constant or a trend term to the right hand side of the equation.

There are a large number of studies in the literature on testing the stationarity of time series and most of them test whether the data generating process of a series follows a random walk process. These studies include; Dickey and Fuller (1979), Sargan and Bhargava (1983), Phillips and Perron (1988) among others. The following sections present a brief review of a few widely used tests in determining the stationarity of time series.

3.2.1. Dickey-Fuller and Augmented Dickey-Fuller tests

Almost all tests proposed in the literature to determine the stationary nature of a series are based on examining whether the series follows a random walk process. Dickey and Fuller (1979) utilise this property of a random walk process and propose a procedure to test for

stationarity of a time series. This procedure is based on testing whether the coefficient of the autoregressive term in the following equation is unity; that is, $\rho=1$.

$$y_t = \rho y_{t-1} + u_t \quad u_t \sim \text{iid}(0, \sigma^2) \quad (3.2)$$

Subtracting y_{t-1} from both sides of equation (3.2) and rearranging the equation results in

$$(1-B) y_t = \Delta y_t = (\rho-1) y_{t-1} + u_t \quad u_t \sim \text{iid}(0, \sigma^2) \quad (3.3)$$

$$= \rho^* y_{t-1} + u_t \quad (3.3')$$

where B is the back shift operator. Dickey and Fuller (1979) test whether ρ in the regression equation (3.3) is significantly different from unity, which is equivalent to testing whether the estimated value of ρ^* in equation (3.3) is significantly different from zero. If ρ^* is not significantly different from zero, then the series follows a random walk and is nonstationary. On the other hand, if ρ^* is significantly different from zero ($\rho^* < 0$ or $\rho < 1$), then the series does not follow a random walk process and is stationary. This means that the future value of the series will depend on its current value with a coefficient less than one. As a consequence, the moments of the series are constant (perhaps around a linear trend which can be zero) over time. If the series in equation (3.3) are not stationary then the statistical distributions will be different from the conventional ones and critical values have been calculated through Monte Carlo simulations, see Dickey and Fuller (1979).

A crucial point in using the Dickey-Fuller, or any other unit root test, is the correct specification of the regression model in terms of its deterministic components (constant and trend). This is important since such deterministic components change the distributional properties of unit root tests. In fact, the data generating process assumed for the unit root test in equation (3.1) is too restrictive and the model assumes that the mean of the dependent variable is zero, i.e. the series does not drift. It is also assumed that there is no trend in the data generating process. Dickey and Fuller (1981) relax these constraints by including different deterministic components in equation (3.3), and reproducing the critical values for the more general tests. Thus, (3.4) includes a constant, while (3.4') includes both a constant as well as a linear trend.

$$\Delta y_t = \mu + \rho^* y_{t-1} + u_t \quad u_t \sim iid(0, \sigma^2) \quad (3.4)$$

and

$$\Delta y_t = \mu + \gamma t + \rho^* y_{t-1} + u_t \quad u_t \sim iid(0, \sigma^2) \quad (3.4')$$

Once more the DF test involves estimating equation (3.4) or (3.4') using OLS and testing the null hypothesis of a unit root, $H_0: \rho^*=0$, against the alternative, $H_1: \rho^*<0$. Appropriate critical values are provided for different sample sizes and model specifications by Dickey and Fuller (1981) and denoted as, τ for model (3.3'), τ_μ for model (3.4) and τ_τ for model (3.4').

They also suggest testing the joint hypothesis that $\mu=\rho^*=0$ in model (3.4), $\gamma=\rho^*=0$ and $\gamma=\mu=\rho^*=0$ in model (3.4'), through non-standard F statistics, Φ_1 , Φ_3 and Φ_2 , respectively. This would allow one to identify the correct model for unit root testing. Appropriate critical values for these tests for different sample sizes can be found in Dickey and Fuller (1981).

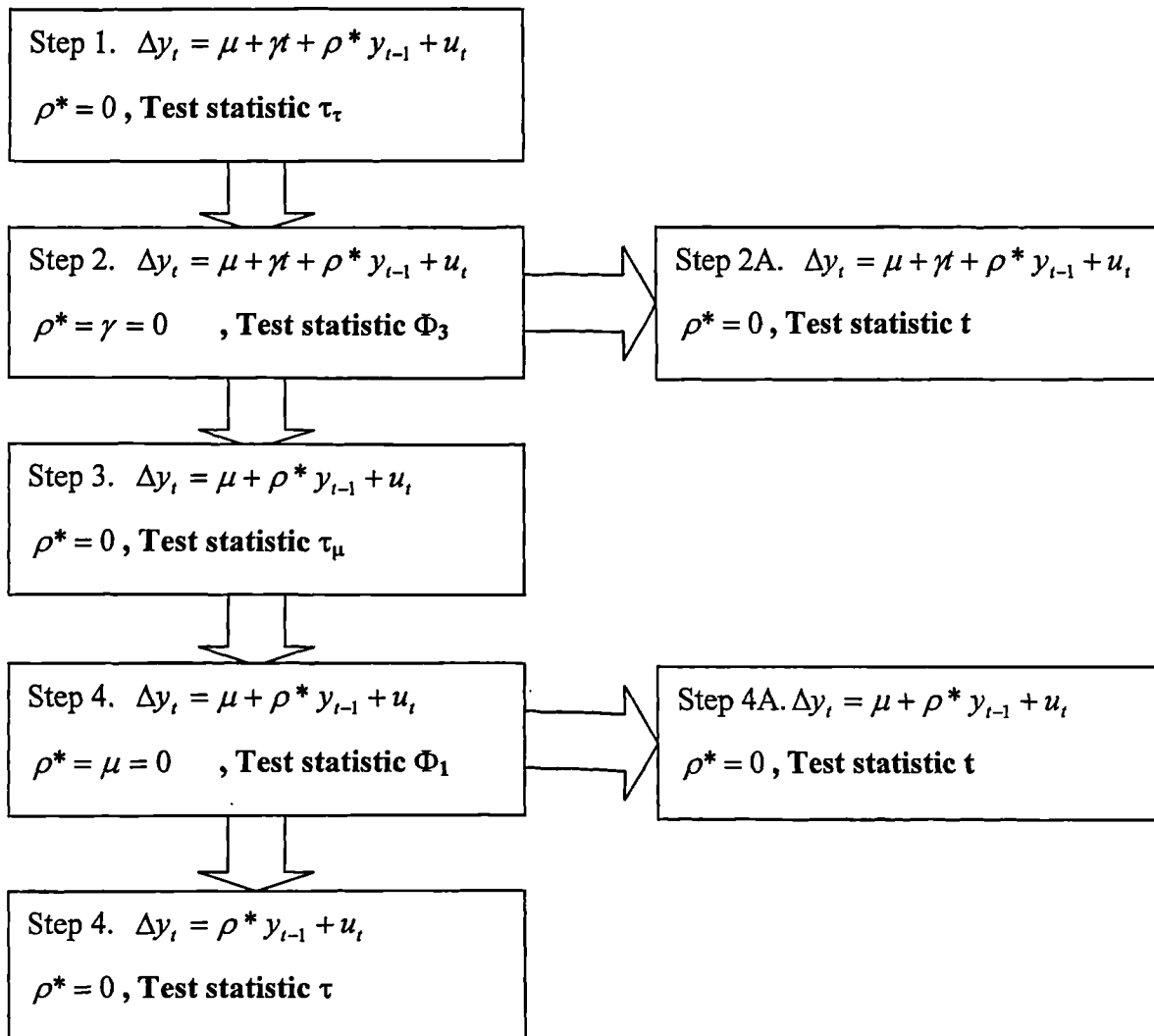
Table 3.1: Critical values for Dickey-Fuller test with deterministic components

	Model 1- AR(1) without drift			Model 2- AR(1) with drift			Model 3- AR(1) with drift And linear trend			
	$\Delta y_t = \rho^* y_{t-1} + u_t$			$\Delta y_t = \mu + \rho^* y_{t-1} + u_t$			$\Delta y_t = \mu + \gamma t + \rho^* y_{t-1} + u_t$			
	1%	5%	10%	1%	5%	10%	1%	5%	10%	
Sample Size	Null : $\rho^* = 0$			Null : $\rho^* = 0$			Null : $\rho^* = 0$			
	Critical values for τ			Critical values for τ_μ			Critical values for τ_τ			
	50	-2.62	-1.95	-1.61	-3.58	-2.93	-2.60	-4.15	-3.50	-3.18
	100	-2.60	-1.95	-1.60	-3.51	-2.89	-2.58	-4.04	-3.45	-3.15
	250	-2.58	-1.95	-1.60	-3.46	-2.88	-2.57	-3.99	-3.43	-3.13
Sample Size				Null: $\rho^* = \mu = 0$			Null : $\rho^* = \gamma = 0$			
				Critical values for Φ_1			Critical values for Φ_3			
	50			7.06	4.86	3.94	9.31	6.73	5.61	
	100			6.70	4.71	3.86	8.73	6.49	5.47	
	250			6.52	4.63	3.81	8.43	6.34	5.39	
Sample Size							Null : $\rho^* = \mu = \gamma = 0$			
							Critical value for Φ_2			
	50						7.02	5.13	4.31	
	100						6.50	4.48	4.16	
	250						6.22	4.75	4.07	

Source: Dickey and Fuller (1981)

A problem that arises here is that the true data generating process is not known. That is, it is not known whether equation (3.3), (3.4) or (3.4') should be used for testing. Perron (1988) proposes a sequential testing approach, which starts with the most general test; that is, a model with intercept and trend. Then, insignificant terms are dropped one by one, using the procedure shown in Figure 3.1 and critical values from Table 3.1, until the final model is obtained.

Figure 3.1: Sequential testing procedure for Dickey-Fuller test when the true data generating process is unknown



Following Perron's sequential testing procedure, failing to reject the null of unit root using the least restrictive model in terms of deterministic components (step 1) and the τ_τ statistic, one has to test whether deterministic terms are significant. Therefore, if in step 2, using the Φ_3 statistic, the joint test of $\rho^* = \gamma = 0$ is rejected, it means that the trend is significant and model 2A is appropriate and the null of $\rho^* = 0$ can be tested using critical values for standard t-distributions. However, if the null of $\rho^* = \gamma = 0$ could not be rejected, one should proceed to step 3 and restrict the model further. At this stage, if the null of $\rho^* = 0$ is rejected by the τ_μ statistic, then the joint F test, $\rho^* = \mu = 0$, of stage 4 should be performed. Rejection of the joint test through the Φ_1 statistic implies that the constant is significant; that is, the series drifts over time and step 5 should be followed. However, not rejecting the joint test in step 4, implies that the series does not drift and step 5, which excludes the constant term from the test, should be followed.

Clearly most of economic as well as shipping variables are not generated by a simple first order Autoregressive, AR(1), process. In fact, they might be generated by more complicated AR(p) or ARMA(p,q) processes. Therefore, using regression equation (3.4) or (3.4') for unit root tests may result in autocorrelated error term, while in the DF test the error terms are assumed to be identically and independently distributed with zero mean and constant variance; that is, $\varepsilon_t \sim \text{iid}(0, \sigma^2)$. Since this strong assumption does not hold in most cases, two ways are proposed in the literature to modify the standard Dickey-Fuller test. The first approach which is suggested by Dickey and Fuller (1981) and Said and Dickey (1984), is a parametric approach which augments the test using lagged values of the dependent variable in order to make the residuals white noise. The second method, which is proposed by Phillips and Perron (1988) is to apply some form of nonparametric corrections to the test statistics from equation (3.4) and (3.4'), (see section 3.2.2 for further discussion on Phillips and Perron test).

In the former approach, Dickey and Fuller (1981) augmented the regression equation (3.4) and (3.4') by adding lagged dependent variables to the right hand side of the equations so as to make the residuals white noise, as in equation (3.5). The ADF test based on this equation is known as the Augmented Dickey-Fuller test (ADF).

$$\Delta y_t = \mu + \gamma + (\rho - 1)y_{t-1} + \sum_{i=1}^k \delta_i \Delta y_{t-i} + u_t \quad u_t \sim iid(0, \sigma^2) \quad (3.5)$$

A problem which arises in augmenting the DF test is to find the optimal order of augmentation (lag-length, k) in equation (3.5). It has been observed that the power of the test is sensitive to the number of lags used, especially in small samples. Different methods are suggested in the literature for this purpose, each with its own advantages and disadvantages. For example, one can use the Akaike or Schwarz Bayesian Information Criteria (AIC, SBIC) to find the optimum autoregressive lag length using the following formula.

$$AIC = \log \hat{\sigma}_l^2 + 2l/T \quad SBIC = \log \hat{\sigma}_l^2 + l \log(T)/T$$

Where l is the number of lags included for augmentation, T is the number of observations and $\hat{\sigma}_l^2$ is the estimate of the variance of the residuals from the corresponding ADF equation.

Hall (1994) proposes a general to specific approach in selecting the appropriate lag length. This method first estimates the ADF equation with a large number of lagged dependent variables and then drops the ones, which are not significant. An alternative strategy is to select the number of autoregressive terms using specification tests such LM and Ljung-Box tests to eliminate residual autocorrelation in equation (3.5).

3.2.2. Phillips and Perron tests

Phillips and Perron (1988) suggest an alternative, non-parametric correction to t-statistic of regression (3.4), to overcome the problem associated with the possible autocorrelation of the error terms in equation (3.4).

As Perron (1988) points out, the bias in drawing inferences on estimates of regression (3.4), is because of the difference in the true population variance and the variance of the residuals in regression equation (3.4), which arises due to the existence of autocorrelation in the residuals. The difference between the consistent estimator of the variances of the population and the sample is

$$S_{\varepsilon}^2 = T^{-1} \sum_{t=1}^T \varepsilon_t^2 \quad (3.6)$$

$$S_p^2 = T^{-1} \sum_{t=1}^T \varepsilon_t^2 + 2T^{-1} \sum_{t=1}^l \sum_{j=t+1}^T \varepsilon_t \varepsilon_{t-j} \quad (3.7)$$

where S_{ε}^2 , S_p^2 are the sample and population variance of residuals, respectively, and l represents the lag truncation for the autocorrelation in the residuals. The second term on the right hand side of equation (3.7) is the difference between the sample and population variance of the residuals due to autocorrelation. If there is no autocorrelation in the residuals the second term on the right hand side of equation (3.7) will be zero; that is, the true and the estimated value of the residual variance will be equal and the estimates in equation (3.7) will be unbiased. Therefore, the corrected version of the DF test according to Phillips and Perron (1988) can be

$$Z(\tau_{\mu}) = (S_{\varepsilon} / S_p) \tau_{\mu} - 0.5(S_p^2 - S_{\varepsilon}^2) \left\{ S_p \left[T^2 \sum_{t=2}^T (Y_{t-1} - \bar{Y}_{t-1}) \right]^{1/2} \right\}^{-1} \quad (3.8)$$

where τ_{μ} represents the t statistics for testing unit roots in the DF test, equation (3.4). $Z(\tau_{\mu})$ is the Phillips-Perron statistic for testing unit roots in the presence of residual autocorrelation. The critical values are the same as in the DF test and when there is no serial correlation in the error term the t statistics from both tests, ADF and PP are equal.

Like any other statistical tool, these unit root tests also suffer from problems of size and power. The sample size is an important factor for such tests since in finite samples the distinction between a trend stationary (TS) process and a difference stationary (DS or unit root) process is not clear and may cause confusion. Existence of structural breaks and mean-shift within the sample period is another problem, which may distort the results. A permanent shift in the trend of a process which is stationary around its trend or even a permanent change in the mean of the series can be quite misleading in deciding whether a series is stationary or not. A treatment for this ambiguity is to add dummies when this type of shift is known. This method, which is proposed by Perron (1989), requires a new set of critical values. Perron (1989 and 1990) reports critical values for such tests.

Following the discussion on unit roots, when a series is non stationary and exhibits a unit root, as revealed by ADF or PP tests, it might be possible to turn this series to a *stationary* series by some sort of transformation. In most cases the first difference $[(1-B)y_t = \Delta y_t]$ of economic series are found to be stationary. In time series analysis a series with this property is called an integrated series of order one, $I(1)$. By the same token, a stationary series is presented as $I(0)$. There are cases where a series needs to be differenced twice to be transformed into a stationary series. The original series is then said to be integrated of order two, $I(2)$. In general, a series which needs to be differenced d times to become stationary is denoted as $I(d)$. It is however important to conduct such test carefully in order to avoid over- or under-differencing. Abeysinghe (1994) outlines the problems of over- and under-differencing. He argues that over-differencing can result in loss of important information regarding the relation among the variables, while under differencing can lead to spurious regression results.

Finally, unit roots tests such as DF, ADF, and Phillips and Perron tests fail to take account of unit roots at different frequencies, such as seasonal and periodic unit roots in cases where periodic time series are involved. A number of studies in recent years have documented the importance of detecting unit roots at frequencies other than zero for model building and forecasting. These studies include Hylleberg et al (1990), Franses (1994), Beaulieu and Miron (1993), Engle et al (1993) and Franses and Hobijn (1997), among others. These unit root tests can be considered as more general form of ADF test which take into account of periodicity of time series and detect unit roots at frequencies other than zero, better known as seasonal unit roots. A full discussion of these tests is given in section 3.3.3 after the discussion on seasonality and periodicity.

3.3. Stochastic and Deterministic Seasonality

A time series, measured more than once a year (e.g. at monthly, quarterly or semi-annual intervals), is said to contain seasonal components when there are systematic patterns in the series at the measured points (seasons) within the year. This may be due to changes in the weather, the calendar, or the behaviour of agents involved in decision making. These systematic changes may or may not be regular due to different circumstances such as technological changes, political reforms or changes in consumers' tastes.

The number of studies testing and verifying the seasonal behaviour of financial and economic time series has increased recently as the importance of the matter in econometric and structural time series modelling and forecasting is recognised (see, for example, Han and Thury (1997), Albertson and Aylen (1997), Kulendran and King (1997) and Lee and Siklos (1991)). As Wallis (1974) notes, it is important to study the seasonal behaviour of the data because using seasonally adjusted data may distort the dynamics of the constructed models and result in biased estimates. At the same time, knowing the seasonal behaviour of the data allows better model specification, which in turn can improve the reliability of forecasts. Therefore, when modelling time series with seasonal frequencies such as quarterly, monthly or even weekly data, the seasonal behaviour of the series should be examined first.

Seasonal behaviour of economic time series can take three forms; stochastic, deterministic, or a combination of the two. A series with stochastic seasonality does not follow a unique seasonal pattern. Its behaviour changes over time (for example, winter becomes summer), whereas a series with deterministic seasonality has the same seasonal behaviour (peaks and troughs) every year. In addition, series with stochastic seasonality retain the shocks for a long period, unlike the deterministic seasonal series in which shocks diminish relatively quickly.

It is important to distinguish between different types of seasonality in time series analysis, both from the econometric and the economic point of view. Failing to recognise the existence of stochastic seasonality in time series may lead to spurious regression results (see for example Hylleberg et al 1990), while taking account of deterministic seasonality of time series may improve the explanatory power of econometric models and result in better forecasts. From the economic point of view, distinguishing between stochastic and

deterministic seasonality would improve the effectiveness of decisions and policies based on the seasonal behaviour of the series; that is, if the pattern of seasonality changes over time (i.e. if it is stochastic), then policies should be revised periodically.

3.3.1. Deterministic Seasonality

Deterministic seasonal variations in a series can be investigated by regressing the growth rate of the variable, ΔX_t , (where X_t is the natural logarithm of the series), against a constant, β_0 , and a set of seasonal dummy variables, as in equation (3.9),

$$\Delta X_t = \beta_0 + \sum_{i=2}^{12} \beta_i Q_{i,t} + \varepsilon_t \quad ; \quad \varepsilon_t \sim \text{iid}(0, \sigma_\varepsilon^2) \quad (3.9)$$

Where Q_{it} , $i=2, \dots, s$, are relative seasonal dummies¹, s is the number of periods the variable is measured over the year (for example $s=4$ for quarterly series and $s=12$ for monthly series), β_i are the parameters of interest and ε_t is a white noise error term².

The above model can be estimated by OLS. The significance of each seasonal dummy indicates the existence of deterministic seasonality in the respective period; that is, a significant change in the dependent variable compared to its long-run mean, β_0 . The overall contribution of deterministic seasonal variation in the behaviour of a time series can be measured by the coefficient of determination, R^2 , of the model when no other variable is included in the equation. The joint significance of these seasonal dummies may be tested using likelihood ratio, LR, Wald and F statistics.

¹ Relative seasonal dummies are constructed as $Q_{it} = D_{i,t} - D_{1,t}$, $i=2, \dots, 12$ where $D_{1,1}, \dots, D_{12,1}$ are 0, 1 monthly dummies. In this case, the coefficient for the base month, January, can be calculated as $\beta_1 = -\sum_{i=2}^{12} \beta_i$. The standard error of the January coefficient can be calculated from the estimated variance-covariance matrix of the coefficients as $se(\beta_1) = \left\{ \sum_{i=2}^{12} Var(\beta_i) + 2 \sum_{i=2}^{12} \sum_{j=2}^{12} Cov(\beta_i, \beta_j) \right\}^{1/2}$. See also Suits (1984) and Greene and Seaks (1991) for an alternative restricted least squares procedure.

² Alternatively, one can regress the growth rate of the series, ΔX_t on 12 seasonal dummies, $D_{i,t}$ where $i=1, \dots, 12$. In such case, the significance of a dummy coefficient indicates a change in the series in that particular month compared to the previous month.

If the ε_t in equation (3.9) is not white noise, the standard error of the parameter estimates may be corrected for heteroscedasticity using the White (1980) heteroscedasticity consistent covariance matrix, or for both heteroscedasticity and serial correlation using the Newey and West (1987) method³. ARCH effects are not a problem as long as the ARCH coefficients show stationarity (see Greene 1997, p. 570).

3.3.2. Seasonality under different market conditions

Canova and Ghysels (1994), using a generalised predictive power tests, argue that the magnitude of seasonality in a series might not be constant over time. They find that the deterministic seasonal coefficients in many macroeconomic variables depend on the prevailing market conditions; that is, on the business cycle phase. This is an important issue in the cyclical shipping freight markets since the elasticity of supply is thought to be high during troughs and low in peaks of the shipping business cycle. As a result, changes in demand during the recovery period of the cycle produce stronger reactions in rates compared to market downturns. Therefore, one needs to take into account such market cyclicity before drawing any conclusions on the seasonal behaviour of the series. The following sub-sections present alternative methods that deal with cyclical seasonality.

3.3.2.1. Switching regression model for seasonality

To investigate seasonality under different market conditions, we extend equation (3.9) to the following threshold switching seasonal regression model, (see, e.g. Campbell et al (1997), p. 472).

$$\Delta X_t = \beta_{1,0}d_{1,t} + \sum_{i=2}^{12} \beta_{1,i}(d_{1,t}Q_{i,t}) + \beta_{2,0}d_{2,t} + \sum_{i=2}^{12} \beta_{2,i}(d_{2,t}Q_{i,t}) + \varepsilon_t \quad ; \quad \varepsilon_t \sim \text{iid}(0, \sigma_\varepsilon^2) \quad (3.10)$$

³ Alternatively, equation (3.9) can be estimated with an ARMA structure in order to capture the serial correlation in the error terms.

$$\text{where state dummies } d_{1,t} \text{ and } d_{2,t} \text{ are } \begin{cases} d_{1,t} = 1 \text{ and } d_{2,t} = 0 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} > 0 \quad \text{upturn} \\ d_{1,t} = 0 \text{ and } d_{2,t} = 1 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} \leq 0 \quad \text{downturn} \end{cases}$$

In the threshold switching seasonal model of equation (3.10) two dummies, d_1 and d_2 , allow estimation of different seasonal coefficients according to the prevailing market conditions. The state of the market is distinguished according to whether the freight growth rate at each point in time is above or below the 12-month trend in the market, as defined by a centred moving average process. A comparison between the OLS estimates of parameters in equation (3.10), $\beta_{1,i}$ and $\beta_{2,i}$, $i=0, \dots, 12$, can give an indication of differences in seasonal behaviour of freight rate series under different market conditions. For example, $\beta_{1,0}$ and $\beta_{2,0}$ coefficients show the average growth/decline in freight rates during market expansion and recession, respectively. The two sets of seasonal coefficients, $\beta_{1,i}$ and $\beta_{2,i}$, $i=1, \dots, 12$, show the seasonal rise or fall in freight rates with respect to the monthly average under each market condition during market expansions and contractions, respectively⁴.

3.3.2.2. Markov switching model for seasonality

Alternatively, one can investigate whether seasonal effects vary under different market conditions, by extending equation (3.9) to the following two-state Markov switching seasonal regression model, which allows structural shifts in the behaviour of the time series over the estimation period (see, e.g. Hamilton (1989, 1994)).

$$\Delta X_t = \beta_{0,S_t} + \sum_{i=2}^{12} \beta_{i,S_t} Q_{i,t} + \varepsilon_{S_t,t} \quad ; \quad \varepsilon_{S_t,t} \sim \text{iid}(0, \sigma_{S_t}^2), \quad S_t = 1, 2 \quad (3.11)$$

where S_t is an unobserved state variable, which determines the state of the market; that is, expansion or contraction. Therefore, seasonal parameters in equation (3.11) depend on the state of the market, S_t . The variable S_t follows a two-state first order Markovian process with the following transition probabilities (see Kavussanos and Alizadeh, 2001, for more detail).

⁴ However, some studies in the literature such as Lo and Mackinlay (1990) argue against this method in which the differentiation of market conditions is based on prior investigation of data and is somehow ad hoc.

3.3.3. Stochastic Seasonality and Seasonal Unit Roots

An additional problem when testing for deterministic seasonality is that if the X_t series is (seasonally) stochastic, then inferences are invalidated, see Franses et al (1995). This suggests determining the stochastic properties of the series before considering the issue of deterministic seasonality. Several procedures have been proposed in the literature for testing the stochastic properties of seasonal (periodic) series; see for example, Dickey et al (1984), Osborn et al (1988), Hylleberg et al (1990) and Franses (1991 and 1994). The Hylleberg et al (1990), so called HEGY, approach seems to be the most promising. HEGY (1990) recognise that unit roots in a periodic series may exist at more than one frequency⁵. They propose a procedure to test for the existence of unit roots at all possible frequencies, seasonal and non-seasonal, for quarterly series⁶. The intuition behind the HEGY test is to filter the series from all possible unit roots except one and test for the significance of that unit root. Then use another filter to separate a different set of unit roots except one and test for the latter. This procedure is continued until the existence of all possible unit roots is tested for.

More formally, if a seasonal differencing operator can transform the series into a stationary series, then it is possible to write

$$(1-B^s)X_t = \Delta^s X_t = \varepsilon_t \quad (3.12)$$

where ε_t is white noise. This seasonal back shift operator can have up to s roots, which are the characteristic roots of the polynomial $(1-B^s)$. Some of these roots are real while others are complex. The aim is to test for each unit root individually. In order to achieve this, Hylleberg et al (1990) suggest a method which linearises the seasonal lag polynomial, $(1-B^s)$, around all

⁵ For time series that can be observed more than once a year (e.g. weekly, monthly or quarterly) the number of observations or data points within a year is called the periodicity of the data, denoted as s . Correspondingly, a series with a periodicity equal to s may contain $(s-1)$ cycles called seasonal cycles. Each cycle is associated with a seasonal frequency which can be denoted as $\alpha=2\pi j/s$, $j=1, \dots, s-1$, and a zero frequency which is associated with no cycle.

⁶ A major problem with the other methods of testing seasonal unit roots, Dickey et al (1984) and Osborn et al (1988), is that they do not recognise the possibility that unit roots may exist at different frequencies (possibly more than one). In modelling, this leads to over-differencing of the series, since these test procedures require the series to be differenced twice at the zero frequency. Abeyasinghe (1994) outlines the problems of over-differencing and under-differencing. He argues that over-differencing can result in loss of important information regarding the relation among the variables, while under differencing can lead to spurious regression results.

the possible roots at different frequencies. This makes it possible to distinguish the roots and test the original series for all the existing seasonal and non- seasonal unit roots at different frequencies by simple OLS regressions.

Beaulieu and Miron (1993) extend the HEGY (1990) method to monthly series. In order to find the possible characteristic roots for all the frequencies, the polar representation of a seasonal root is written as $e^{\alpha i}$ where α is the frequency of that root (see Appendix 3.A for more details). Therefore, for monthly series with frequencies equal to $\pi, \pm\pi/2, \mp 2\pi/3, \pm\pi/3, \mp 5\pi/6, \pm\pi/6$ with the corresponding cycles of 6, 3, 9, 8, 4, 2, 10, 7, 5, 1 and 11, the seasonal unit roots are

$$-1 ; \pm i ; -\frac{1}{2}(1 \pm \sqrt{3}i) ; \frac{1}{2}(1 \pm \sqrt{3}i) ; -\frac{1}{2}(\sqrt{3} \pm i) ; \frac{1}{2}(\sqrt{3} \pm i)$$

respectively. Out of these 11 seasonal roots, the first one is real and the rest are complex.

Having found the seasonal roots, expanding the seasonal back shift operator, $(1-B^{12})$, around these roots, following some algebraic manipulations and including deterministic components, such as a constant, α_0 , a trend, t , and seasonal dummies, $\sum Q_{i,t}$, as well as lagged values of the dependent variable, $\sum \Delta^{12} X_{t-i}$, to account for possible serial correlation in the residuals, result in

$$(1-B^{12})X_t = \Delta^{12}X_t = \alpha_0 + \beta_0 t + \sum_{i=2}^{12} \beta_i Q_{i,t} + \sum_{j=1}^{12} \pi_j Y_{j,t-1} + \sum_{k=1}^p \gamma_k \Delta^{12} X_{t-k} + \varepsilon_t \quad (3.13)$$

where $Y_{j,t-1}$ are different seasonal filters in the form of back-shift polynomials defined in the appendix, and π_j are the seasonal and non-seasonal unit root coefficients. In equation (3.13), tests for the significance of $\pi_j, j=1, \dots, 12$, as proposed by Hylleberg et al(1990) and Beaulieu and Miron(1993), are equivalent to testing for seasonal unit roots at the associated frequencies. Critical values for these tests are tabulated in Beaulieu and Miron (1993). Inclusion of seasonal dummies in the equation allows joint determination of the existence of deterministic and stochastic seasonality (seasonal unit roots). Significance of the β_i parameters would indicate the presence of deterministic seasonality in the series.

The null hypothesis of the existence of a unit root at each frequency is: $H_0: \pi_j=0, j=1, \dots, 12$ for monthly data. The alternative of stationarity is $H_1: \pi_j < 0$ for $j=1, 2$; that is, zero and one cycle per year frequencies. The condition for a unit root to exist for all other frequencies is, $\pi_j=0$, for $j=2$ and a joint F-test of $\pi_{j-1}=\pi_j=0$, for $j \geq 4$. It is possible to reject the existence of unit root at all frequencies other than zero, if $\pi_j \neq 0$, for $j=2$. The joint F-test is used because the pairs of complex roots cannot be distinguished and they always operate together. Beaulieu and Miron (1993) produced and tabulated the critical values for testing the significance of the parameters of interest for monthly data with different combinations of intercept, trend and seasonal dummies.

Other methods for testing seasonal unit roots in monthly series have also been developed recently which use the same basic principle as the HEGY (1990) method. The first method, which is proposed by Franses (1991)⁷ should give the same results as Beaulieu and Miron (1993) since they use the same principle. The second, proposed in Franses (1994)⁸ cannot be applied to our data set since it requires longer samples compared to what we have available.

⁷ Franses (1991) proposes a method for testing seasonal unit roots in a univariate framework using a similar approach to HEGY(1990) and Beaulieu and Miron (1993), i.e. linearisation of the seasonally differenced polynomial, $(1-B^{12})$, around its characteristic roots. Franses and Hobijn (1997) tabulate the critical values for Franses (1991) and Beaulieu and Miron (1993) seasonal unit root tests with different deterministic components and sample sizes. The results from Franses (1991) test should be equivalent to Beaulieu and Miron (1993).

⁸ Another approach for testing the existence of seasonal unit roots is proposed by Franses (1994). This is a multivariate approach which can be performed by decomposing the seasonal series (monthly or quarterly) into $s(12 \text{ or } 4)$ different annual series. The method uses Johansen's multivariate approach to determine the existence of cointegrating vectors among the annual series. One problem with this approach is that when the sample period is not long, the test is not applicable. This is due to the loss of degrees of freedom. In such cases, it is better to follow the Beaulieu and Miron (1993) procedure to check for the presence of stochastic seasonality.

3.4. Vector Autoregression

When several variables are related to each other, normal econometric practice suggests modelling those variables in a simultaneous system of equations. Therefore, for a vector of variables $\mathbf{z}_t = (y_{1t}, y_{2t}, \dots, y_{nt})$, the following model can be specified to capture the dynamic relationships between them:

$$\mathbf{A}\mathbf{z}_t = \mathbf{A}_0 + \mathbf{A}_1\mathbf{z}_{t-1} + \dots + \mathbf{A}_p\mathbf{z}_{t-p} + \mathbf{\Psi}\mathbf{w}_t + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{IN}(0, \Sigma) \quad (3.14)$$

\mathbf{z}_t is $(n \times 1)$ vector of variables, \mathbf{w} is a $(p \times 1)$ vector of exogenous variables, $\mathbf{\Psi}$ is a $(p \times p)$ matrix of parameters for exogenous variables and each \mathbf{A}_i is an $(n \times n)$ matrix of parameters. The above model implies that each variable in the vector \mathbf{z}_t is explained in terms of its own lag values as well as the current and lagged values of other variables present in the system. Therefore the parameters in \mathbf{A}_i explain the dynamic interrelationships among the variables in \mathbf{z}_t .

However, there are major problems associated with this type of modelling, such as identification, exogeneity and dynamics, which are discussed in detail in econometric textbooks, see Pindyck and Rubinfeld (1998). Sims (1980) proposes the Vector-Autoregression (VAR) method as an alternative to simultaneous equation modelling to overcome the problem of identification and dynamics in a system. He suggests that since all the variables in an economic system are in continuous interaction, it is difficult and sometimes impossible to distinguish between exogenous and endogenous variables, therefore one can consider all these variables as endogenous variables and model them simultaneously in a system. Therefore, ignoring the set of exogenous variables, \mathbf{w}_t , and constant terms, \mathbf{A}_0 , in (3.14) for simplicity, a two variable VAR(1) model can be written as

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} a_{11}^1 & a_{12}^1 \\ a_{21}^1 & a_{22}^1 \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}, \quad \boldsymbol{\varepsilon}_t \sim \text{IN}(0, \Sigma_\varepsilon) \quad (3.15)$$

where

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, \quad \mathbf{A}_1 = \begin{pmatrix} a_{11}^1 & a_{12}^1 \\ a_{21}^1 & a_{22}^1 \end{pmatrix}, \quad \Sigma_\varepsilon = \begin{pmatrix} \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1 \varepsilon 2} \\ \sigma_{\varepsilon 2 \varepsilon 1} & \sigma_{\varepsilon 2}^2 \end{pmatrix}$$

The above system of simultaneous equations is known as the structural VAR, where a_{12} and a_{21} measure contemporaneous effects of y_{2t} on y_{1t} and y_{1t} of y_{2t} , respectively. It is however possible to pre-multiply the VAR system in (3.15) by A^{-1} to obtain

$$\begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}^{-1} \begin{pmatrix} a_{11}^1 & a_{12}^1 \\ a_{21}^1 & a_{22}^1 \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}^{-1} \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \quad (3.16)$$

Such re-parameterisation results in a new set of parameters in terms of the elements of A and A_1 . Therefore the new VAR model which is known as the reduced form of the VAR can be written as

$$\begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \end{pmatrix} + \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix}, \quad \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix} \sim \left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{u1}^2 & \sigma_{u1u2} \\ \sigma_{u2u1} & \sigma_{u2}^2 \end{pmatrix} \right) \quad (3.17)$$

where

$$\begin{aligned} \phi_{11} &= (a_{22}a_{11}^1 - a_{21}a_{21}^1)/|A|, & \phi_{12} &= (a_{22}a_{12}^1 - a_{22}^1a_{21})/|A| \\ \phi_{21} &= (-a_{12}a_{11}^1 + a_{11}a_{21}^1)/|A|, & \phi_{22} &= (-a_{12}a_{12}^1 + a_{11}a_{22}^1)/|A| \\ \sigma_{u1}^2 &= (a_{22}^2\sigma_{\varepsilon1}^2 - 2a_{12}a_{22}\sigma_{\varepsilon1\varepsilon2} + a_{12}^2\sigma_{\varepsilon2}^2)/|A|^2 \\ \sigma_{u1u2}^2 &= (-a_{21}a_{22}\sigma_{\varepsilon1}^2 + (a_{21}a_{12} + a_{11}a_{22})\sigma_{\varepsilon1\varepsilon2} - a_{12}a_{11}\sigma_{\varepsilon2}^2)/|A|^2 \\ \sigma_{u2}^2 &= (a_{21}^2\sigma_{\varepsilon1}^2 - 2a_{21}a_{11}\sigma_{\varepsilon1\varepsilon2} + a_{11}^2\sigma_{\varepsilon2}^2)/|A|^2 \\ |A| &= \text{determinant of } A \end{aligned} \quad (3.18)$$

It can be seen that estimating the VAR model (3.17) (the reduced form of the VAR) yields seven parameters, namely, $\phi_{11}, \phi_{12}, \phi_{21}, \phi_{22}, \sigma_{u1}^2, \sigma_{u1u2}$ and σ_{u2}^2 . However, there are a total of eleven parameters in the structural VAR model in equation (3.15), these are; $a_{11}, a_{12}, a_{21}, a_{22}, a_{11}^1, a_{12}^1, a_{21}^1, a_{22}^1, \sigma_{\varepsilon1}^2, \sigma_{\varepsilon1\varepsilon2}$ and $\sigma_{\varepsilon2}^2$. This means that four restrictions (11-7=4) must be imposed on the structural VAR model of (3.15), in order for the model to be identified; that is, to be able to find unique values for the parameters of (3.15).

One approach is to restrict the values of the parameters in matrix A in the structural VAR of (3.15) in such a way so that the matrix A represents an identity matrix, i.e. $a_{11}=1$, $a_{12}=0$, $a_{21}=0$ and $a_{22}=1$. The four restrictions imposed on A means that there is no contemporaneous relationship between the two variables, y_{1t} and y_{2t} . Imposing such restrictions ensures an identified model since there are exactly seven parameters to estimate. Imposing the above restrictions on parameter estimates in (3.18) results in

$$\begin{aligned} \phi_{11} &= a_{11}^1, & \phi_{12} &= a_{12}^1, & \phi_{21} &= a_{21}^1, & \phi_{22} &= a_{22}^1 \\ \sigma_{U1}^2 &= \sigma_{\varepsilon 1}^2, & \sigma_{U1U2}^2 &= \sigma_{\varepsilon 1\varepsilon 2}, & \sigma_{U2}^2 &= \sigma_{\varepsilon 2}^2 \end{aligned}$$

However, it can be seen that the residual variance matrix might not be diagonal, which means that error terms might be correlated. This is because by restricting a_{21} or a_{12} in A , we impose the restriction that there is no contemporaneous relationship between the variables y_{1t} and y_{2t} . Therefore, such contemporaneous relationship between the variables might be reflected in the residuals and result in a non-diagonal covariance matrix.

An alternative approach to ensure identification as well as diagonal covariance matrix in estimation of (3.22) is to place 3 restrictions on matrix A and set the covariance of residuals to be zero; that is, $a_{11}=1$, $a_{21}=0$, $a_{22}=1$ and $\sigma_{\varepsilon 1\varepsilon 2}=0$, which result in the following reduced form VAR(1)

$$\begin{pmatrix} 1 & a_{12} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} y_{1t} \\ y_{2t} \end{pmatrix} = \begin{pmatrix} a_{11}^1 & a_{12}^1 \\ a_{21}^1 & a_{22}^1 \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}, \quad \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \sim \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1\varepsilon 2} \\ \sigma_{\varepsilon 2\varepsilon 1} & \sigma_{\varepsilon 2}^2 \end{pmatrix} \quad (3.19)$$

$$\varepsilon_t \sim IN(0, \Sigma_\varepsilon)$$

In order to impose the last restriction, i.e. $\sigma_{\varepsilon 1\varepsilon 2}=0$, it is necessary to re-parameterise the covariance matrix of the residuals in (3.19) to get $\Sigma_\varepsilon = \Lambda \Lambda'$, where Λ is the re-scaled covariance matrix of residuals, and Λ is a (2x2) matrix of parameters. Therefore, we can write

$$\begin{aligned} \sigma_{\varepsilon 1}^2 &= \lambda_{11}^2 + \lambda_{12}^2 \\ \sigma_{\varepsilon 1\varepsilon 2} &= \sigma_{\varepsilon 2\varepsilon 1} = \lambda_{11}\lambda_{21} + \lambda_{12}\lambda_{22} \\ \sigma_{\varepsilon 2}^2 &= \lambda_{21}^2 + \lambda_{22}^2 \end{aligned} \quad (3.20)$$

The restriction on the covariance matrix, $\sigma_{\varepsilon_1\varepsilon_2}=0$, requires both λ_{12} and λ_{21} to be zero. In other words, two restrictions, $\lambda_{12}=0$ and $\lambda_{21}=0$, should be imposed on Λ to ensure that the residuals are not correlated, which means an additional restriction (five in total) compared to the set of restrictions suggested previously for identification of the VAR.

Once the VAR model is specified in its reduced form and identified, different estimation techniques such as OLS, ML or GMM can be used to estimate the model. However, in order to obtain unbiased estimates of the matrices of parameters and draw correct inferences around them, an additional condition should be met. This condition requires all the variables included in \mathbf{z}_t to be stationary, $I(0)$. Maintaining the stationarity condition in estimating the VAR model is important because of problems associated with spurious regression and hypothesis testing. It is difficult to maintain such a condition for all the variables in a system, especially economic variables. One method to overcome this problem is to transform the series into stationary series by taking first (or second) differences of the series and use the transformed variables to estimate the following VAR model

$$\Delta \mathbf{z}_t = \sum_{i=1}^k \mathbf{A}_i \Delta \mathbf{z}_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim \text{IN}(0, \Sigma) \quad (3.21)$$

where $\Delta \mathbf{z}_t = \mathbf{z}_t - \mathbf{z}_{t-1}$ is a vector of first differences of $I(1)$ variables \mathbf{z}_t .

However, this approach is not recommended since it considers only first differences of variables, and omits the long run relationship between variables and consequently the information content in such relationships when estimating the model, see Engle and Granger (1987) and Johansen (1988).

An alternative method to overcome the problems associated with the existence of nonstationary variables in a VAR system is to use the cointegration relationships between variables in \mathbf{z}_t . The following section, which is devoted to the cointegration methodology, discusses different methods proposed in the literature to establish cointegration relationships between variables and estimating error correction models when variables are cointegrated.

3.4.1. Cointegration and Error Correction Models

Engle and Granger (1987) recognise that although, in general, a linear combination of two or more nonstationary series $I(d)$ will also be a nonstationary series with the same degree of integration, $I(d)$, there might exist a linear combination of nonstationary series $I(d)$, which has a lower degree of integration $I(d-b)$ where $d \geq b$. This property of nonstationary time series is known as cointegration. For example, if y_t and x_t are two $I(1)$ series, then there might exist a linear combination of y_t and x_t ; that is, $y_t - \beta x_t = \varepsilon_t$, which is stationary, where $\varepsilon_t \sim I(0)$. In this case, y_t and x_t are said to be cointegrated of order $I(1,1)$ and $\beta = (1 \ -\beta)$ is the cointegrating vector. Existence of a cointegrating relationship between y_t and x_t means that there is a long run relationship between the two series and they move closely together over time. Thus, the difference between y_t and x_t , in the cointegrating space (ε_t) is stationary. The difference between x_t and y_t , ε_t , can also be interpreted as the disequilibrium or short term deviation of x_t and y_t from their long run relationship, $y_t - \beta x_t$.

Engle and Granger (1987) recognise the cointegration relationship between nonstationary variables and propose a method to test whether two nonstationary series, x_t and y_t , are cointegrated. This method, known as the Engle-Granger two-step method, involves an OLS regression of y_t on x_t and testing the residual from this regression, ε_t , for unit roots.

$$\text{Step1} \quad y_t = \beta_0 + \beta x_{t-1} + \varepsilon_t \quad (3.22)$$

$$\text{Step2} \quad \Delta \varepsilon_t = \rho \varepsilon_{t-1} + \sum_{i=1}^k \delta_i \Delta \varepsilon_{t-i} + u_t \quad u_t \sim iid(0, \sigma_u^2) \quad (3.23)$$

The distribution of the unit root test statistic for, ε_t , is not the DF distribution anymore and new set of critical values obtained in MacKinnon (1991) should be used for inference in the second step; that is, for the unit root test for ε_t . This is because the OLS estimation in the first step forces the residuals to have minimum variance. As a result the residuals tend to show stationarity more often than usual and reject the null of unit root even when the two series y_t and x_t are not cointegrated.

Moreover, Engle and Granger (1987) suggest that if two series, y_t and x_t , are cointegrated with cointegrating vector $y_t - \beta x_t$, then an error correction model (ECM) can be specified which explains the changes in one variable in terms of lagged Δy_t and Δx_t and the error correction term lagged in the following form

$$\Delta y_t = \gamma_0 + \sum_{i=1}^p \gamma_i \Delta x_{t-i} + \sum_{i=1}^p \mu_i \Delta y_{t-i} + \alpha(y_{t-1} - \beta x_{t-1}) + v_t ; \quad v_t \sim iid(0, \sigma_v^2) \quad (3.24)$$

and since $\varepsilon_{t-1} = y_{t-1} - \beta x_{t-1}$, (3.24) can be written as

$$\Delta y_t = a_0 + \sum_{i=1}^p a_i \Delta x_{t-i} + \sum_{i=1}^p b_i \Delta y_{t-i} + \alpha \varepsilon_{t-1} + v_t , \quad v_t \sim iid(0, \sigma_v^2) \quad (3.25)$$

The lagged error term in (3.25) is in fact last period's disequilibrium from the long run relationship between the two nonstationary series (y_t and x_t) and the coefficient of this term, α , which is known as the speed of adjustment, measures the response of the dependent variable to such disequilibrium. According to Engle and Granger (1987), the above error correction model can be estimated using OLS since all the variables involved, including the error correction term, are stationary. Another advantage of the ECM is that it captures both the long run relationships between the variables and their short run dynamics.

Although quite appealing and useful, the Engle-Granger two-step cointegration method has several limitations. For example, it fails to detect more than one cointegrating relationship between variables, when there are more than two variables involved in the model. This leads to inefficiently estimated coefficients, since the Engle-Granger method fails to utilise the full information set. Moreover, hypothesis tests cannot be performed on the long run relationship between variables involved since the exact limiting distributions for such tests are unknown.

Johansen (1988) proposes an alternative method for cointegration analysis between a set of nonstationary variables, which takes into account such limitations. This method, which uses all the available information set, involves transforming the VAR model, equation (3.15), by deducting z_{t-1} from both sides to obtain

$$\mathbf{z}_t - \mathbf{z}_{t-1} = \mathbf{A}_0 + \mathbf{A}_1 \mathbf{z}_{t-1} - \mathbf{z}_{t-1} + \mathbf{A}_2 \mathbf{z}_{t-2} + \mathbf{A}_3 \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \quad (3.26)$$

Or

$$\Delta \mathbf{z}_t = \mathbf{A}_0 + (\mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-1} + \mathbf{A}_2 \mathbf{z}_{t-2} + \mathbf{A}_3 \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \quad (3.26')$$

Adding and subtracting $(\mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-2}$ from the right hand side of equation (3.26') yields

$$\Delta \mathbf{z}_t = \mathbf{A}_0 + (\mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-1} + (\mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-2} + \mathbf{A}_2 \mathbf{z}_{t-2} - (\mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-2} + \mathbf{A}_3 \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \quad (3.27)$$

which can be written as

$$\Delta \mathbf{z}_t = \mathbf{A}_0 + (\mathbf{A}_1 - \mathbf{I}) \Delta \mathbf{z}_{t-1} + (\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-2} + \mathbf{A}_3 \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \quad (3.28)$$

adding and subtracting $(\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-3}$ from the right hand side, this time yields

$$\begin{aligned} \Delta \mathbf{z}_t = \mathbf{A}_0 + (\mathbf{A}_1 - \mathbf{I}) \Delta \mathbf{z}_{t-1} + (\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-2} + (\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-3} + \mathbf{A}_3 \mathbf{z}_{t-3} \\ - (\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \end{aligned} \quad (3.29)$$

which can be written as

$$\Delta \mathbf{z}_t = \mathbf{A}_0 + (\mathbf{A}_1 - \mathbf{I}) \Delta \mathbf{z}_{t-1} + (\mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \Delta \mathbf{z}_{t-2} + (\mathbf{A}_3 + \mathbf{A}_2 + \mathbf{A}_1 - \mathbf{I}) \Delta \mathbf{z}_{t-3} + \dots + \mathbf{A}_k \mathbf{z}_{t-k} + \mathbf{u}_t \quad (3.30)$$

By repeating this procedure one can obtain the following Vector Error Correction Model (VECM) which is a re-parameterised version of equation (3.15).

$$\Delta \mathbf{z}_t = \sum_{i=1}^k \Gamma_i \Delta \mathbf{z}_{t-i} + \Pi \mathbf{z}_{t-k} + \mathbf{u}_t, \quad \mathbf{u}_t \sim \text{IN}(0, \Sigma) \quad (3.31)$$

where: $\Gamma_i = -(\mathbf{I} - \mathbf{A}_1 - \dots - \mathbf{A}_{k-i})$, $i = 1, \dots, k-1$

$$\Pi = -(\mathbf{I} - \mathbf{A}_1 - \dots - \mathbf{A}_k)$$

Assuming that \mathbf{z}_t is a vector of nonstationary variables $I(1)$, in the above re-parameterised version of the VAR model, all the terms involving $\Delta \mathbf{z}_{t-i}$ are $I(0)$ since these are first differences of nonstationary variables. The condition for residuals to be stationary, $\mathbf{u}_t \sim I(0)$, is that the second term on the RHS of equation (3.31), $\Pi \mathbf{z}_{t-k}$, must be stationary $I(0)$. This

condition depends on the rank⁹ of the Π matrix, r . Since the Π matrix ($n \times n$) relates nonstationary variables in \mathbf{z}_t to each other, for $\Pi \mathbf{z}_{t-k}$ to be stationary, the rank of the Π matrix should be less than its dimension and greater than zero; that is, $0 < r < n$. This is because if the Π matrix has a rank of zero, $r=0$, then all the elements in the matrix are zero which means that there is no linear relationship between the variables in \mathbf{z}_{t-k} with stationary properties. In this case a VAR in first differences would be an appropriate model, equation (3.21). On the other hand if the Π matrix is full rank, $r=n$, then any linear relationship between variables in \mathbf{z}_{t-k} is stationary, which means that all variables in \mathbf{z}_t are stationary. In this case an appropriate model would be a VAR model in levels. The only instance when $\Pi \mathbf{z}_{t-k}$ is stationary is when the Π matrix has a reduced rank, $0 < r < n$. This implies that there are r linear combination of variables in \mathbf{z}_{t-k} which are stationary, and a VECM is an appropriate model. Therefore, determination of the number of cointegration relationships in \mathbf{z}_t amounts to determining the rank of the Π matrix. Once it is established that the Π matrix has a reduced rank, it can be decomposed into two matrices.

Johansen (1988) proposes a procedure, known as reduced rank regression, to estimate the cointegrating relationships between variables in \mathbf{z}_t in equation (3.31). This method, which is known as the reduced rank estimation method, determines the rank of the Π matrix (see next section for more details). Once the rank of Π is determined, Π can be decomposed into two matrices α ($n \times r$) and β ($n \times r$), where $\Pi = \alpha\beta'$ and r is equal to the rank of Π . Matrix β' contains r linearly independent rows and the product of β' and \mathbf{z}_t ($\beta_1' \mathbf{z}_t, \dots, \beta_r' \mathbf{z}_t$) are r stationary long run relationships between variables in \mathbf{z}_t . Matrix α on the other hand contains elements, which measure the response of changes in each variable to deviation from these long run relationships. Therefore, the VECM in (3.31) can be written as

$$\Delta \mathbf{z}_t = \sum_{i=1}^k \Gamma_i \Delta \mathbf{z}_{t-i} + \alpha \beta' \mathbf{z}_{t-k} + \mathbf{u}_t, \quad \mathbf{u}_t \sim \text{IN}(0, \Sigma) \quad (3.32)$$

Where

$$\alpha = \begin{pmatrix} \alpha_{11} & \cdots & \alpha_{1r} \\ \alpha_{21} & \cdots & \alpha_{2r} \\ \vdots & \ddots & \vdots \\ \alpha_{n1} & \cdots & \alpha_{nr} \end{pmatrix} \quad \beta' = \begin{pmatrix} \beta_{11} & \beta_{12} & \cdots & \beta_{1n} \\ \vdots & \ddots & & \vdots \\ \beta_{r1} & \beta_{r2} & \cdots & \beta_{rn} \end{pmatrix}$$

⁹ The rank of a square matrix is equal to the number of linearly independent rows or columns in that matrix.

Once cointegration relationships between variables in \mathbf{z}_t are established, equation (3.32) can be estimated using OLS. However, if some of the lagged dependent variables are found to be insignificant, then they can be excluded from the model to make it more parsimonious. The new parsimonious VECM model, which is known as partial VECM, has to be estimated using seemingly unrelated regression, SUR, estimation methods to yield efficient estimates.

3.4.1.1. Johansen's reduced rank estimation method

It has been mentioned that the number of rows in β , i.e. the number of cointegrating vectors, is equal to the rank of Π matrix. In order to determine the rank of Π , the Johansen (1988) reduced rank estimation method can be used, which involves regression of $\Delta \mathbf{z}_t$ and \mathbf{z}_{t-k} on $\Delta \mathbf{z}_{t-1}$ to $\Delta \mathbf{z}_{t-k+1}$, as follows:

$$\Delta \mathbf{z}_t = \mathbf{P}_1 \Delta \mathbf{z}_{t-1} + \dots + \mathbf{P}_{k-1} \Delta \mathbf{z}_{t-k+1} + \mathbf{R}_{0t} \quad (3.33)$$

$$\mathbf{z}_{t-k} = \mathbf{T}_1 \Delta \mathbf{z}_{t-1} + \dots + \mathbf{T}_{k-1} \Delta \mathbf{z}_{t-k+1} + \mathbf{R}_{kt} \quad (3.34)$$

and forming the following residuals product moment matrix

$$\mathbf{S}_{ij} = \mathbf{T}^1 \sum_{i=1}^T \mathbf{R}_{it} \mathbf{R}'_{jt} \quad ; \quad i, j = 0, k \quad (3.35)$$

The maximum likelihood estimate of β is then obtained as the eigenvectors corresponding to the r largest eigenvalues from solving the following characteristic equation of the product moment matrix

$$|\lambda \mathbf{S}_{kk} - \mathbf{S}_{k0} \mathbf{S}_{00}^{-1} \mathbf{S}_{0k}| = 0 \quad (3.36)$$

Eigenvalues are characteristic roots of equation (3.36) which are sorted in descending order $\hat{\lambda}_1 = \hat{\lambda}_1 > \hat{\lambda}_2 \dots > \hat{\lambda}_n$ and their corresponding eigenvectors are $\hat{\mathbf{v}}_i = \hat{\mathbf{v}}_1, \hat{\mathbf{v}}_2, \dots, \hat{\mathbf{v}}_n$. The r largest eigenvalues ($\hat{\lambda}_i = \hat{\lambda}_1 > \hat{\lambda}_2 \dots > \hat{\lambda}_r$) are those, which represent the largest squared canonical correlation between the two sets of residuals (levels and first difference regressions (3.33)

and (3.34)). Therefore, eigenvectors corresponding to the r largest eigenvalues are the only vectors, which their inner products (linear combination) with z_t , produce stationary series, i.e. $\hat{v}_i' z_t \sim I(0)$, ($i=1, \dots, r$). These r eigenvectors $(\hat{v}_1, \hat{v}_2, \dots, \hat{v}_r)$ comprise the maximum likelihood estimates of $\hat{\beta} = (\hat{v}_1, \hat{v}_2, \dots, \hat{v}_r)$.

Johansen (1988) proposes two different tests for identifying the rank of Π matrix, which amounts to testing the null of $\hat{\lambda}_i = 0$ ($i=1, 2, \dots, n$), against the alternative of $\hat{\lambda}_i \neq 0$, where only the first r eigenvalues are different from zero. Such restrictions can be placed on different values of r in order to obtain the maximum log-likelihood function for the restricted model, which can be compared to the maximum log-likelihood for the unrestricted model to obtain a standard LR with a non-normal distribution. The first test, which is based on the likelihood ratio between restricted and unrestricted models, is known as the trace test and is defined as

$$\lambda_{\text{trace}} = -2\log(Q) = -T \sum_{i=r+1}^n \log(1 - \hat{\lambda}_i) \quad r = 0, 1, 2, \dots, n-1 \quad (3.37)$$

where $\hat{\lambda}_i$ are the estimated eigenvalues, r is the number of the largest eigenvalues and Q is the ratio between the restricted and unrestricted maximised likelihood. The trace statistic tests the null hypothesis that there are at most $r=r^*$ ($r^*=1, \dots, n-1$) cointegrating vectors against the alternative of $r=n$. The asymptotic critical values for this test for a model with deterministic components (intercept and/or trend) can be obtained from Osterwald-Lenum (1992).

The second test statistic which is called maximal-eigenvalue (λ_{max}) can be defined as

$$\lambda_{\text{max}} = -T \log(1 - \hat{\lambda}_{r+1}) \quad r=0, 1, \dots, n-1 \quad (3.38)$$

where $\hat{\lambda}_{r+1}$ are the estimated eigenvalues, r is the number of the largest eigenvalues. The Maximal eigenvalue test statistic, λ_{max} , tests the null hypothesis of the existence of r cointegrating vectors against the alternative of $r+1$ cointegrating vectors. The critical values for models with different deterministic terms (constant and trend in the cointegrating vectors and short run models) are computed and tabulated in Osterwald-Lenum (1992). These critical values should be used with caution when other deterministic (dummy) and stationary

variables are included in the system¹⁰. The reason is that the critical values are sensitive to these variables.

There are also problems with λ_{\max} and λ_{trace} tests when the sample is small. Reimers (1992) notes that the Johansen procedure over-rejects the null more often in small samples. Therefore, he suggests taking account of the number of parameters to be estimated in the model and making an adjustment by replacing T by $T-nk$ in λ_{\max} and λ_{trace} tests (T =sample size, n =number of endogenous variables and k =lag length). However, one can compute critical values to suit the sample size and specification of the model in terms of deterministic terms and intervention dummies, using Monte Carlo simulations.

Using the Johansen (1988) procedure to determine the number of cointegrating relationships among several variables requires correct model specification in terms of selecting a model with appropriate lag length and deterministic components both in the short run model and the cointegration vectors. The number of lagged dependent variables in the cointegrating model is usually selected using Akaike (1978) or Schwarz (1978) information criteria when estimating the unrestricted VAR model (3.15). However, the specification of the VECM in terms of the deterministic components is more complicated since the distributional properties of λ_{trace} and λ_{\max} statistics are dependent on the deterministic components included in the model. In most cases there is no a priori economic argument on what terms should be included in the VECM, however, Johansen (1991) propose a likelihood ratio test to determine whether it is appropriate to include deterministic terms in the short run model and/or the cointegrating vectors. This test involves comparison of the eigenvalues of the restricted and unrestricted model in the following form

$$-T[\ln(1 - \hat{\lambda}_2^*) - \ln(1 - \hat{\lambda}_2)] \sim \chi^2(1) \quad (3.39)$$

where $\hat{\lambda}_2^*$ and $\hat{\lambda}_2$ are the smallest eigenvalues of the unrestricted and restricted models, respectively. When the eigenvalues are close the probability of rejecting the null hypothesis that the restricted model is appropriate is higher. However, when the difference between the

¹⁰ Osterwald-Lenum (1992) critical values can be used in the presence of seasonal dummies as long as the seasonal dummies are centralised since these will not affect the distributional properties of test statistics.

eigenvalues is large the probability of rejecting the null that the restricted model is the appropriate model is small. This also indicates that it is more likely to find cointegrating relationships using the unrestricted model since it is more likely for the larger eigenvalues to be close to unity in the unrestricted model.

3.4.2. Impulse Response Analysis in VAR models

Impulse response analyses in VAR models are used to measure and trace the impact or response of variables in the system over a period of time to a shock to one variable (equation). In order to measure the responses of variables and trace their time profiles to a shock on a particular variable in a VAR model, the Vector Moving Average (VMA) representation of the VAR system should be used. Eliminating the exogenous variables for simplicity in equation (3.15) and substituting for \mathbf{z}_{t-1} results in

$$\mathbf{z}_t = \mathbf{A}_1(\mathbf{A}_1\mathbf{z}_{t-2} + \dots + \mathbf{A}_k\mathbf{z}_{t-k-1} + \boldsymbol{\varepsilon}_{t-1}) + \mathbf{A}_2\mathbf{z}_{t-2} + \dots + \mathbf{A}_k\mathbf{z}_{t-k} + \boldsymbol{\varepsilon}_t \quad (3.40)$$

or

$$\begin{aligned} \mathbf{z}_t = & (\mathbf{A}_1^2 + \mathbf{A}_2)\mathbf{z}_{t-2} + (\mathbf{A}_1\mathbf{A}_2 + \mathbf{A}_3)\mathbf{z}_{t-3} + \dots + (\mathbf{A}_1\mathbf{A}_k + \mathbf{A}_k)\mathbf{z}_{t-k} \\ & + \mathbf{A}_1\mathbf{A}_k\mathbf{z}_{t-k-1} + \mathbf{A}_1\boldsymbol{\varepsilon}_{t-1} + \boldsymbol{\varepsilon}_t \end{aligned} \quad (3.41)$$

Repeating the substitution for values of \mathbf{z}_{t-2} , \mathbf{z}_{t-3} , ..., the following VMA representation of the VAR model can be obtained

$$\mathbf{z}_t = \sum_{n=0}^{\infty} \boldsymbol{\Phi}_n \boldsymbol{\varepsilon}_{t-n} \quad (3.42)$$

where $\boldsymbol{\Phi}_n$ are $(m \times m)$ matrices of coefficients of the moving average terms and can be estimated recursively as follows

$$\boldsymbol{\Phi}_n = \mathbf{A}_1\boldsymbol{\Phi}_{n-1} + \mathbf{A}_2\boldsymbol{\Phi}_{n-2} + \dots + \mathbf{A}_k\boldsymbol{\Phi}_{n-k} \quad , \quad i = 1, \dots, \infty \quad (3.43)$$

also $\boldsymbol{\Phi}_n = 0$ for $n < 0$ and $\boldsymbol{\Phi}_0 = \mathbf{I}$. For example, for a three-variable VAR system, where $\mathbf{z}_t = [y_{1,t}, y_{2,t}, y_{3,t}]$, the VMA representation is

$$\mathbf{z}_t = \begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{bmatrix} = \sum_{i=0}^{\infty} \begin{bmatrix} \phi_{11,n} & \phi_{12,n} & \phi_{13,n} \\ \phi_{21,n} & \phi_{22,n} & \phi_{23,n} \\ \phi_{31,n} & \phi_{32,n} & \phi_{33,n} \end{bmatrix}^n \begin{bmatrix} \varepsilon_{y1,t-n} \\ \varepsilon_{y2,t-n} \\ \varepsilon_{y3,t-n} \end{bmatrix} \quad (3.44)$$

The above moving average representation can be used to examine the impact of a shock to one variable on other variables in the system. Therefore, Φ_n contain the impulse response multipliers over time, i.e. $\phi_{j,l}(n)$ for $j,l = 1,2,3$ and $n=0, \dots, \infty$ indicates the truncation. For instance, $\phi_{1,2}(0)$ represents the instantaneous impact of a shock to y_2 on y_1 , *ceteris paribus*. While $\phi_{1,3}(2)$ represents the response of y_1 to a shock applied to y_3 two periods before. Plot of the impulse responses functions ($\phi_{j,l}(n)$ for $j,l = 1,2,3$) against n present a visual representation of the behaviour of each variable in response to shocks.

It is mentioned that impulse response functions trace the impact of a shock to one variable on others assuming everything else is constant. However, it can be seen that the covariance of the residuals across the system of equations might not be diagonal which means that the error terms are not orthogonal. In other words, residuals might be correlated across equations, which is not desirable since the effects of the shocks on different variables cannot be distinguished. Therefore, some measures must be taken to make the error terms orthogonal.

Orthogonalisation of residuals is important because it isolates the effects of a shock to each series while the co-movements of the variables are maintained through lagged values. Sims (1980) proposes a method for orthogonalisation, known as the Cholesky decomposition, using a lower triangular matrix, \mathbf{P} , which is constructed from the covariance matrix of residuals, Σ , in the following form

$$\mathbf{P}'\mathbf{P} = \Sigma, \quad \mathbf{P} = \begin{bmatrix} 1 & 0 & 0 \\ \phi_{21} & 1 & 0 \\ \phi_{31} & \phi_{32} & 1 \end{bmatrix}$$

where ϕ_{ij} $i,j=1,2,3$ are covariances between i^{th} and j^{th} sets of residuals. Using orthogonalised shocks to the system, the vector moving average can be written for the equation (3.42)

$$\mathbf{z}_t = \sum_{n=1}^{\infty} \mathbf{\Phi}^*_{n} \boldsymbol{\xi}_{t-n} \quad (3.45)$$

where $\xi_t = P^{-1}\varepsilon_t$, $\Phi^*_i = \Phi_i P$, and $\xi'_t \xi_t = (P^{-1}\varepsilon_t)' (P^{-1}\varepsilon_t) = (P^{-1})' \varepsilon_t \varepsilon_t' P^{-1} = I_3$. The advantage of this orthogonalisation is that the new error terms constructed using the transformation matrix P are contemporaneously uncorrelated and have unit standard errors. This ensures that effects of scaled shocks applied to variables be isolated and tractable. Therefore, the orthogonalised impulse response of a shock, at time t , to the system after n periods, considering the initial state of the system to be at zero, can be written as

$$\text{OIR}_z(n) = \Phi_n P \quad (3.46)$$

where OIR_z stands for orthogonalised impulse responses of z , and n is the number of periods in the future that the impulse response is measured. The impact of a shock to a particular variable, y_j , on any other variable, y_i , after n periods is then distinguished and measured using selection vectors e_i and e_j as

$$\text{OIR}_{z(i)}(n, e_j) = e'_i \Phi_n P e_j = e'_i \Phi^*_n e_j \quad (3.47)$$

where e_i and e_j are selection vectors with i^{th} and j^{th} elements equal to 1 and 0's elsewhere, respectively. Once impulse responses of a variable to shocks in another variable over different periods, $n=1,2,\dots,N$, are obtained, a useful practice is to plot such responses against n since such graph gives a visual indication of the profile of the response over time.

One feature of the orthogonalised impulse response analysis is that the shocks are allowed to have instantaneous effects in one direction, while feedback effects are restricted to be effective (through lags) as we go from the first variable to the last. As pointed out by Hansen and Sargent (1991), Braun and Mittnik (1993) and Lee and Pesaran (1993), this type of orthogonalisation implies an asymmetric effect on the multivariate system in which the ordering of the series in this type of impulse response analysis will become important¹¹.

¹¹ Another problem associated with the orthogonalised impulse response functions is that it does not accommodate provisions for the asymmetric impact of shocks (in terms of sign and size) to the system. The issue has been investigated extensively in Beaudry and Koop (1993), Potter (1995) and Koop et al (1996). They argue that negative and positive shocks should have different impact in future behaviour of the series. They also argue that not only the historical behaviour of the series might affect the impulse response analysis, however, there might be an element of size bias involved in traditional (orthogonalised) impulse response functions. Therefore, they suggest investigating the impulse response functions in non-linear models in order to allow for these types of asymmetry.

Lütkepohl and Reimers (1992) argue that orderings of variables in the orthogonalised impulse response analysis can be based on economic theory, parameter restrictions and cross equation restrictions as well as tests like Granger-causality. However, they suggest using different orderings of the variables in multivariate system in order to find the right ordering according to the most plausible result. Granger causality tests also provide some indication on the direction of the transmission of shocks from one variable to another. In this case, the ordering could start from the variable with the most significant Granger-causality to the least significant. It is also possible to look at the covariance matrix of the error terms in the system and carry out likelihood ratio tests in order to identify the contemporaneous correlation of shocks for variable ordering purposes. It should be stressed, however, that the above methods in selecting the right ordering for the variables in a system may be extremely difficult in practice and in many cases lead to inconclusive results.

One approach to overcoming the problem of ordering the variables (composition problem) is proposed by Koop et al (1996) and Pesaran and Shin (1997). This method, known as generalised impulse response (GIR) analysis, uses system-wide shocks¹², s_t^* , and takes the difference between the expected state of the system with and without the presence of the shock, in order to solve the composition problem in a linear multivariate system.

$$GIR_Z(n, s_t^*, \Omega_{t-1}) = E(z_{t+n} | s_t = s_t^*, \Omega_{t-1}) - E(z_{t+n} | \Omega_{t-1}) \quad (3.48)$$

where $E(\cdot)$ denotes the expectations operator, Ω_t is the information set available at time t and s_t^* is the system-wide shock. Equation (3.48) implies that the Generalised Impulse Response (GIR) of the system n periods ahead is equal to the expected value of the variables in the system n periods after the system is being shocked (by a system-wide shock) minus the value of the variables in the system after n period in the absence of the shock.

$$GIR_Z(n, s_t^*, \Omega_{t-1}) = \Phi_n s_t^* \quad (3.49)$$

¹² A system-wide shock, s_t^* , is defined as a shock drawn from the multivariate normal distribution, i.e. $s_t^* \sim N(0, \Sigma)$. Consequently, the GIR will have the following normal distribution $GIR_Z(n, s_t^*, \Omega_{t-1}) \sim N(0, \Phi_n \Sigma \Phi_n')$.

As Koop et al (1996) mention, it is also possible to define the GIR conditional on a shock to a specific variable, i.e. if the system is perturbed by the scaled variable specific shock, $s^*_{i,t} = \delta_i$, the GIR function will be

$$\text{GIR}_Z(n, \delta_i, \Omega_{t-1}) = E(z_{t+n} | \delta_i, \Omega_{t-1}) - E(z_{t+n} | \Omega_{t-1}) \quad (3.50)$$

and using the expected value of the system-wide shock when perturbed by $s_{i,t} = \delta_i$,

$$E(s_t | s_{i,t} = \delta_i) = \frac{(\sigma_{1j}, \sigma_{2j}, \dots, \sigma_{mj})\delta_i}{\sigma_{ij}} \quad (3.51)$$

or

$$E(s_t | s_{i,t} = \delta_i) = \frac{\sum e_i \delta_i}{\sigma_{i,i}} \quad (3.52)$$

where $e_i = [0 \dots 0 \ 1 \ 0 \dots 0]$ is the selection vector and $i = 1, 2, \dots, m$ denotes the number of variables in the system. Therefore, if $\delta_i = \sqrt{\sigma_{ii}}$, then the standardised GIR function of the VAR system in equation (3.42) can be written as

$$\text{GIR}_Z(n, \delta_i, \Omega_{t-1}) = \frac{\Phi_n \sum e_i}{\sqrt{\sigma_{ii}}} \quad (3.53)$$

Similarly, the GIR of the specific variable j can be derived from

$$\text{GIR}_{i,j,n} = \frac{e'_j \Phi_n \sum e_i}{\sqrt{\sigma_{ii}}} \quad , \quad i, j = 1, 2, \dots, m \quad (3.54)$$

This approach is quite convenient since not only the problem of ordering of the variables in the multivariate system is circumvented, it also ensures that the impulse responses are history independent.

3.4.2.1. Impulse response and persistence profiles in cointegrating systems

Pesaran and Shin (1997) extend the generalised impulse responses method to measure the effect of shocks in cointegrating VAR models. They formulate the moving average representation of the VECM in equation (3.42) as

$$\Delta \mathbf{z}_t = \sum_{i=0}^{\infty} \Phi_i \varepsilon_{t-i} \quad (3.55)$$

where Φ_i are $(m \times m)$ matrices of coefficients of the moving average terms and $\Phi_0 = \mathbf{I}_m$, and $\beta' \Phi_1 = 0$ is the necessary and sufficient condition for cointegration, where $\Phi_1 = \sum_{i=0}^{\infty} \Phi_i$ and rank of Φ_1 is $m-r$ (m =number of variables in the VECM and r =number of cointegrating vectors). They suggest then that the GIR of the variables in the $\Delta \mathbf{z}_t$ vector to the system-wide shocks can be estimated as

$$\text{GIR}_{i,j,n} = \frac{\mathbf{e}_j' \Phi_n \Sigma \mathbf{e}_i}{\sqrt{\sigma_{ii}}} \quad , \quad i, j = 1, 2, \dots, m \quad (3.56)$$

It is also argued that the GIR of the variables in \mathbf{z}_t can be estimated using the cumulative effect matrix, in the following form

$$\text{GIR}_{i,j,n} = \frac{\mathbf{e}_j' \Theta_n \Sigma \mathbf{e}_i}{\sqrt{\sigma_{ii}}} \quad , \quad i, j = 1, 2, \dots, m \quad (3.57)$$

where the cumulative effect matrix, Θ_n , is $\Theta_n = \sum_{i=0}^n \Phi_i$ and $\Theta_0 = \Phi_0 = \mathbf{I}_m$.

Pesaran and Shin (1996) extend the generalised impulse response functions approach to measure the impact of the system-wide shocks on the convergence of cointegrating relations to long run equilibrium in a VECM. In other words, they propose a method to measure and track the response of the equilibrium relations, $\Pi \mathbf{z}_t$, to shocks drawn from the multivariate distribution of ε_t without orthogonalising the shocks. This type of analysis allows one to distinguish between the cointegrating and non-cointegrating relations, since in a non-cointegrating relation, $\beta_1' \mathbf{z}_t \sim I(1)$, the effect of a shock will persist for ever in contrast to a cointegrating relation $\beta_2' \mathbf{z}_t \sim I(0)$, where the shock will die after a certain period; that is when the system returns to equilibrium. In addition, this approach provides important information on the speed at which the system returns to the long run equilibrium. Pesaran and Shin (1996) also point out that the dynamic responses of cointegrating relations to system-wide shocks are invariant of the ordering to the variables in the VAR system.

Pesaran and Shin (1996) show that the responses of the j^{th} cointegrating relations in a VECM to a unit change in the i^{th} orthogonalised shock, $\sqrt{\sigma_{ii}}$, after n periods can be formulated as

$$\text{OIR}_i(n, \beta_j' z_t) = \beta_j' \Theta_n P e_i, \quad j=1, \dots, r \text{ and } n=1, 2, \dots, N \quad (3.58)$$

where $\Theta_n = \sum_{i=0}^n \Phi_i$, $\Theta_0 = \Phi_0 = I_m$, $P'P = \Sigma$ and β_j' is the j^{th} cointegrating vector and, therefore, $\beta_j' z_t$ is the j^{th} cointegrating relationship. Similarly, the generalised impulse responses of the cointegrating relations in the VECM can be formulated as

$$\text{GIR}_i(n, \beta_j' z_t) = \frac{\beta_j' \Theta_n \Sigma e_i}{\sqrt{\sigma_{ii}}} \quad (3.59)$$

While the above equation explains the response of the cointegrating vectors to a variable specific shock, using the system-wide shocks, Pesaran and Shin (1996) define the scaled persistence profiles of the j^{th} cointegrating vector in the following form

$$h(n, \beta_j' z_t) = \frac{\beta_j' \Theta_n \Sigma \Theta_n' \beta_j}{\beta_j' \Sigma \beta_j} \quad (3.60)$$

Therefore if the j^{th} vector is a cointegrating vector for the variables in the system, its persistence profile will approach zero as n increases. This means that any shock to the system initially will tend to have an impact on each variable, but in the long term the system, if cointegrated, will return to the initial long-run equilibrium. Pesaran and Shin (1996) apply the method in order to analyse the persistence profile of the cointegrating relations in the Johansen and Juselius (1992) model for UK data. They find that out of the two long-run relations, namely Uncovered Interest Rate Parity and Purchasing Power Parity, the latter is more sluggish in response to the shocks.

3.5. Estimation of Models with Rational Expectations

Investigating the validity of the EMH in formation of prices or returns in a market involves formulating a statistical test(s) based on the implications of the theory and empirical examination of the test(s) using regression analysis, parameter restrictions and drawing inferences.

In general, the literature on the EMH is mainly concerned with the proposition that agents use all available information to exploit (arbitrage) any profitable opportunities in the market and this usually involves agents forming expectations about future prices, returns and events. The RE hypothesis has featured widely in the literature as the main assumption for the formation of expectations in conjunction with testing the EMH. This is due to the relevance of the axioms of the RE (see below) to the EMH in terms of utilisation of information and the fact that agents are assumed to be rational. The latter implies that, for example, agents do not make systematic errors in forming their expectations, use the true model for prediction and utilise all the available information.

Direct tests for RE and the EMH involve multi-period expectations (forecasts) and this raises estimation problems. The following discussion is aimed to highlight these estimation issues and discuss the methods proposed in the econometric literature to resolve them.

3.5.1. Multi-step forecasts, errors in variables and serial correlation

Assuming RE, a multi-step forecast of x_t can be written as

$$x_{t+i} = E_t(x_{t+i} | \Lambda_t) + \varepsilon_{t+i} \quad (3.61)$$

where $E_t(x_{t+i} | \Lambda_t)$ denotes the expected value of x_{t+i} at time t and Λ_t is the available information set available at time t . RE forecast of x_t requires unbiased forecast errors with

constant variance, no autocorrelation in the forecast errors and no correlation between the error terms and the information set¹³. In mathematical form RE requires

$$E(\varepsilon_{t+i})=0 \quad , \quad E(\varepsilon_{t+i}^2)=\sigma^2 \quad , \quad E(\varepsilon_{t+i}, \varepsilon_{t-j})=0 \quad , \quad E(\varepsilon_{t+i}, \Lambda_t)=0 \quad j=0,1,..$$

Assuming RE, in order to test the validity of the EMH, the following equation (equivalent to equation (5.1) in chapter 5) needs to be estimated using multi-period forecast values

$$Y_t = \sum_{i=1}^p \beta_i E_t(x_{t+i}) + v_t \quad , \quad u_t \sim N(0, \sigma_u^2) \quad (3.62)$$

Two major problems are associated with the estimation of this type of model i) serial correlation in the error terms and ii) correlation between the variables and error terms. One way to test the expectations hypothesis in equation (3.62) is to replace the expected values of $E(x_{t+i})$ with their actual values x_{t+i} , assuming RE (equation (3.61)); that is, $E_t(x_{t+i}) = x_{t+i} - \varepsilon_{t+i}$. Therefore, in order to estimate the following model (note that here the *RE assumption is imposed*)

$$Y_t = \beta_1 (x_{t+1} - \varepsilon_{t+1}) + \beta_2 (x_{t+2} - \varepsilon_{t+2}) + \dots + \beta_p (x_{t+p} - \varepsilon_{t+p}) + v_t \quad (3.63)$$

it is possible to rearrange (3.63) to yield

$$Y_t = \beta_1 x_{t+1} + \beta_2 x_{t+2} + \dots + \beta_p x_{t+p} + (v_t - \beta_1 \varepsilon_{t+1} - \beta_2 \varepsilon_{t+2} - \dots - \beta_p \varepsilon_{t+p}) \quad (3.64)$$

and estimate the following model

$$Y_t = \beta_1 x_{t+1} + \beta_2 x_{t+2} + \dots + \beta_p x_{t+p} + \xi_t \quad (3.65)$$

¹³ This is because:

i- If the forecast errors are biased, then the forecast can be improved by eliminating the bias, which is not consistent with the RE assumptions.

ii- If the variance is not constant, the variance of the error terms are either explosive or time varying, which means that the agents cannot correct their expectations and keep repeating their mistakes. This is not consistent with the RE assumptions.

iii- There should not be any correlation between the error terms and the information set because it means that the information set is not fully used for prediction and the forecast values are biased. This also is inconsistent with the RE assumptions.

where $\xi_t = (v_t - \beta_1 \varepsilon_{t+1} - \beta_2 \varepsilon_{t+2} - \dots - \beta_p \varepsilon_{t+p})$. It can be seen that OLS estimation of equation (3.65) is not appropriate since not only independent variables are correlated with error term, the error terms are also autocorrelated of order $p-1$; that is the errors are MA($P-1$). In fact OLS estimates are not BLUE due to problems of errors in variables (nonorthogonal errors and variables) and residual autocorrelation. The problem of correlation between variables and error terms is more severe than residual autocorrelation since in this case OLS yields biased and inconsistent estimates. However, the presence of serial correlation results in inefficient OLS estimates.

In order to see the effect of the correlation between independent variables and error terms, consider $\mathbf{X} = (x_{t+1}, x_{t+2}, \dots, x_{t+p})$ as a vector of independent variables and ξ as a vector of error terms in equation (3.65), then OLS estimates of the parameters, $\hat{\beta}$, can be written as follows

$$\hat{\beta} = (\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\mathbf{Y}) - (\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\xi) \quad (3.66)$$

where $\hat{\beta}$ is a vector of OLS parameter estimates. Using the probability limits, the probability limit of $\hat{\beta}$ in equation (3.66) can be written as

$$P\lim \hat{\beta} = P\lim(T^{-1})[(\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\mathbf{Y})] - P\lim(T^{-1})[(\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\xi)] \quad (3.67)$$

or

$$P\lim \hat{\beta} = P\lim(\beta) - P\lim(T^{-1})[(\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\xi)] \quad (3.68)$$

Now, the first term on the RHS of the equation (3.68) represent the true parameter estimates, and the second term should asymptotically approach zero, for $\hat{\beta} = \beta$. Otherwise, if the second term in (3.68) does not asymptotically approach zero, when \mathbf{X} and ξ are correlated, then OLS results in biased estimates. This can be shown by taking probability limit of the second term in (3.68); that is, the probability limit of the following term

$$P\lim(T^{-1})[(\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\xi)] \quad (3.69)$$

First, taking the Plim of $(\mathbf{X}'\mathbf{X})$ and substituting the \mathbf{X} by its equivalent, $E_t\mathbf{X} + \varepsilon$, results in

$$P \lim(T^{-1})(X'X) = P \lim(T^{-1})[(E_tX + \varepsilon)'(E_tX + \varepsilon)] \quad (3.70)$$

According to the RE assumption E_tX and ε are not correlated, therefore, (3.70) can be written as

$$P \lim(T^{-1})(X'X) = P \lim(T^{-1})[(E_tX)'(E_tX)] + P \lim(T^{-1})(\varepsilon'\varepsilon) \quad (3.71)$$

or

$$Var(X_t) = Var(E_tX_t) + Var(\varepsilon_t) \quad (3.72)$$

On the other hand, since $(\xi = v - \beta\varepsilon)$, the probability limit of the $(X'\xi)$ in (3.69) can be written as

$$P \lim(T^{-1})(X'\xi) = P \lim(T^{-1})[(X)'(v - \hat{\beta}\varepsilon)] = P \lim(T^{-1})(X'v) - \hat{\beta} P \lim(T^{-1})(X'\varepsilon) \quad (3.73)$$

since $P \lim(T^{-1})(X'v) = 0$, substituting the RE values of X ($EX = X + \varepsilon$) in equation (3.73) yields

$$\begin{aligned} P \lim(T^{-1})(X'\xi) &= -\hat{\beta}[P \lim(T^{-1})((E_tX + \varepsilon)'\varepsilon)] \\ &= -\hat{\beta}[P \lim(T^{-1})(E_tX'\varepsilon) + P \lim(T^{-1})(\varepsilon'\varepsilon)] \end{aligned} \quad (3.74)$$

According to the RE assumptions, the first term in the square bracket is zero, therefore, (3.74) can be simplified to

$$P \lim(T^{-1})(X'\xi) = -\hat{\beta} P \lim(T^{-1})(\varepsilon'\varepsilon) = -\hat{\beta} VAR(\varepsilon_t) \quad (3.75)$$

Therefore, substituting (3.75) and (3.71) in (3.68) will result in

$$P \lim \hat{\beta} = \beta + \frac{\beta \sum_{i=1}^p Var(\varepsilon_{t+i})}{\sum_{i=1}^p Var(E_tX_{t+i}) + \sum_{i=1}^p Var(\varepsilon_{t+i})} \quad (3.76)$$

One way to overcome the problem of biasedness and inconsistency of OLS estimators is to use the Instrumental Variables (IV) estimation method. This method replaces the independent variables in the regression equation by a different set of variables, $Z_t = (z_{1,t} \ z_{2,t} \ . \ . \ . \ z_{p,t})$, known as instruments, which have a high degree of correlation with the independent

variables, X_t and zero correlation with the error terms, ξ_t . Therefore, the Instrumental Variables estimates, $\hat{\beta}^*$, can be written as

$$\hat{\beta}^* = (Z'Z)^{-1}(Z'Y) + (Z'Z)^{-1}(Z'\xi) \quad (3.77)$$

where $\hat{\beta}^*$ is the vector of the instrumental variable estimators. The high degree of correlation between X and Z means that the first term in (3.77) will approach the actual values of β , while zero correlation between Z and the error terms, ξ_t , means that the second term approach zero asymptotically. It should be noted that the choice of instruments is important to ensure unbiased and consistent parameters estimates (see Greene 1997 page 528).

3.5.2. Correction for serial autocorrelation using the Generalised Method of Moments

The moving average error terms, MA(P-1) in equation (3.65), will result in a serial correlation of order (P-1) in the residuals, which implies a non-diagonal variance-covariance matrix of the following form

$$E[\xi_t' \xi_t] = \sigma_0^2 \Sigma = \sigma_0^2 \begin{bmatrix} 1 & \rho_1 & \rho_2 & \dots & \rho_{p-1} & 0 & \dots & 0 \\ \rho_1 & 1 & \rho_1 & \dots & & & & \\ \rho_2 & \rho_1 & 1 & \dots & & & & \\ \vdots & & & \ddots & \rho_1 & & & 0 \\ \rho_{p-1} & \dots & \rho_1 & 1 & & & \rho_{p-1} & \\ 0 & & & & \ddots & & \vdots & \\ \vdots & & & & & & \rho_1 & \\ 0 & \dots & 0 & \rho_{p-1} & \dots & \rho_1 & 1 \end{bmatrix} \quad (3.78)$$

where σ_0 is the variance and Σ is the normalised variance-covariance matrix of autocorrelated residuals. Although using this form of the variance covariance matrix of the residuals does not affect the unbiasedness and consistency of OLS estimates, but these estimates are no longer efficient. Consequently inferences on parameter estimates are not appropriate. However, Hansen and Hodrick (1980) method can be used to correct the covariance of the residuals. This method computes the autocorrelated residuals of the IV estimates using the actual variables, X , and instrumental variables parameters, $\hat{\beta}^*$, in the following way

$$\hat{\varepsilon}^* = Y - \hat{\beta}^* X \quad (3.79)$$

In order to estimate consistent variance-covariance matrix of the residuals, the autocovariances are then estimated as follows

$$\hat{\sigma}_i^2 = (T^{-1}) \sum_1^T \varepsilon_t^* \varepsilon_{t-i}^* \quad , \quad i=0,1,\dots,p-1 \quad (3.80)$$

and correlation coefficients in the variance-covariance matrix are estimated using the variance and autocovariances of the residuals as

$$\hat{\rho}_i = \frac{\hat{\sigma}_i^2}{\hat{\sigma}_0^2} \quad i = 1, 2, 3, \dots, p-1 \quad (3.81)$$

In the next stage these variance and autocovariances are used to estimate the variance of the following IV parameter estimates.

$$\hat{\beta}^* = \beta + (Z'Z)^{-1} Z' \xi \quad (3.82)$$

Thus the variance of the IV parameter estimates can be written as

$$Var(\hat{\beta}^*) = Var[\beta + (Z'Z)^{-1} Z' \xi] = Plim(T^{-1})[\beta + (Z'Z)^{-1} Z' \xi] \quad (3.83)$$

Since $Plim(T^{-1})(\beta)=0$, we can write

$$Var(\hat{\beta}^*) = Plim(T^{-1})[(Z'Z)^{-1} Z' \xi \xi' Z (Z'Z)^{-1}] \quad (3.84)$$

And knowing that $\xi \xi' = \sigma_0^2 \Omega$, variance of IV estimates corrected for MA(p-1) can be written as

$$Var(\hat{\beta}^*) = \sigma_0^2 (Z'Z)^{-1} Z' \Omega Z (Z'Z)^{-1} = (Z'Z)^{-1} Z' \Sigma Z (Z'Z)^{-1} \quad (3.85)$$

Hansen (1982) suggests that one can compute the covariance matrix, $\xi' \xi$, (in the first iteration or by other methods) and use it as a weighting matrix to correct the variance and standard errors of the IV estimates for the effect of serial correlation (and/or heterosceasticity). Now

two special cases of this general form will emerge. First, it can be seen that if there is no serial correlation, $\xi'\xi$, will reduce to a diagonal variance-covariance matrix which yields efficient standard errors. Second, when the serial correlation is the only problem, i.e. there is no correlation between variables and error terms, then using the actual independent variables, $\mathbf{X} = (x_{i+1}, x_{i+2}, \dots, x_{i+p})$ instead of the instruments, \mathbf{Z} , is the same as OLS with a correction for residuals autocorrelation (Newey-West method, see Greene 1997 page 529).

3.6. ARCH and GARCH Models

An area, which has been developed quite extensively in recent years in time series analysis, is investigating and modelling the behaviour of the second moment (variance) of time series. Such analysis is proved to be important in financial economics since the second moment of financial time series is considered as a measure of volatility and is of interest to the agents involved both in terms of forecasting and risk management. It has been argued in the literature that the second moment of a time series may take different values and vary over time. In fact, Mandelbort (1963) notes that large (small) changes tend to be followed by large (small) changes, a phenomenon he defines as volatility clustering. Mandelbort's study inspired a series of studies in investigating and modelling the behaviour of variance of financial and economic time series. For instance, Klein (1977) estimates a time-varying variance model using a rolling sample method, whereas Engle (1982) introduces Autoregressive Conditional Heteroscedasticity, ARCH, for modelling the time-varying volatility of time series.

In his pioneering study, Engle (1982) introduces a formal model for conditioning the variance of a time series, which adds a new dimension to analysis of financial and economic time series. Engle (1982) conditions the variance of a time series on the square of lagged shocks to the series in an autoregressive form (details of this model is given in the next section). Since the introduction of the original form of autoregressive conditional variance model a vast number of studies in the literature are devoted to developing and finding the best functional form for this type of models. For example, Bollerslev (1986) proposes the Generalised ARCH (GARCH) model; Engle et al (1986) introduces ARCH in mean model; Bollerslev et al (1988) develops Multivariate GARCH model; Geweke (1986) and Pantula (1986) introduce Nonlinear ARCH models; Nelson (1991) extends ARCH models to allow for asymmetric effects of shocks on volatility (Exponential ARCH), among many others. Different forms of time-varying risk models are used for modelling purposes in different areas such as asset pricing, exchange rate, interest rate etc. Bera and Higgins (1992), Bollerslev, Chou and Kroner (1992) and Engle (1993) are among the recent reviews of the extensions of ARCH family models and cite a large number of papers in different directions of specification, estimation, and applications of ARCH models. The following sections

provide a review of ARCH and GARCH methodology in modelling volatility as well as the risk-return relationship in the financial econometrics literature.

3.6.1. The theory of ARCH models

One of the assumptions of classical linear regression for the parameter estimates to be the Best Linear Unbiased Estimators (BLUE) is that the residuals must be homoscedastic. In other words, the variance of the residuals, σ^2 , in the following regression should be constant.

$$y_t = \alpha + \beta_1 x_{1,t} + \dots + \beta_p x_{p,t} + \varepsilon_t \quad , \quad \varepsilon_t \sim \text{IN}(0, \sigma^2) \quad (3.86)$$

However, if σ^2 is time dependent, i.e. residuals show time-varying heteroscedasticity, then the OLS estimators are not BLUE. This is due to the lack of efficiency of parameter estimates caused by the time-varying variance of residuals, σ_t^2 .

$$y_t = \alpha + \beta_1 x_{1,t} + \dots + \beta_p x_{p,t} + \varepsilon_t \quad , \quad \varepsilon_t \sim \text{IN}(0, \sigma_t^2) \quad (3.87)$$

In a pioneering study, Engle (1982) proposes a test to detect such variations in the variance and then uses these variations to measure and model the volatility of the dependent variable(s). Engle's (1982) test is based on an auxiliary regression on squared residuals of equation (3.87) in the following form

$$\varepsilon_t^2 = \gamma + \sum_{i=1}^p \delta_i \varepsilon_{t-i}^2 + v_t \quad , \quad v_t \sim \text{IN}(0, \sigma_v^2) \quad (3.88)$$

where, ε_t are estimated residuals (shocks) and v_t are independently and normally distributed error terms with zero mean and constant variance, σ_v^2 . The joint significance of parameters of lagged squared residuals can be tested using LM or F tests and indicates that lagged squared residuals can explain the current squared residuals. Engle (1982) also argues that the conditional variance of the dependent variable in the regression equation (3.87), which is equivalent to the variance of the error terms, can be modelled using a similar autoregressive equation as follows

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^m \alpha_i \varepsilon_{t-i}^2 \quad (3.89)$$

where α_0 and α_i , $i=1, \dots, m$, are parameters of interest, and conditions for the variance to be positive and stationary at all times are $\alpha_0 > 0$ and $0 < \sum \alpha_i < 1$, respectively. Notice that if the parameters of lagged squared error terms are not statistically significant, there is no correlation between the lagged squared residuals, which means that the variance is constant and there are no autoregressive conditional heteroscedasticity (ARCH) effects in the error terms.

Bollerslev (1986) extends the idea behind the ARCH models and proposes a parsimonious model for the conditional variance, known as the Generalised Autoregressive Conditional Heteroscedasticity (GARCH) model. In this setting, the variance is conditioned on both its own lagged values as well as lagged squared error terms as

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^p \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2 \quad (3.90)$$

where the variables are the same as before and α_i , β_j are the parameters of interest. Significance of lagged variance parameters, β_i , in equation (3.90) indicates the dependence of the current value of the conditional variance on its lagged values. On the other hand, if the parameters of lagged squared errors and variance are not statistically significant, then the variance of the regression is constant.

The number of the lagged error terms and the variances in the variance equation is called the order of ARCH or GARCH model [denoted as ARCH (p) or GARCH (p,q)]. Although many versions of the GARCH models have been introduced since Engle's (1982) paper, the most common type of GARCH (p,q) model used in the literature to model the economic variables is GARCH (1,1).

3.6.2. Exponential GARCH model

Nelson (1991) argues that ARCH and GARCH models suffer from three major drawbacks. First, ARCH and GARCH models fail to take into account the asymmetric effect of the shocks on conditional volatility. In fact, conventional GARCH models allow shocks, positive or negative to have a symmetric effect on the conditional variance. Second, GARCH models do not take into account the asymmetric effect of the shocks with different magnitude on the conditional volatility. It has been argued in the literature that the relative impact of small shocks might be smaller than the relative impact of large shocks to the conditional volatility. Finally, GARCH models imply non-negativity restrictions on the parameters, which, sometimes lead to estimation problems. Nelson (1991) proposes exponential GARCH (EGARCH) specification as a remedy for these shortcomings in GARCH models. He uses the nonlinear form of ARCH models, suggested by Geweke (1986) and Milhoj (1987) in order to relax the assumption of non-negativity of the parameters in the variance model

$$\log(\sigma_t^2) = \alpha_0 + \sum_{i=1}^p \alpha_i \log(\varepsilon_{t-i}^2) \quad (3.91)$$

He then introduces an extra term in the specification of the variance equation, which can take into account any asymmetric effects in the following form

$$\begin{aligned} Y_t &= a_0 + b_1 X_t + \varepsilon_t, & \varepsilon_t &\sim \text{iid}(0, \sigma_t^2) \\ \sigma_t^2 &= \exp \left(\alpha_0 + \sum_{i=1}^p \alpha_i g(z_{t-i}) + \sum_{j=1}^q \beta_j \log(\sigma_{t-j}^2) \right) \\ g(z_t) &= \theta(z_t) + \gamma (|z_t| - E|z_t|) & , & \quad z_t = \frac{\varepsilon_t}{\sigma_t} \end{aligned} \quad (3.92)$$

where innovations, ε_t are assumed to be independently and normally distributed with zero mean and constant variance¹⁴. The conditional variance, as specified in the system of equations (3.92), is known as Nelson's (1991) Exponential GARCH model and allows the conditional variance parameters, α_i and β_j , to take any real number. The functional form of the innovations, $g(z_t)$, allows the variance to respond differently to positive and negative

¹⁴ Nelson (1991) assumes a generalised error distribution, GED, for innovations, which relaxes the assumption of normality. The GED takes into account the

shocks. In fact, the slope of the *news impact curve* with regard to innovations varies according to the sign and size of these innovations (see Engle and Ng (1993a) for the shape of news impact curves). The asymmetric effects of innovations on the conditional variance in an EGARCH specification are as follows. If the coefficient of standardised residual, θ , is negative (positive), then negative (positive) shocks, tend to increase (decrease) the conditional variance. This form of specification for variance also allows for the size bias effect evidenced in GARCH models by introducing an extra term which represents the difference between the size of the shock at time t and the expected value of the shock, $[|z_t| - E|z_t|]$. Therefore, if the estimate of γ is positive, then larger shocks tend to increase the volatility relatively more compared to smaller shocks.

3.6.3. Asymmetric news and their impact on volatility

It has been argued in the financial economics literature that news (shocks) might have different impact on the behaviour of the volatilities of time series, i.e. the impact of a positive shock on the volatility can be different from the impact of the negative shock with the same magnitude. This phenomenon which is known as leverage is quite important when modelling the second order moments of the time series. Since GARCH models allow a symmetric effect on the time varying variance by the past residuals, in the presence of the leverage effect, GARCH models are misspecified and lead to biased estimates of volatilities as well as inaccurate forecast intervals.

Engle and Ng (1993a) develop a set of tests to detect any form of misspecification in GARCH models due to the asymmetric behaviour of volatility to shocks. These tests are based on regressing the standardised residuals, $(e\sigma_t^2 = \hat{e}_t / \sigma_t)$, on a series of dummies which are constructed using the sign and relative size of shocks (a_t) in the mean equation. These are S_{t-1}^- which is equal to 1 when a_{t-1} is negative and zero otherwise and S_{t-1}^+ which is equal to $1 - S_{t-1}^-$. The suggested tests are as the followings

$$e\sigma_t^2 = a_0 + a_1 S_{t-1}^- + \beta z_0 + \omega_t \quad (3.93a)$$

$$e\sigma_t^2 = a_0 + a_1 S_{t-1}^- \varepsilon_{t-1} + \beta z_0 + \omega_t \quad (3.93b)$$

$$e\sigma_t^2 = a_0 + a_1 S_{t-1}^+ \varepsilon_{t-1} + \beta z_0 + \omega_t \quad (3.93c)$$

$$e\sigma_t^2 = a_0 + a_1 S_{t-1}^- + a_2 S_{t-1}^- \varepsilon_{t-1} + a_3 S_{t-1}^+ \varepsilon_{t-1} + \beta z_0 + \omega_t \quad (3.93d)$$

where β and z_0 are the parameters and variables in the specification of the conditional variance, respectively. In equation (3.93a), significance of the term, a_1 , implies that negative shocks (bad news) have a relatively greater impact on volatility than positive shocks (good news). Significance of the a_1 coefficients in equations (3.93b) and (3.93c) implies that the shocks with different magnitudes have different relative impact on the volatility; that is negative and positive size biases, respectively. The final equation, (3.93d), performs a joint LM test, in which the null is $H_0: a_1=a_2=a_3=0$, in order to detect any sign and size biases in the impact of the shocks on the conditional variance.

Engle and Ng (1993a) recommend performing sign and size bias tests on the unconditional mean and variance of dependent variable too, i.e. before attempting to model the variance, in order to determine the functional form of the GARCH model. However, the tests based on unconditional means and variances should be considered with caution only as an indication of possible biases. The residuals from different functional forms of the mean the residuals from the GARCH models should be tested again for further presence of sign and size biases.

3.6.4. GARCH and EGARCH in mean models

In a seminal paper, Engle et al (1987) propose a different version of GARCH models in order to investigate the risk/return relationship between bonds with different terms to maturity, known as ARCH in the mean (ARCH-M). Engle et al (1987) use an ARCH-M setting to model the time-varying risk premia and explain the failure of the expectations hypothesis of the term structure relationship between long and short term T-bills in the US. Since then several authors utilised different functional forms of ARCH-M type models in order to investigate the existence of time-varying risk in equity, bond and foreign exchange markets.

For example, French et al (1987) use GARCH-M specification to investigate the relationship between volatility and return in Standard and Poor's composite portfolio, Chou (1988) studies the time-varying risk/return relationship of NYSE value weighted index, Taylor (1992) investigates the existence of time-varying risk premia in the UK long term bond market, Hurn et al (1995) model the time-varying risk premia in the UK Libor, among others.

In GARCH in mean models, a functional form of the time-varying variance, $f(h_t)$, is included in the mean specification to increase the explanatory power of the mean equation. Nelson (1991) also extends the GARCH-M model to Exponential GARCH-M in which the time-varying variance is used as a determinant of the mean in the following form

$$\begin{aligned} Y_t &= a_0 + b_1 X_t + \phi f(\sigma_t^2) + \varepsilon_t, & \varepsilon_t &\sim \text{iid}(0, \sigma_t^2) \\ \sigma_t^2 &= \exp\left(\alpha_0 + \sum_{i=1}^p \alpha_i g(z_{t-i}) + \sum_{j=1}^q \beta_j \log(\sigma_{t-j}^2)\right) \\ g(z_t) &= \theta(z_t) + \gamma(\|z_t\| - E\|z_t\|) & z_t &= \frac{\varepsilon_t}{\sigma_t} \end{aligned} \quad (3.94)$$

The form in which the time varying variance enters the specification of the mean is a matter of empirical evidence, but the square root, logs or even levels of the variance are used in the literature for this purpose. For example, Engle et al (1987) use the log of the variance in the mean to model the excess holding yield on 6 month over 3-month T-bills, while, Bollerslev, Engle and Wooldridge (1988) use the square root of the conditional variance in the mean specification. However, French et al (1987) report that when the exponent of the risk term (conditional variance or standard deviation) is estimated freely, the coefficient was closer to 2 rather than to 1, suggesting that the standard deviations should be used in the mean equation.

3.6.5. Multivariate GARCH models

Another extension of GARCH models is the multivariate GARCH, which is introduced to model the means and variances of two or more variables simultaneously. These type of models have been suggested by Bollerslev et al (1988) in asset pricing specifications. They find that multivariate models perform better than univariate models in econometric terms. Koutmos and Tucker (1996) extend the multivariate GARCH model in order to estimate the interaction between the means and variances of the returns on spot and future stock indices

through a Bivariate Exponential GARCH. They also report that the multivariate model outperforms the univariate models of volatility.

A multivariate GARCH model can be set up by specifying a multivariate model for the mean, for example a bivariate or trivariate VAR, and a corresponding multivariate setting for the time-varying variance and covariance terms as follows

$$\begin{aligned}
 y_{i,t} &= a_{i,0} + \sum_{l=1}^L a_{i,l} y_{i,t-l} + \sum_{l=1}^L b_{j,l} y_{j,t-l} + \varepsilon_{i,t} \quad ; \quad \varepsilon_{i,t} \sim \text{iid}(0, \sigma_{ii,t}^2) \\
 \sigma_{ii,t}^2 &= \beta_{i,0} + \sum_{n=1}^N \beta_{i,n} \sigma_{ii,t-n}^2 + \sum_{m=1}^M \gamma_{i,m} \varepsilon_{i,t-m}^2 \\
 \sigma_{ij,t}^2 &= \rho_{i,0} + \sum_{r=1}^{R_1} \rho_{i,r} \sigma_{ii,t-r}^2 + \sum_{r=1}^{R_2} \rho_{j,r} \sigma_{jj,t-r}^2 + \sum_{r=1}^{R_{12}} \rho_{ij,r} \sigma_{ij,t-r}^2
 \end{aligned} \tag{3.95}$$

Where i is the number of endogenous variables in the system, $y_{i,t}$ are dependent variables, $\sigma_{ii,t}$ are conditional variances, and $\sigma_{ij,t}$ are the time-varying covariance terms between i^{th} and j^{th} equations. However, this increases the number of parameters to be estimated and consequently leads to a loss of degrees of freedom very quickly. Another problem with the above specification is that it is often difficult to estimate. This is because of the problems with non-negativity of parameter estimates. Engle and Kroner (1995) propose the Generalised Multivariate GARCH, known as BEKK¹⁵ model, as a solution for the non-negativity problem associated with multivariate GARCH, in which the time-varying variance-covariance matrix is guaranteed to be positive definite.

$$\begin{aligned}
 \mathbf{y}_t &= \mathbf{\Pi}' \mathbf{x}_t + \boldsymbol{\varepsilon}_t \\
 \boldsymbol{\Sigma}_t &= \mathbf{C}\mathbf{C}' + \sum_{j=1}^n \mathbf{A}_j \boldsymbol{\Sigma}_{t-j} \mathbf{A}_j' + \sum_{j=1}^m \mathbf{B}_j \boldsymbol{\varepsilon}_{t-j} \boldsymbol{\varepsilon}_{t-j}' \mathbf{B}_j' + \mathbf{D}\mathbf{z}_t \mathbf{z}_t' \mathbf{D}'
 \end{aligned} \tag{3.96}$$

Where \mathbf{y}_t is an $(n \times 1)$ vector of dependent variables, \mathbf{x}_t is an $(k \times 1)$ vector of independent variables, \mathbf{z}_t is $(p \times 1)$ vector of exogenous variables, $\boldsymbol{\varepsilon}_t$ is an $(n \times 1)$ vector of regression residuals and $\mathbf{\Pi}$ is an $(n \times k)$ matrix of parameters in the mean equation. In the variance equation, $\boldsymbol{\Sigma}_t$ is a symmetric variance-covariance matrix, and \mathbf{C} is a $(n \times n)$ lower triangular matrix of constant parameters, \mathbf{A}_j and \mathbf{B}_j are $(n \times n)$ matrices of parameters for the lagged

¹⁵ The BEKK model originally proposed by Baba, Engle, Kroner and Kraft (1989) where it takes its name.

variance and squared residual terms and \mathbf{D} is an $(n \times p)$ matrix of parameters for exogenous variables. Although the specification in (3.96) ensures a positive definite variance covariance matrix, it requires estimation of a large number of parameters, which results in loss of degrees of freedom, especially when the sample is not very large. One way to overcome this problem is to restrict some or all of the off-diagonal elements in \mathbf{A}_j and \mathbf{B}_j matrices as follows

$$\mathbf{C} = \begin{pmatrix} c_{11} & 0 & \dots & 0 \\ c_{21} & c_{22} & \dots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{pmatrix}, \quad \mathbf{A}_1 = \begin{pmatrix} a_{11} & 0 & \dots & 0 \\ 0 & a_{22} & \dots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \dots & a_{nn} \end{pmatrix}, \quad \mathbf{B}_1 = \begin{pmatrix} b_{11} & 0 & \dots & 0 \\ 0 & b_{22} & \dots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \dots & b_{nn} \end{pmatrix}, \quad \Sigma_t = \begin{pmatrix} \sigma_{1,t}^2 & 0 & \dots & 0 \\ \sigma_{12,t} & \sigma_{2,t}^2 & \dots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ \sigma_{1n,t} & \sigma_{2n,t} & \dots & \sigma_{n,t}^2 \end{pmatrix}$$

However, such off-diagonal terms measure the spillover effects between volatilities and restricting them might involve some misspecification costs, if such effects exist between time-varying conditional variances. In order to measure volatility spillover effects, we construct an additional matrix containing specific parameters measuring such effects (see section 3.6.5.1).

An alternative solution to the problem of non-negativity in multivariate GARCH models is to use the multivariate EGARCH model of Koutmos and Booth (1995) and Koutmos and Tucker (1996) used to investigate the interaction between the means and variances of the returns on spot and future stock indices.

$$\begin{aligned} y_{i,t} &= a_{i,0} + \sum_{l=1}^L a_{i,l} y_{i,t-l} + \sum_{l=1}^L a_{j,l} y_{j,t-l} + \varepsilon_{i,t} ; \quad \varepsilon_{i,t} \sim \text{iid}(0, \sigma_{ii,t}^2) \quad , \quad i, j=1, 2, \dots \\ \sigma_{ii,t}^2 &= \exp \left(\beta_{0i} + \sum_{n=1}^N \beta_{i,n} \ln \sigma_{ii,t-n}^2 + \sum_{m=1}^M \gamma_{i,m} g_{i,t-m} + \sum_{p=1}^P \psi_{i,p} \ln \sigma_{jj,t-n}^2 \right) \\ \sigma_{ij,t} &= \rho \sqrt{\sigma_{ii,t}^2 \sigma_{jj,t}^2} \\ g_{i,t} &= \theta \varepsilon_{i,t} + \left(|\varepsilon_{i,t} / \sigma_{ii,t}| - E(\varepsilon_{i,t} / \sigma_{ii,t}) \right) \end{aligned} \tag{3.97}$$

This setting allows for non-negativity of variance parameters as well as a direct measure of spillover effects between conditional variances of the variables through the $\psi_{i,p}$ parameters, however, the constant correlation limitation for this model still exists.

3.6.5.1. VECM-GARCH BEKK models in measuring volatility spillovers

In order to analyse the dynamic behaviour of variables and the spillover effects between time-varying volatilities of variables in \mathbf{z}_t , say $\mathbf{z}_t = [y_{1t}, y_{2t}, y_{3t}]$ in a simultaneous framework, the VECM model of (3.32) can be extended to the following diagonal BEKK VECM-GARCH model

$$\Delta \mathbf{z}_t = \boldsymbol{\mu}_0 + \boldsymbol{\mu}_1 t + \sum_{i=1}^k \boldsymbol{\Gamma}_i \Delta \mathbf{z}_{t-i} + \boldsymbol{\alpha} \boldsymbol{\beta}' \mathbf{z}_{t-k} + \boldsymbol{\Psi} \mathbf{D}_t + \boldsymbol{\varepsilon}_t \quad , \quad \boldsymbol{\varepsilon}_t \sim \text{student-t}(0, \boldsymbol{\Sigma}_t) \quad .98)$$

$$\boldsymbol{\Sigma}_t = \mathbf{A} \mathbf{A}' + \mathbf{B} \boldsymbol{\Sigma}_{t-1} \mathbf{B}' + \mathbf{C} \boldsymbol{\varepsilon}_{t-1} \boldsymbol{\varepsilon}_{t-1}' \mathbf{C}' + \mathbf{S1} \mathbf{u}_{1,t-1}' \mathbf{u}_{1,t-1} \mathbf{S1}' + \mathbf{S2} \mathbf{u}_{2,t-1}' \mathbf{u}_{2,t-1} \mathbf{S2}' + \mathbf{S3} \mathbf{u}_{3,t-1}' \mathbf{u}_{3,t-1} \mathbf{S3}'$$

Where

$$\Delta \mathbf{z}_t = \begin{pmatrix} \Delta y_{1t} \\ \Delta y_{2t} \\ \Delta y_{3t} \end{pmatrix} \quad , \quad \boldsymbol{\mu}_0 = \begin{pmatrix} \mu_{10} \\ \mu_{20} \\ \mu_{30} \end{pmatrix} \quad , \quad \boldsymbol{\mu}_1 = \begin{pmatrix} \mu_{11} \\ \mu_{21} \\ \mu_{31} \end{pmatrix} \quad , \quad \mathbf{D}_t = \begin{pmatrix} d_{1,t} \\ \vdots \\ d_{11,t} \end{pmatrix} \quad , \quad \boldsymbol{\varepsilon}_t = \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{pmatrix}$$

$$\boldsymbol{\Gamma}_1 = \begin{pmatrix} \gamma_{1,11} & \gamma_{1,12} & \gamma_{1,13} \\ \gamma_{1,21} & \gamma_{1,22} & \gamma_{1,23} \\ \gamma_{1,31} & \gamma_{1,32} & \gamma_{1,33} \end{pmatrix} \quad , \quad \boldsymbol{\Gamma}_k = \begin{pmatrix} \gamma_{k,11} & \gamma_{k,12} & \gamma_{k,13} \\ \gamma_{k,21} & \gamma_{k,22} & \gamma_{k,23} \\ \gamma_{k,31} & \gamma_{k,32} & \gamma_{k,33} \end{pmatrix} \quad , \quad \boldsymbol{\alpha} = \begin{pmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \end{pmatrix}$$

$$\boldsymbol{\beta}' = \begin{pmatrix} \beta_{10} & \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ \beta_{20} & \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \end{pmatrix} \quad , \quad \mathbf{z}_t = \begin{pmatrix} c \\ t \\ y_{1,t-1} \\ y_{2,t-1} \\ y_{3,t-1} \end{pmatrix} \quad \boldsymbol{\Psi} = \begin{pmatrix} \varphi_{1,1} & \cdots & \varphi_{1,11} \\ \varphi_{2,1} & \cdots & \varphi_{2,11} \\ \varphi_{3,1} & \cdots & \varphi_{3,11} \end{pmatrix}$$

$$\boldsymbol{\Sigma}_t = \begin{pmatrix} \sigma_{1,t}^2 & \sigma_{12,t} & \sigma_{13,t} \\ \sigma_{21,t} & \sigma_{2,t}^2 & \sigma_{23,t} \\ \sigma_{31,t} & \sigma_{32,t} & \sigma_{3,t}^2 \end{pmatrix} \quad , \quad \mathbf{A} = \begin{pmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \quad , \quad \mathbf{B} = \begin{pmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{pmatrix} \quad , \quad \mathbf{C} = \begin{pmatrix} c_{11} & 0 & 0 \\ 0 & c_{22} & 0 \\ 0 & 0 & c_{33} \end{pmatrix}$$

$$\mathbf{S1} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & s1_{21} & 0 \\ 0 & 0 & s1_{31} \end{pmatrix} \quad , \quad \mathbf{S2} = \begin{pmatrix} s2_{12} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & s2_{32} \end{pmatrix} \quad , \quad \mathbf{S3} = \begin{pmatrix} s3_{13} & 0 & 0 \\ 0 & s3_{23} & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\mathbf{u}_{1,t} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \varepsilon_{1,t} & 0 \\ 0 & 0 & \varepsilon_{1,t} \end{pmatrix} \quad , \quad \mathbf{u}_{2,t} = \begin{pmatrix} \varepsilon_{2,t} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \varepsilon_{2,t} \end{pmatrix} \quad , \quad \mathbf{u}_{3,t} = \begin{pmatrix} \varepsilon_{3,t} & 0 & 0 \\ 0 & \varepsilon_{3,t} & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Expanding matrices of coefficients and variables explaining the mean model results in the following model

$$\begin{aligned}
\Delta y_{1,t} &= \mu_{10} + \mu_{11}t + \sum_{i=1}^{p-1} a_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} a_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} a_{3,i} \Delta y_{3,t-i} + \alpha_{11} \beta_1 z_{t-1} + \alpha_{12} \beta_2 z_{t-1} + \sum_{i=1}^{11} \varphi_{1,i} d_i + \varepsilon_{1,t} \\
\Delta y_{2,t} &= \mu_{20} + \mu_{21}t + \sum_{i=1}^{p-1} b_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} b_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} b_{3,i} \Delta y_{3,t-i} + \alpha_{21} \beta_1 z_{t-1} + \alpha_{22} \beta_2 z_{t-1} + \sum_{i=1}^{11} \varphi_{2,i} d_i + \varepsilon_{2,t} \\
\Delta y_{3,t} &= \mu_{30} + \mu_{31}t + \sum_{i=1}^{p-1} c_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} c_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} c_{3,i} \Delta y_{3,t-i} + \alpha_{31} \beta_1 z_{t-1} + \alpha_{32} \beta_2 z_{t-1} + \sum_{i=1}^{11} \varphi_{3,i} d_i + \varepsilon_{3,t}
\end{aligned} \tag{3.99}$$

Where $\beta_1 = (\delta_{10} + \delta_{11} + \beta_{11} + \beta_{12} + \beta_{13})$ and $\beta_2 = (\delta_{20} + \delta_{21} + \beta_{21} + \beta_{22} + \beta_{23})$ represent two cointegrating vectors; that is, the long run relationships between 3 variables in z_t .

Similarly, expanding the variance specification to show elements in matrices of coefficients and variables results in the following specification

$$\begin{aligned}
\sigma_{1,t}^2 &= a_{11}^2 + b_{11}^2 \sigma_{1,t-1}^2 + c_{11}^2 \varepsilon_{1,t-1}^2 + s_{11}^2 \varepsilon_{2,t-1}^2 + s_{11}^2 \varepsilon_{3,t-1}^2 \\
\sigma_{2,t}^2 &= a_{21}^2 + a_{22}^2 + b_{22}^2 \sigma_{2,t-1}^2 + c_{22}^2 \varepsilon_{1,t-1}^2 + s_{22}^2 \varepsilon_{1,t-1}^2 + s_{22}^2 \varepsilon_{3,t-1}^2 \\
\sigma_{3,t}^2 &= a_{31}^2 + a_{32}^2 + a_{33}^2 + b_{33}^2 \sigma_{3,t-1}^2 + c_{33}^2 \varepsilon_{3,t-1}^2 + s_{33}^2 \varepsilon_{1,t-1}^2 + s_{33}^2 \varepsilon_{2,t-1}^2 \\
\sigma_{12,t} &= a_{11}a_{21} + b_{11}b_{22} \sigma_{12,t-1} + c_{11}c_{22} \varepsilon_{1,t-1} \varepsilon_{2,t-1} \\
\sigma_{13,t} &= a_{11}a_{31} + b_{11}b_{33} \sigma_{13,t-1} + c_{11}c_{33} \varepsilon_{1,t-1} \varepsilon_{3,t-1} \\
\sigma_{23,t} &= a_{21}a_{31} + a_{22}a_{32} + b_{22}b_{33} \sigma_{23,t-1} + c_{22}c_{33} \varepsilon_{2,t-1} \varepsilon_{3,t-1}
\end{aligned} \tag{3.100}$$

Where s_{ij} (i and $j = 1, 2, 3, i \neq j$) coefficients are used to measure freight rate volatility spillovers between different size in each market (spot, 1-year and 3-year time-charter).

3.6.6. Estimation of ARCH and GARCH models

Maximum likelihood estimation has been used extensively in estimation of ARCH models in empirical studies due to its simplicity and power. Assuming normality, this is done by specifying the log likelihood function of the ARCH model in the following form (not considering the constant)

$$l(\alpha, \beta) = \frac{1}{T} \sum_{t=1}^T l_t(\alpha, \beta) \tag{3.101}$$

and

$$l_t(\alpha, \beta) = -\frac{1}{2} \log(h_t) - \frac{\sum \varepsilon_i^2}{2\sigma_i} \tag{3.102}$$

where α , β are vectors of the parameters in the mean and variance equations respectively. If the specification of the variance model is symmetric, then the information matrix is block diagonal (i.e. it contains non-zero elements on the principal diagonal and zeros elsewhere), which is normally the case for symmetric ARCH models. Therefore, it is also possible to maximise the above log likelihood function using the Berndt, Hall, Hall and Hausman (1974), BHHH, iterative optimisation methods. This method uses the partial derivatives of the log likelihood function with respect to each vector of parameters α_i and β_j in order to update the previous parameter estimates recursively in the following form

$$\alpha^{r+1} = \alpha^r + \left[\sum_{t=1}^T \left(\frac{\partial l_t}{\partial \alpha} \right) \left(\frac{\partial l_t}{\partial \alpha} \right)' \right]^{-1} \sum_{t=1}^T \frac{\partial l_t}{\partial \alpha} \quad (3.103)$$

and

$$\beta^{r+1} = \beta^r + \left[\sum_{t=1}^T \left(\frac{\partial l_t}{\partial \beta} \right) \left(\frac{\partial l_t}{\partial \beta} \right)' \right]^{-1} \sum_{t=1}^T \frac{\partial l_t}{\partial \beta} \quad (3.104)$$

However, if the specification of the ARCH model allows for asymmetry such as in EGARCH or EARCH-M models, then the information matrix is no longer block diagonal and has non zero $(i,j)^{th}$ elements. Therefore optimisation methods like BHHH should be carried out jointly for the mean and variance equation parameters in the following form

$$\theta^{(r+1)} = \theta^r + \left[\sum_{t=1}^T \left(\frac{\partial l_t}{\partial \theta} \right) \left(\frac{\partial l_t}{\partial \theta} \right)' \right]^{-1} \sum_{t=1}^T \frac{\partial l_t}{\partial \theta} \quad (3.105)$$

where $\theta=(\alpha_i, \beta_j)$ is a vector of parameters in the conditional mean and variance equations.

The extension of the univariate log likelihood function of ARCH and GARCH models to multivariate ones is straightforward and can be done by replacing the variance and the error terms by their corresponding matrix, Σ_t , and the vector, ε_t in the multivariate specification as follows

$$l(\alpha, \beta) = -\frac{1}{2} \sum_{t=1}^T \left[\log(\Sigma_t) + \frac{\varepsilon_t' \varepsilon_t}{\Sigma_t} \right] \quad (3.106)$$

where Σ_t is a symmetric time-varying variance-covariance matrix with variance terms as the main diagonal and covariance terms as off-diagonal elements.

3.6.7. Non-Normality, Excess Kurtosis and Fat-Tails

Another important assumption regarding maximisation of the log likelihood function is that of normality. There are occasions where the normality assumption regarding the residuals in GARCH models does not hold, therefore specifying a normal log likelihood function for estimation purposes would be inappropriate. This issue has been pointed out and explored by many authors in the growing literature of GARCH models specification and estimation (see, for example, Bollerslev (1987), Nelson (1991) and Bollerslev and Wooldridge (1992)). Different density functions are proposed in various studies where authors find that residuals (standardised residuals) do not satisfy the normality assumption. For example, Bollerslev (1987) proposes a student-t distribution in order to capture fat-tails in the conditional density using the following conditional density specification

$$l(\varepsilon_{t+1}(\alpha, \beta)) = \Gamma\left(\frac{k+1}{2}\right) \Gamma\left(\frac{k}{2}\right)^{-1} (k-2)^{-1/2} \left(1 + \frac{\varepsilon_{t+1}(\alpha, \beta)^2}{k-2}\right)^{-(k+1)/2} \quad (3.107)$$

where $\Gamma(\cdot)$ is the gamma function¹⁶ and k is the degrees of freedom. The student-t distribution converges to the normal distribution as k increases ($k \rightarrow \infty$), however, in empirical applications the results are the same for $k=20$ (see Pesaran and Pesaran, 1995). For $k \leq 4$ the kurtosis for the distribution is not defined since the theoretical kurtosis of a t distribution is $3(v-2)/(v-4)$. Bollerslev (1987) reports superior performance of the student-t compared to a normal density function for non-normal disturbances.

Nelson (1991), with an argument along similar lines, uses the normalised generalised error distribution, GED, with zero mean and unit variance in order to define the density function and estimate the maximum log-likelihood function of his EGARCH model. The GED density function for GARCH/EGARCH models can be defined as

$$l(\varepsilon_{t+1}(\alpha, \beta)) = \frac{k \exp\left(-\frac{1}{2} \left|\varepsilon_{t+1} / \lambda\right|^k\right)}{\lambda 2^{[(k+1)/k]} \Gamma(1/k)} \quad (3.108)$$

¹⁶ The Gamma function, interpolates the factorials in the sense that $\Gamma(v+1) = v!$, for $v > 0$; see Feller (1966).

Where $\lambda = \left\{ \frac{2^{(-2/k)} \Gamma(1/k)}{\Gamma(3/k)} \right\}^{1/2}$ and k represents the number of degrees of freedom which can take values $0 < k < +\infty$. If $k=2$, then the above density function is the standard normal, and if $k < 2$ then the distribution has thicker tails than normal, whereas $2 < k$ indicates that the distribution has thinner tails than normal.

Finally, Engle and Gonzales-Rivera (1991) introduce non-parametric methods for estimation of non-normal densities. Bollerslev and Wooldridge (1992) show that, since non-normality affects the standard errors of parameter estimates, one can continue to work with the conditional normal likelihood, however, the standard errors for parameter estimates should be calculated using a robust covariance matrix estimator. Bollerslev and Wooldridge (1992) propose the quasi maximum likelihood (QML, i.e. maximum likelihood based on incorrect assumptions) estimation procedure. This procedure uses robust standard error estimation techniques to correct the standard errors, which are not consistent¹⁷. Weiss (1986) points out that even if the normality assumption does not hold, the quasi maximum likelihood estimators, i.e. estimates of the log likelihood function in the absence of normality, will be consistent if the mean and variance models are correctly specified.

¹⁷ In the case of the multivariate GARCH BEKK model of (3.98) with a multivariate normal log-likelihood function $L(\Sigma_t, \varepsilon_t, \theta) = -\log 2\pi - 0.5 \log |\Sigma(\theta)_t| - 0.5 [\varepsilon'(\theta)_t (\Sigma(\theta)_t)^{-1} \varepsilon(\theta)_t]$, which is maximised with respect to unknown parameters, θ . Using standard MLE, the variance-covariance matrix of the estimated coefficients is given by $\text{var}(\tilde{\theta}) = J^{-1}$ where J is the information matrix, i.e. $J = -E(\partial^2 L / \partial \theta \partial \theta')$. Under QML estimation, $\text{var}(\tilde{\theta}) = J^{-1} K J^{-1}$ where K is the outer product of the first-order derivatives, $K = \sum_{t=1}^T (\partial L / \partial \theta)(\partial L / \partial \theta)'$.

3.7. Conclusions

This chapter presented recently developed econometric methods and time series models, which are used extensively in later chapters of the thesis. In particular, univariate properties of time series including stationarity, seasonality and related the statistical problems, which may arise in the presence of nonstationary series in regression models, are discussed. Dickey and Fuller (1979 and 1981) and Phillips and Perron (1988) unit root tests along with their limitations for investigating stochastic properties of time series are explained. A more complete test for presence of unit roots proposed by Beaulieu and Miron (1993) is also discussed, which takes into account the periodicity of the series in testing for unit roots. This is essentially an extension of the Hylleberg et al (1990) test for quarterly series to monthly data. Models for identifying and measuring deterministic seasonality in time series were also presented and extended to a model to investigate the cyclical changes in seasonal fluctuations.

In the context of multivariate time series analysis, the VAR methodology including identification and estimation problems are presented. The multivariate analysis of time series is then extended to models, which take into account stochastic properties of the series. In this respect, the Engle-Granger (1987) two-step cointegration method and the Johansen's (1988) full information maximum likelihood cointegration technique were presented. VECM models, which capture both the short run dynamics as well as the long run relationships between variables through cointegration relationships, are also discussed in detail. A new technique in tracing the effect of shocks to variable on other variables in a multivariate system, i.e. the GIR analysis of Pesaran and Shin (1997) is discussed and analysed.

Finally, recently developed ARCH and GARCH models, which are used extensively to investigate and model the time-varying behaviour of variances and covariances of economic and financial time series, were presented. Extensions of GARCH model to multivariate framework including related issues on specification and estimation of these models are presented. As an extension to multivariate GARCH models, a VECM-GARCH BEKK model is proposed to investigate the interrelationship between levels and variances of variables.

These tests and modelling techniques are used in chapters 4 to 7 to: 1) test the stochastic and deterministic properties of freight rate series measured at monthly intervals including seasonality and seasonal unit roots; 2) measure and compare seasonality across different size and contract durations, and over different market conditions, 3) investigate the cointegration relationship between spot and period rates; 4) test the validity of the expectations hypothesis of the term structure in the freight market using the VAR methodology; 5) model the time-varying risk premia in formation of period rates using EGARCH-M model; 6) investigate interrelationships and dynamics between level and variance of freight rates for different sizes of dry bulk carriers using VECM-GARCH BEKK specification; 7) examine the EMH in the formation of prices for newbuilding and second-hand dry bulk vessels using the present value model and the VAR methodology; 8) and finally, investigate the existence of time-varying risk premia in the formation second-hand prices.

Appendix 3.A

Beaulieu and Miron (1990) seasonal unit roots

It is mentioned in section 3.3.3 that Hylleberg et al (1990) and Beaulieu and Miron (1993) used the root partitioning method to test the series for existence of unit roots at each frequency. In HEGY(1990) this root partitioning has been done by linearising the seasonal back shift operator around all possible unit roots (roots at all frequencies) as a sum of several simple operators as

$$(1 - B^S) = \sum_{k=1}^S \lambda_k \Delta(B) \frac{1 - \delta_k(B)}{\delta_k(B)} + \Delta(B) \varphi^*(B) \quad (3.A.1)$$

where

$$\delta_k(B) = 1 - \frac{1}{\theta_k} B \quad , \quad \Delta(B) = \prod_{k=1}^S \delta_k(B) \quad , \quad \lambda_k = \frac{\varphi(\theta_k)}{\prod_{j \neq k} \delta_j(\theta_k)}$$

$\varphi^*(B)$ is an infinite polynomial and θ_k , $k=1, \dots, S$ are the roots of the polynomial at different frequencies. Hylleberg et al (1990) also argued that polynomial $(1 - B^S)$ will have a root at θ_k if and only if λ_k is equal to zero. Therefore, testing for a unit root at each of these frequencies is equivalent to testing for $\lambda_k = 0$, $k=1, \dots, S$, which amounts to (3.A.2), for monthly data

$$\begin{aligned} (1 - B^{12}) = & \lambda_1 \sum_{i=1}^{12} \cos(0i\pi) B^{i-1}(X_t) + \lambda_2 \sum_{i=1}^{12} \cos(i\pi) B^{i-1}(X_t) \\ & + \lambda_3 \sum_{i=1}^{12} \cos(i\pi / 2) B^{i-1}(X_t) + \lambda_4 \left[- \sum_{i=1}^{12} \sin(i\pi / 2) B^{i-1}(X_t) \right] \\ & + \lambda_5 \sum_{i=1}^{12} \cos(2i\pi / 3) B^{i-1}(X_t) + \lambda_6 \sum_{i=1}^{12} \sin(2i\pi / 3) B^{i-1}(X_t) \\ & + \lambda_7 \sum_{i=1}^{12} \cos(i\pi / 3) B^{i-1}(X_t) + \lambda_8 \sum_{i=1}^{12} \sin(0i\pi) B^{i-1}(X_t) \\ & + \lambda_9 \sum_{i=1}^{12} \cos(5i\pi / 6) B^{i-1}(X_t) + \lambda_{10} \sum_{i=1}^{12} \sin(5i\pi / 6) B^{i-1}(X_t) \\ & + \lambda_{11} \sum_{i=1}^{12} \cos(i\pi / 6) B^{i-1}(X_t) + \lambda_{12} \sum_{i=1}^{12} \sin(i\pi / 6) B^{i-1}(X_t) \end{aligned} \quad (3.A.2)$$

These trigonometric terms can be expanded to produce polynomials in the back shift operator as follows

$$\begin{aligned}
X_{1,i} &= \sum_{j=1}^{12} \cos(0i\pi) B^{j-1}(Y_i) = Y_i + Y_{i-1} + Y_{i-2} + Y_{i-3} + Y_{i-4} + Y_{i-5} + Y_{i-6} + Y_{i-7} + Y_{i-8} + Y_{i-9} + Y_{i-10} + Y_{i-11} \\
X_{2,i} &= \sum_{j=1}^{12} \cos(i\pi) B^{j-1}(Y_i) = -Y_i + Y_{i-1} - Y_{i-2} + Y_{i-3} - Y_{i-4} + Y_{i-5} - Y_{i-6} + Y_{i-7} - Y_{i-8} + Y_{i-9} - Y_{i-10} + Y_{i-11} \\
X_{3,i} &= \sum_{j=1}^{12} \cos(i\pi/2) B^{j-1}(Y_i) = -Y_{i-1} + Y_{i-3} - Y_{i-5} + Y_{i-7} - Y_{i-9} + Y_{i-11} \\
X_{4,i} &= \sum_{j=1}^{12} \sin(i\pi/2) B^{j-1}(Y_i) = -Y_i + Y_{i-2} - Y_{i-4} + Y_{i-6} - Y_{i-8} + Y_{i-10} \\
X_{5,i} &= \sum_{j=1}^{12} \cos(2i\pi/3) B^{j-1}(Y_i) = -\frac{1}{2}(Y_i + Y_{i-1} - 2Y_{i-2} + Y_{i-3} + Y_{i-4} - 2Y_{i-5} + Y_{i-6} + Y_{i-7} - 2Y_{i-8} + Y_{i-9} + Y_{i-10} - 2Y_{i-11}) \\
X_{6,i} &= \sum_{j=1}^{12} \sin(2i\pi/3) B^{j-1}(Y_i) = \frac{\sqrt{3}}{2}(Y_i - Y_{i-1} + Y_{i-3} - Y_{i-4} + Y_{i-6} - Y_{i-7} + Y_{i-9} - Y_{i-10}) \\
X_{7,i} &= \sum_{j=1}^{12} \cos(i\pi/3) B^{j-1}(Y_i) = -\frac{1}{2}(Y_i - Y_{i-1} - 2Y_{i-2} - Y_{i-3} + Y_{i-4} + 2Y_{i-5} + Y_{i-6} - Y_{i-7} - 2Y_{i-8} - Y_{i-9} + Y_{i-10} + 2Y_{i-11}) \\
X_{8,i} &= \sum_{j=1}^{12} \sin(i\pi/3) B^{j-1}(Y_i) = -\frac{\sqrt{3}}{2}(Y_i + Y_{i-1} - Y_{i-3} - Y_{i-4} + Y_{i-6} + Y_{i-7} - Y_{i-9} - Y_{i-10}) \\
X_{9,i} &= \sum_{j=1}^{12} \cos(5i\pi/6) B^{j-1}(Y_i) = -\frac{1}{2}(\sqrt{3}Y_i - Y_{i-1} + Y_{i-3} - \sqrt{3}Y_{i-4} + 2Y_{i-5} - \sqrt{3}Y_{i-6} + Y_{i-7} - Y_{i-9} + \sqrt{3}Y_{i-10} - 2Y_{i-11}) \\
X_{10,i} &= \sum_{j=1}^{12} \sin(5i\pi/6) B^{j-1}(Y_i) = \frac{1}{2}(Y_i - \sqrt{3}Y_{i-1} + 2Y_{i-2} - \sqrt{3}Y_{i-3} + Y_{i-4} - Y_{i-6} + \sqrt{3}Y_{i-7} - 2Y_{i-8} + \sqrt{3}Y_{i-9} - Y_{i-10}) \\
X_{11,i} &= \sum_{j=1}^{12} \cos(i\pi/6) B^{j-1}(Y_i) = -\frac{1}{2}(\sqrt{3}Y_i + Y_{i-1} - Y_{i-3} - \sqrt{3}Y_{i-4} - 2Y_{i-5} - \sqrt{3}Y_{i-6} - Y_{i-7} + Y_{i-9} + \sqrt{3}Y_{i-10} + 2Y_{i-11}) \\
X_{12,i} &= \sum_{j=1}^{12} \sin(i\pi/6) B^{j-1}(Y_i) = -\frac{1}{2}(Y_i + \sqrt{3}Y_{i-1} + 2Y_{i-2} + \sqrt{3}Y_{i-3} + Y_{i-4} - Y_{i-6} - \sqrt{3}Y_{i-7} - 2Y_{i-8} + \sqrt{3}Y_{i-9} - Y_{i-10})
\end{aligned}
\tag{3.A.3}$$

Therefore equation (3.A.2) can be written as

$$\begin{aligned}
(1 - B^{12}) &= \lambda_1(1 + B + B^2 + B^3 + B^4 + B^5 + B^6 + B^7 + B^8 + B^9 + B^{10} + B^{11}) \\
&+ \lambda_2(-1 + B - B^2 + B^3 - B^4 + B^5 - B^6 + B^7 - B^8 + B^9 - B^{10} + B^{11}) \\
&+ \lambda_3(-B + B^3 - B^5 + B^7 - B^9 + B^{11}) \\
&+ \lambda_4(-1 + B^2 - B^4 + B^6 - B^8 + B^{10}) \\
&+ \lambda_5 \frac{1}{2}(-1 - B + 2B^2 - B^3 - B^4 + 2B^5 - B^6 - B^7 + 2B^8 - B^9 - B^{10} + 2B^{11}) \\
&+ \lambda_6 \frac{\sqrt{3}}{2}(1 - B^2 + B^3 - B^4 + B^6 - B^7 + B^9 - B^{10}) \\
&+ \lambda_7 \frac{1}{2}(1 - B - 2B^2 - B^3 + B^4 + 2B^5 + B^6 - B^7 - 2B^8 - B^9 + B^{10} + 2B^{11}) \\
&+ \lambda_8 \frac{\sqrt{3}}{2}(-1 - B^2 + B^3 + B^4 - B^6 - B^7 + B^9 + B^{10}) \\
&+ \lambda_9 \frac{1}{2}(-\sqrt{3} + B - B^3 + \sqrt{3}B^4 - 2B^5 + \sqrt{3}B^6 - B^7 + B^9 - \sqrt{3}B^{10} + 2B^{11}) \\
&+ \lambda_{10} \frac{1}{2}(1 - \sqrt{3}B + 2B^2 - \sqrt{3}B^3 + B^4 - B^6 + \sqrt{3}B^7 - 2B^8 + \sqrt{3}B^9 - B^{10}) \\
&+ \lambda_{11} \frac{1}{2}(\sqrt{3} + B - B^3 - \sqrt{3}B^4 - 2B^5 - \sqrt{3}B^6 - B^7 + B^9 + \sqrt{3}B^{10} + 2B^{11}) \\
&+ \lambda_{12} \frac{1}{2}(-1 - \sqrt{3}B - 2B^2 - \sqrt{3}B^3 - B^4 + B^6 + \sqrt{3}B^7 + 2B^8 + \sqrt{3}B^9 + B^{10}) \\
&+ \varphi * (B)(1 - B^{12})
\end{aligned}$$

(3.A.4)

where values for λ_k , $k=1,\dots,12$, in (3.A.4) can also be written as

$$\begin{aligned}
 \lambda_1 &= -\pi_1 & \lambda_7 &= \frac{1}{2}(-\pi_7 + i\pi_8) \\
 \lambda_{21} &= -\pi_{21} & \lambda_8 &= \frac{1}{2}(-\pi_7 - i\pi_8) \\
 \lambda_3 &= \frac{1}{2}(-\pi_3 + i\pi_4) & \lambda_9 &= \frac{1}{2}(-\pi_9 + i\pi_{10}) \\
 \lambda_4 &= \frac{1}{2}(-\pi_3 - i\pi_4) & \lambda_{10} &= \frac{1}{2}(-\pi_9 - i\pi_{10}) \\
 \lambda_5 &= \frac{1}{2}(-\pi_5 + i\pi_6) & \lambda_{11} &= \frac{1}{2}(-\pi_{11} + i\pi_{12}) \\
 \lambda_6 &= \frac{1}{2}(-\pi_5 - i\pi_6) & \lambda_{12} &= \frac{1}{2}(-\pi_{11} - i\pi_{12})
 \end{aligned} \tag{3.A.5}$$

Therefore, substituting equivalents of λ_k from (3.A.5) in equation (3.A.4) and using the back shift operator notation yields

$$(1 - B^{12})Y_t = \sum_{i=1}^{12} \pi_i X_{t,t-i} + \sum_{i=1}^P \delta_i (1 - B^{12})Y_{t-i} + \varepsilon_t \tag{3.A.6}$$

which is a linear equation and can be estimated using OLS. Critical values for the significance of π_i for quarterly and monthly frequencies can be found in Beaulieu and Miron (1993).

4. CHAPTER FOUR

**STOCHASTIC PROPERTIES OF DRY BULK FREIGHT RATES;
STATIONARITY AND SEASONALITY**

4.1. Introduction

Tramp shipping freight markets, like any other market, are characterised by the interaction of supply and demand for freight services. The demand for shipping services is a derived demand which depends on the economics of the commodities transported, world economic activity and the related macroeconomic variables of major economies (see Stopford (1997 page 238)). These macroeconomic variables have been shown elsewhere to be non-stationary with some deterministic seasonal components in most cases (see Nelson and Plosser (1982), Osborn (1990), Beaulieu and Miron (1992), Dickey (1993) and Canova and Hansen (1995)). The same is also true for trade figures in several commodities; for instance there are seasonal elements in the grain and petroleum trade (see, for example, Stopford (1997, p 238-9) and Moosa and Al-Loughani (1994)). Therefore, it is possible that those seasonalities are transmitted to shipping freight rates and prices. In fact, Denning et al (1994) find that there are elements of seasonality in the Baltic Freight Index, BFI¹.

Recent increases in the use of monthly freight rate series for market analysis and modelling, and the fact that seasonal effects may be present in monthly time series, suggest that the stochastic behaviour of shipping freight rates should be viewed within a framework which takes into account such seasonal effects. Furthermore, it can be argued that if there is a systematic seasonal pattern in freight rate fluctuations within the year, then these may be exploited by the agents involved. However, even though such seasonal behaviour is recognised in standard shipping textbooks such as Stopford (1997 p. 238-9), there is no attempt, to our knowledge, to systematically analyse and compare such behaviour between shipping sectors and types of freight contracts.

The aim of this chapter is to examine the stochastic properties of dry bulk freight rates, including autocorrelation, stationarity and unit roots and seasonality. In particular, the existence, nature and magnitude of seasonality in tramp shipping freight rates are examined across sub-markets of the dry bulk sector and under different market conditions. Since the results on univariate properties of freight series has important implications on methodologies

¹ BFI is a weighted-average index of spot and time-charter rates in 11 routes representing freight rates in the dry bulk sector of the shipping industry. This index is used as the basis for freight futures trading, BIFFEX.

used to study the relationships between these series, this chapter is also a prerequisite for multivariate analysis performed in later chapters,

The structure of this chapter is as follows. The next section discusses the relationship between the world economy and the stochastic behaviour of freight rates. Section 4.2 presents descriptive statistics of spot and time-charter rates for different sub-sectors of the dry bulk market. Section 4.3 examines the existence of stochastic and deterministic trends in freight rate series. The seasonal behaviour of freight rate series is analysed in section 4.4, where seasonality is measured and compared between sub-sectors, duration of contract and under different market conditions. Important implications of the results are considered. The last section of the chapter summarises the results and concludes.

4.2. Descriptive Statistics of Dry Bulk Freight Rates

For analysis, as mentioned in chapter 1, the dry bulk market is divided into three sub-markets by vessel size since different vessel sizes are involved in different commodity trades and routes/regions of the world. Thus, it is possible that freight rates for different size vessels show different univariate and stochastic behaviour over time due to distinct characteristics of supply and demand determinants for shipping services in different commodity trades and shipping routes (see Kavussanos, 1996a and Berg-Andreassen, 1997a).

Descriptive statistics of logarithms of monthly spot rate indices, obtained different issues of LSE, as well as logarithms of monthly 1-year and 3-year time-charter rates on \$/day basis, obtained from CRS, for the period January 1980 to December 1996 for different sizes of dry bulk carriers are reported in Table 4.1². In the dry bulk shipping sector, the historical mean values of spot rate indices are 4.94, 5.22 and 5.08 for capesize, panamax and handysize vessels, respectively. It can be seen that there is no clear relationship between the historical mean of spot indices and vessel size. In contrast to spot rates, time-charter rates are higher for larger vessels compared to smaller size vessels. This is because the cost of hiring large vessels is higher than that of smaller ones. However, in the time-charter market, the cost of transportation on a dollar per ton basis (when time-charter rates are converted into their spot equivalents) is lower for larger vessels than for the smaller ones³ due to the economies of scale.

The distributions of dry bulk freight rates across vessel size and duration of contract are similar; negative coefficients of skewness and kurtosis indicate flat and left skewed distributions. The only exception is the capesize spot rates with a positive coefficient of kurtosis, which indicates a leptokurtic distribution for this series. The last three rows of Table 4.1 contain ARCH tests for autoregressive conditional heteroscedasticity, Ljung-Box tests for serial correlation and Jarque-Bera tests for normality. The results indicate that all the series are autocorrelated and non-normal at any conventional significance levels. F tests for ARCH

² See chapter 1 for more detail on units of measurement and sources of data.

³ Note that the mean of spot and time-charter rates are not comparable since their units of measurement are different. This is because, we use trip charter indices reported by Lloyds Shipping Economist. These are trip charter fixtures over the month on a \$/day basis which are transformed into indices using 1985=100.

effects cannot be rejected at the 1% significant level for all the series. This evidence of the existence of ARCH effects in the series is an indication of strong volatility clustering; that is, large (small) shocks to the series are followed by large (small) shocks.

Table 4.1: Summary statistics of logarithmic dry bulk carrier freight rates

	Spot Rates			1-year Time-charter			3-year Time-charter		
	Capesize	Panamax	Handysize	Capesize	Panamax	Handysize	Capesize	Panamax	Handysize
Mean	4.94***	5.22***	5.08***	9.21***	9.07***	8.73***	9.35***	9.16***	8.80***
St. Dev	0.48	0.43	0.35	0.45	0.39	0.35	0.31	0.29	0.30
C.V	10.04	8.47	7.07	4.95	4.39	4.04	3.34	3.19	3.42
Skewness	-0.93***	-0.49***	-0.40**	-0.47***	-0.52***	-0.54***	-0.52***	-0.62***	-0.79***
Kurtosis	1.25***	-0.69**	-1.00***	-1.05***	-1.13***	-1.26***	-0.85**	-1.05***	-0.52
ARCH (12)	66.9***	121***	189***	548***	612***	821***	403***	862***	398***
L-B(12)	1043***	1338***	1601***	1464***	1651***	1785***	1358***	1655***	1742***
J-B	42.6***	12.3***	14.1***	16.8***	20.0***	23.0***	15.1***	22.3***	23.4***

- Coefficient of Variation, C.V, is a relative measure of risk, which is defined as the standard deviation of a series over its mean value.
- ARCH(12) is the F(12,179) test for 12th order autoregressive conditional heteroscedasticity. The 5% critical value for this statistic is 1.81.
- L-B(12) is the Ljung-Box test for 12th order autocorrelation. The 5% critical value for this statistic is 21.03.
- J-B is the Jarque-Bera test for normality. The 5% critical value for this statistic is 5.99.
- *, ** and *** indicate significance at the 10% , 5% and 1% levels, respectively. The Null hypotheses in the table are that for logarithmic freight rates the mean, skewness, and excess kurtosis are zero, that there are no ARCH effects, no autocorrelation and that the distributions are normal.

Broadly, there seems to be a positive relation between the coefficient of variation (CV) of the series and vessel size irrespective of the duration of the contract; the larger the vessel the higher the freight rate volatility. This is expected since the flexibility of the smaller vessels in terms of operation in different routes and trades versus the restricted operation of larger vessels reduce (increase) the volatility in the small (larger) size vessels. The only exception is 3-year time-charter rates for handysize vessels, which shows a higher relative risk compared to those of capesize and panamax vessels. Comparing CV's of spot and time-charter rates over the same size also point to a negative relation between the CV and the duration of charter contract; that is, the longer the contract the lower the relative risk involved. The unconditional volatility of dry bulk spot rates seems to be higher than those of time-charter rates. A formal analysis and comparison of time-varying volatilities in the dry bulk sector is given in Kavussanos (1996a).

4.2.1. Autocorrelation and Partial Auto correlation functions

The sample autocorrelation function, SACF, for spot, 1-year and 3-year time-charter rates for three different size of dry bulk carriers are computed using the following formulas

$$\rho_k = \frac{E[(y_t - \mu_y)(y_{t-k} - \mu_y)]}{\sqrt{E[(y_t - \mu_y)^2] E[(y_{t-k} - \mu_y)^2]}} = \frac{Cov(y_t, y_{t-k})}{\sqrt{Var(y_t)Var(y_{t-k})}} \quad (4.1)$$

Where ρ_k is the SACF, k is the number of lags, E is the expectation operator and μ_y is the mean of the variable, y_t . The sample partial autocorrelation function, SPACF, for the same series are also estimated as the coefficient of the k lagged variable in an autoregression with k lagged dependent variables, AR(k).

Figures 4.1 to 4.3 plot the SACF's and SPACF's of handysize, panamax and capesize spot rates along with two standard deviation bands, respectively. The SACF's seem to decline at a very slow rate in all cases. Comparison of the correlation functions with their respective standard errors indicates that SACF's are significant beyond the 12th lag. This means that the series show a high degree of persistence. As a result the effect of shocks to the series may remain for quite a long time. This suggests that the underlying data generating process for these series might be nonstationary. On the other hand, the SPACF's are only significant in the first lag and clearly fall within the two standard error bands from the second lag onward. This suggests that the first lag in the autoregressive model is close to one and highly significant in each case, whereas higher order lags are close to zero and insignificant. Therefore, based on the SACF's and SPACF's it can be concluded that these series behave like a random walk process and their first differences may be stationary.

Figures 4.4 to 4.6 present the SACF's and SPACF's of 1-year time-charter rates in the handysize, panamax and capesize markets along with two standard deviation bands, respectively. The shape of the SAFC's of 1-year time-charter rates for different size vessels suggest that the ACF's decline at a very slow rate as the number of lags increase. This is consistent with what is found for spot rates and suggests that the series are highly autocorrelated. The SPAFC's of 1-year time-charter rates are significant and close to unity in the first lag, while the second lag is negative and significant. The SPAFC's of 1-year time-

charter rates fall within the two standard error bands from the third lag onward and therefore are insignificant. Negative and significant second lag SPACF's of 1-year time-charter rates suggests that the data generating process for these series might be mean reverting.

Figure 4.1: SACF and SPACF of Handysize spot rates with 2 SE bands

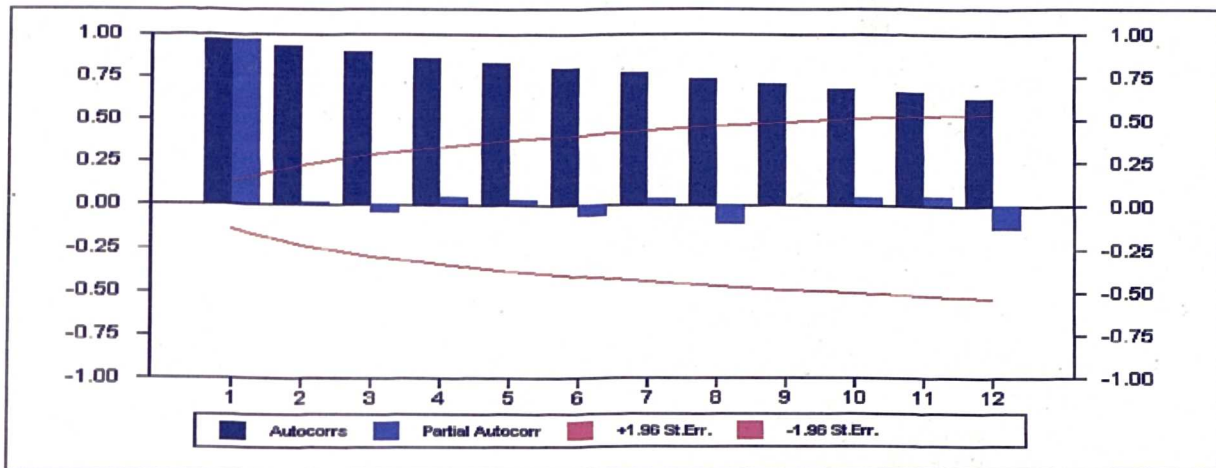


Figure 4.2: SACF and SPACF of Panamax spot rates with 2 SE bands

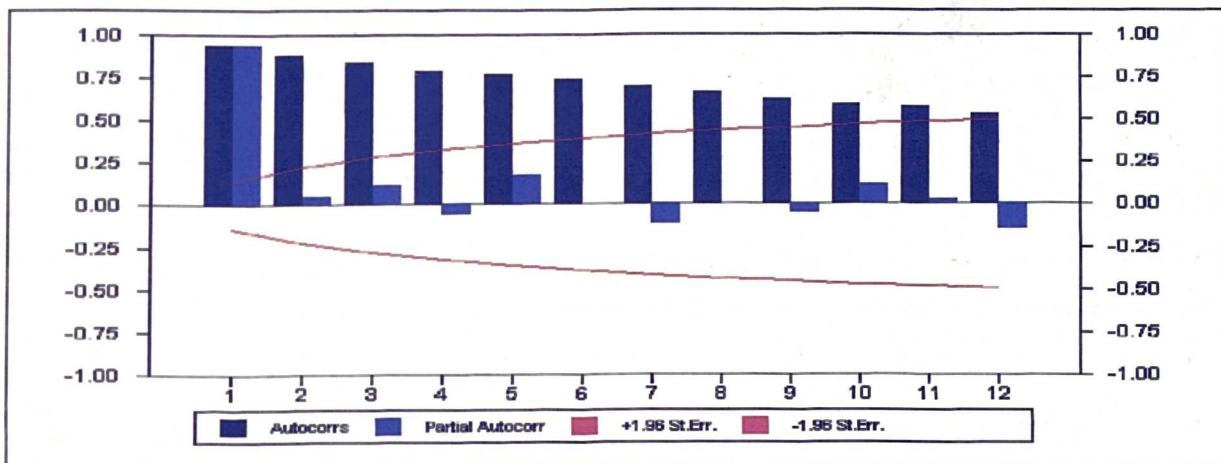


Figure 4.3: SACF and SPACF of Capesize spot rates with 2 SE bands

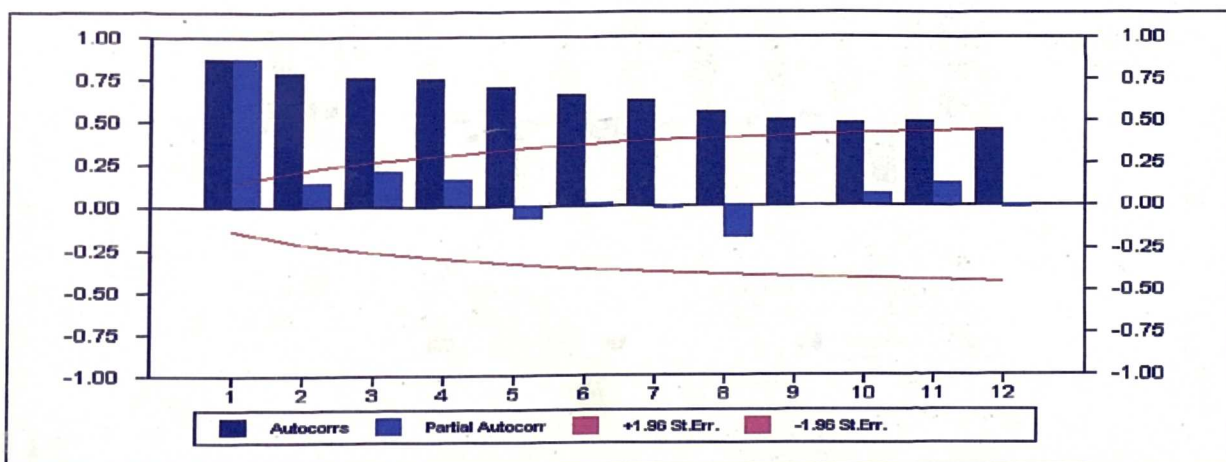


Figure 4.4: SACF and SPACF of Handysize 1-year TC rates with 2 SE bands

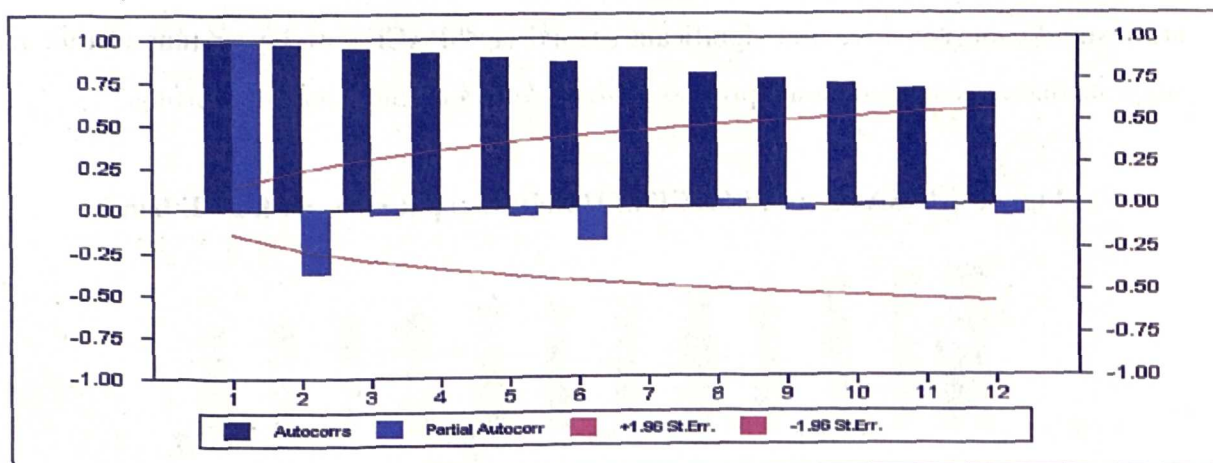


Figure 4.5: SACF and SPACF of Panamax 1-year TC rates with 2 SE bands

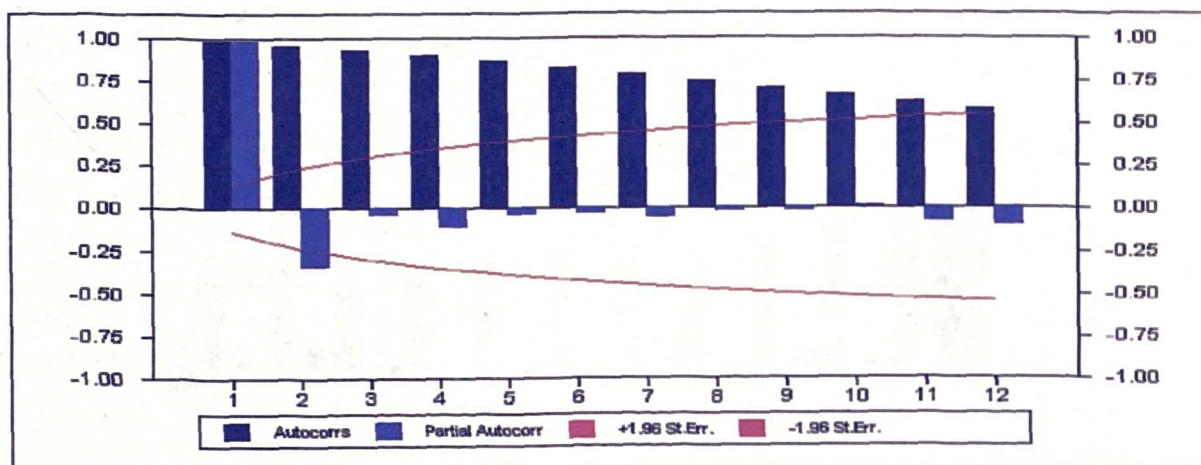


Figure 4.6: SACF and SPACF of Capesize 1-year TC rates with 2 SE bands

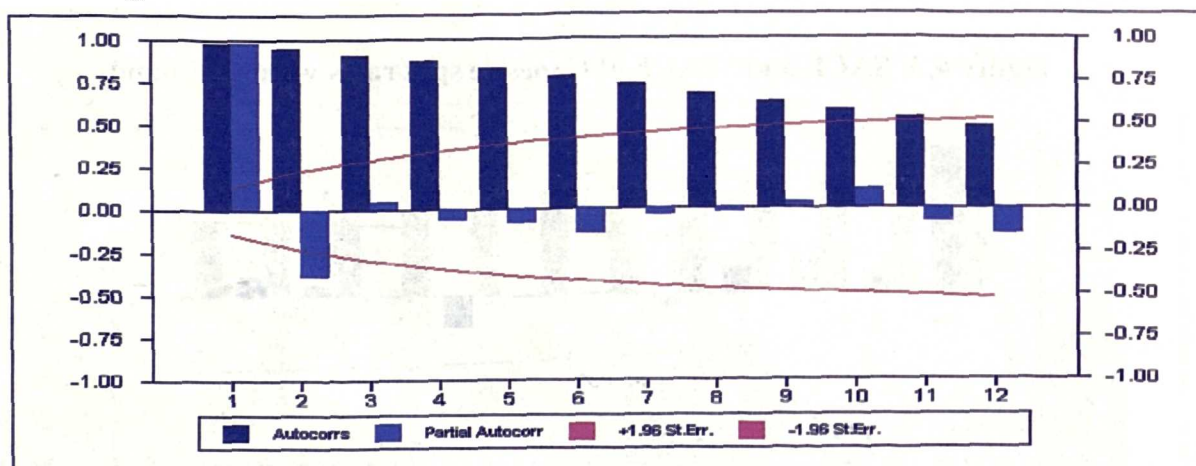


Figure 4.7: SACF and SPACF of Handysize 3-year TC rates with 2 SE bands

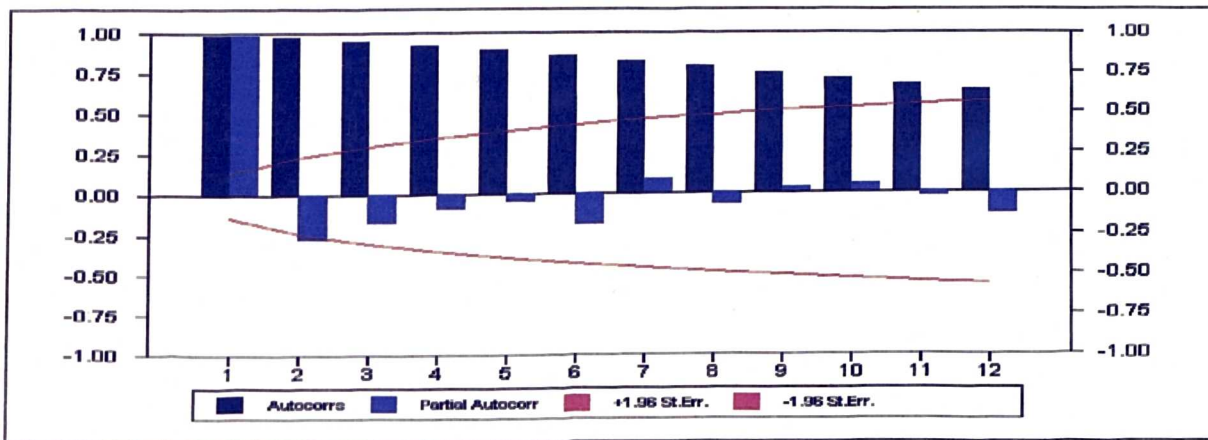


Figure 4.8: SACF and SPACF of Panamax 3-year TC rates with 2 SE bands

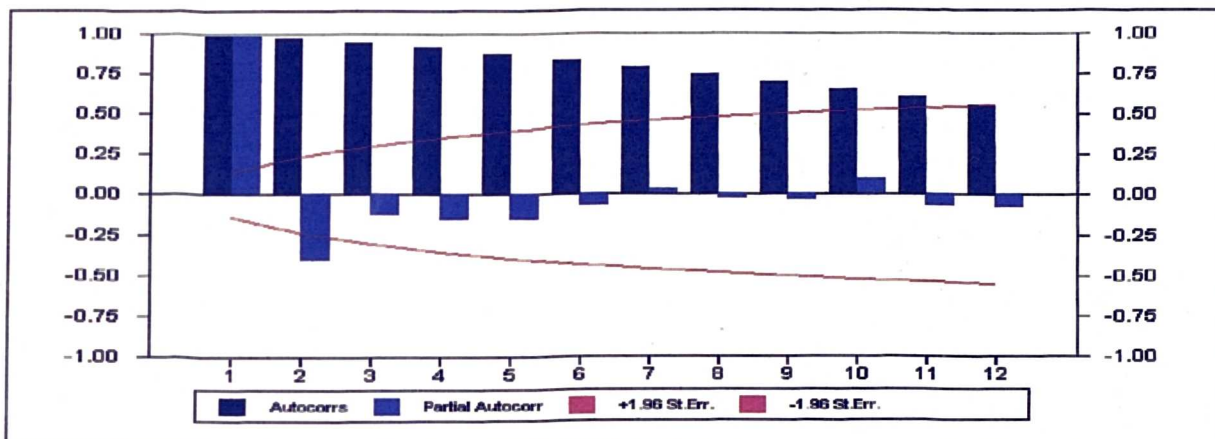
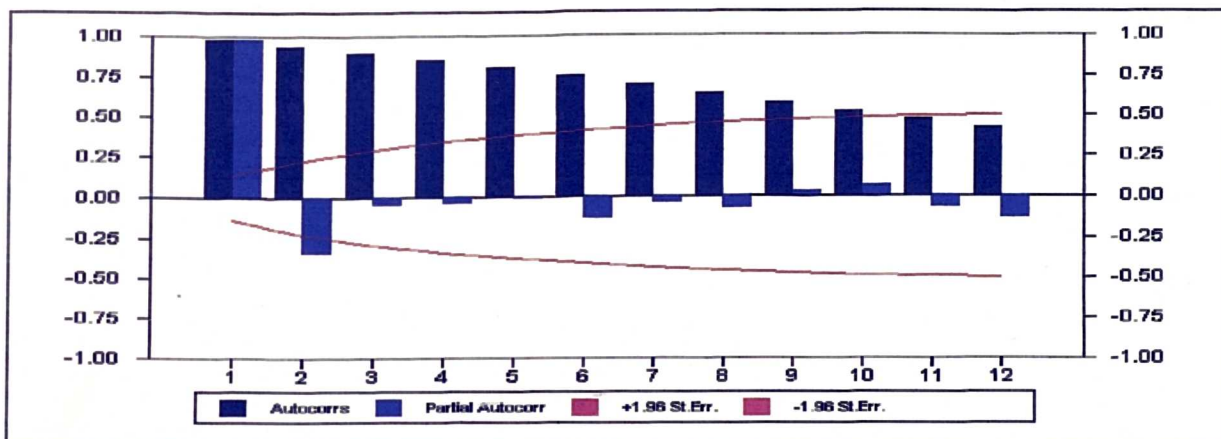


Figure 4.9: SACF and SPACF of Capesize 3-year TC rates with 2 SE bands



SACF's and SPACF's of 3-year time-charter rates in the handysize, panamax and capesize markets along with two standard deviation bands are presented in Figures 4.7 to 4.9, respectively. The shape of the SAFC's and SPACF's of 3-year time-charter rates suggest that these rates behave similarly to 1-year time charter rates.

4.3. Stochastic Trends and Unit Root Tests

Both Augmented Dickey-Fuller and Phillips and Perron unit root tests, explained in chapter 3, are performed on logarithmic levels and logarithmic first differences of freight rate series in order to determine the order of integration of the series. The results of ADF and PP tests on the size differentiated dry cargo rate series are presented in Table 4.2. Following Perron's (1989) sequential testing procedure, the most general form of the ADF test is performed; that is, equation (3.4') is estimated and the number of lagged dependent variables is determined using SBIC. The number of lagged dependent variables in each test is then adjusted to remove any residual autocorrelation detected by LM test. The sequential method, outlined in chapter 3, section 3.2.1, is followed until the best model for ADF test is determined. The truncation lag for Phillips and Perron test is selected using the LM test for autocorrelation in the ADF equation.

Table 4.2: Unit root tests for levels and first differences of variables

	Variables in levels				First Diff. of Variables			
	ADF test		PP test		ADF test		PP test	
	LAGS	STAT	LAGS	STAT	LAGS	STAT	LAGS	STAT
Handysize								
Spot rate (FR)	0 ^b	-2.03	0 ^b	-2.03	0 ^a	-15.06***	0 ^a	-15.06***
1- year time-charter (TC1)	1 ^b	-1.71	1 ^b	-1.33	4 ^a	-4.40***	4 ^a	-9.28***
3- year time-charter (TC3)	2 ^b	-1.73	2 ^b	-1.33	4 ^a	-4.07***	4 ^a	-10.85***
Panamax								
Spot rate (FR)	4 ^b	-2.20	4 ^b	-2.41	3 ^a	-9.21***	3 ^a	-15.48***
1- year time-charter (TC1)	1 ^b	-1.81	1 ^b	-1.43	0 ^a	-9.88***	0 ^a	-9.88***
3- year time-charter (TC3)	1 ^b	-1.64	1 ^b	-1.27	3 ^a	-4.35***	3 ^a	-9.03***
Capesize								
Spot rate (FR)	3 ^b	-2.29	3 ^b	-3.25**	1 ^a	-14.36***	1 ^a	-17.14***
1- year time-charter (TC1)	1 ^b	-2.18	1 ^b	-1.69	0 ^a	-9.19***	0 ^a	-9.19***
3- year time-charter (TC3)	1 ^b	-2.30	1 ^b	-1.80	0 ^a	-9.69***	0 ^a	-9.69***

- Total sample covers the period from 1980:1 to 1996:12 (204 observations).
- The maximum lag length in each test is chosen to eliminate the residual serial correlation using an LM test.
- The lag truncation for the Phillips and Perron nonparametric correction is chosen by the order of the residual autocorrelation as determined by the LM statistics in the ADF test (see, Harris 1996, p. 33).
- Superscript "a" indicates that the test does not include constant or trend terms (equation 3.3'), while superscript "b" indicates that the test includes a constant term (equation 3.4), and superscript "c" indicates that the unit root test includes a constant and a trend (equation 3.4').
- For tests with no deterministic terms, 1%, 5% and 10% critical values are -2.58, -1.94 and -1.62, respectively.
- For tests with a constant deterministic component, 1%, 5% and 10% critical values are -3.45, -2.88 and -2.57, respectively. For tests with a constant and a trend, 1%, 5% and 10% critical values are -3.99, -3.43 and -3.13, respectively.
- Symbols *, ** and *** indicate significance at 1%, 5% and 10%, respectively.

For size differentiated dry bulk freight rate series both ADF and PP unit root test results support the hypothesis that the log levels of series are integrated of the first order, $I(1)$, and only the log of capesize spot rates is showing marginal stationarity which might be due to the sample size and power of the tests. Overall it can be concluded that the log levels of size-differentiated dry bulk freight rates are not stationary, while first differences are stationary.

4.4. Stochastic Seasonality and Seasonal Unit Root Tests

Following Franses et al's (1995) suggestion on testing deterministic and stochastic seasonality (seasonal unit roots) in a simultaneous framework, logarithmically transformed data are used to estimate equation (4.2)

$$(1 - B^{12})X_t = \Delta^{12}X_t = \alpha_0 + \beta_0 t + \sum_{i=2}^{12} \beta_i Q_{i,t} + \sum_{j=1}^{12} \pi_j Y_{j,t-1} + \sum_{k=1}^p \gamma_k \Delta^{12}X_{t-k} + \varepsilon_t \quad (4.2)$$

where $Y_{j,t-1}$ are different seasonal filters in the form of back-shift polynomials defined in Appendix (3.A), and π_j are the seasonal and non-seasonal unit root coefficients.

Three different specifications of equation (4.2); i) with intercept only, ii) with intercept and trend, iii) with intercept, trend and seasonal dummies, are used to select the best specification for seasonal unit root tests. The final results for the selected model are in Table 4.3. The lag structure and deterministic components of each equation is determined using AIC and SBIC, while ensuring that there is no autocorrelation left in the residuals. Since constant and trend terms are found significant in each regression equation, inferences are based on regressions with all the deterministic components present; that is, a constant, trend and seasonal dummies. Having obtained well-specified equations, seasonal unit root tests are performed next to investigate existence of seasonal unit roots in freight rates.

In seasonal unit root test equations, the $F_{i,i+1}$ statistics ($i=3,5,7,9,11$), testing for the joint existence of complex seasonal unit roots at the corresponding frequencies ($\pm\pi/2, \pm2\pi/3, \pm\pi/3, \pm5\pi/6, \pm\pi/6$), are rejected at the 5% level of significance. For example, respective $F_{3,4}$ statistics for capesize, panamax and handysize spot rates are 18.87, 18.94 and 13.60, which are more than the critical value of the test ($F_{crit,5\%}=6.23$). The null hypothesis of a unit root at the π frequency, or six cycles per year, is also rejected for all freight rate series. Overall, it can be argued that the existence of stochastic seasonality at all the seasonal frequencies is rejected for all sub-markets in the dry bulk sector for the period 1980 to 1996.

The existence of unit roots at zero frequency in shipping freight rate series suggests that these series are serially correlated and consequently have a long memory, which in turn implies that the effect of shocks to these series persist. This is consistent with the ARCH effects and

high degree of serial correlation in the level of the series as well as ADF and PP unit root tests reported in Tables 4.1 and 4.2, respectively. The results of seasonal unit root tests performed suggest that series are nonstationary, I(1). As a result, ARIMA models should be used when modelling ocean freight rates in a univariate framework, while modelling of rates in a multivariate framework requires application of vector autoregression (VAR) and cointegration techniques.

Table 4.3: Seasonal unit roots test for logarithms of monthly dry bulk freight rates.

$(1 - B^{12})X_t = \Delta^{12}X_t = \alpha_0 + \beta_0 t + \sum_{i=2}^{12} \beta_i Q_{it} + \sum_{j=1}^{12} \pi_j Y_{j,t-1} + \sum_{k=1}^p \gamma_k \Delta^{12}X_{t-k} + \varepsilon_t \quad \text{Equation (4.2)}$										
		Spot Rates			1-year Time-charter			3-year Time-charter		
Frequency		Capesize	Panamax	Handysize	Capesize	Panamax	Handysize	Capesize	Panamax	Handysize
c	α_0	3.13	3.21	3.03	3.70	3.69	3.09	3.52	3.51	2.30
t	β_0	2.48	2.48	2.39	2.70	2.94	2.47	2.09	2.81	2.58
0	$\pi_1=0$	-3.25	-3.37	-3.15	-3.77	-3.77	-3.14	-3.56	-3.56	-3.34
π	$\pi_2=0$	-4.64	-3.55	-4.63	-4.17	-3.70	-3.64	-4.51	-3.82	-4.49
$\pm\pi/2$	$\pi_3, \pi_4=0$	18.87	18.94	13.60	17.17	20.57	22.25	19.09	17.15	24.46
$\pm 2\pi/3$	$\pi_5, \pi_6=0$	22.05	20.45	21.22	23.53	18.34	16.91	22.64	26.82	18.66
$\pm\pi/3$	$\pi_7, \pi_8=0$	11.48	13.30	14.98	11.19	13.24	19.08	9.52	14.19	16.13
$\pm 5\pi/6$	$\pi_9, \pi_{10}=0$	20.37	36.31	16.10	22.47	23.93	17.55	17.78	17.13	19.18
$\pm\pi/6$	$\pi_{11}, \pi_{12}=0$	22.39	18.59	20.17	14.02	12.28	17.15	12.36	15.63	12.70
\bar{R}^2		0.843	0.897	0.916	0.977	0.977	0.978	0.972	0.984	0.953
Lags		0	0	0	0	0	0	0	0	0
DW		2.032	2.010	2.007	1.995	1.965	2.011	1.986	2.003	2.016
Q(12)		1.345	1.233	0.611	3.309	9.55	2.313	1.857	4.147	0.999
		[0.999]	[0.999]	[0.999]	[0.992]	[0.655]	[0.998]	[0.999]	[0.980]	[0.999]
ARCH(12)		4.960	3.012	0.944	0.595	0.738	0.385	0.866	1.337	2.718
		[0.000]	[0.001]	[0.492]	[0.844]	[0.712]	[0.967]	[0.582]	[0.202]	[0.213]
White-test		20.78	8.112	0.285	8.067	2.523	1.680	1.979	1.949	16.36
		[0.000]	[0.043]	[0.593]	[0.005]	[0.112]	[0.195]	[0.195]	[0.163]	[0.000]
J-B		186	102	1.043	2.413	54.80	19.14	70.12	5.701	5339
		[0.000]	[0.000]	[0.593]	[0.299]	[0.000]	[0.000]	[0.000]	[0.057]	[0.000]

- See notes in Table 4.1 and the following
- The lag structure and deterministic components of each equation is determined using Akaike and Schwarz Information Criteria, AIC and SBIC, while ensuring that there is no autocorrelation left in the residuals.
- Figures in [.] are P-values.
- DW is the Durbin-Watson test for first order serial correlation.
- Q(12) is the Ljung-Box test for 12th order serial correlation in the residuals.
- White-test is the White (1980) test for heteroscedasticity.
- J-B is the Jarque- Bera (1980) test for normality. The 5% critical value for this statistic is $\chi^2(2)=5.99$.
- 1%, 2.5% and 5% critical values for the Beaulieu and Miron (1993) test are:
 $t(\pi_1)=-3.83$, $t(\pi_2)=-3.31$, $F=5.25$;
 $t(\pi_1)=-3.54$, $t(\pi_2)=-3.02$, $F=7.14$;
 $t(\pi_1)=-3.28$, $t(\pi_2)=-2.75$, $F=6.23$, respectively. [Source: Beaulieu and Miron (1993).]

4.5. Deterministic Seasonality in Dry Bulk Freight Rates

Testing the existence of deterministic seasonality when stochastic seasonality is not present through equation (4.2) will reduce the power of the test. This is due to the loss of degrees of freedom in estimating the parameters of the seasonal unit roots. Moreover, excluding seasonal filters from equation (4.2) in order to test only the deterministic seasonality is not appropriate, since the dependent variable is the 12th difference of the series rather than the monthly growth rate of the series. Therefore, the existence of deterministic seasonality in shipping markets is investigated through equation (3.9) in chapter 3.

$$\Delta X_t = \beta_0 + \sum_{i=2}^{12} \beta_i Q_{it} + \varepsilon_t \quad , \quad \varepsilon_t \sim \text{iid}(0, \sigma^2) \quad (4.3)$$

Where, ΔX_t , represents the growth rate of the series, Q_{it} , $i=2, \dots, 12$, are relative seasonal dummies, β_i are the parameters of interest and ε_t is a white noise error term (see chapter 3 for details). The significance of each seasonal dummy indicates the existence of deterministic seasonality in the respective period; that is, a significant change in the dependent variable compared to its long-run mean, β_0 .

Diagnostic tests reveal that some equations have non-spherical disturbances. Thus, the variance-covariance matrices are corrected for heteroscedasticity and/or serial correlation using White (1980) and/or Newey-West (1987) estimates. In equations with significant ARCH effects it is found that these are stationary. As a result (see Greene 1997, p. 570) the unconditional variance of the residuals is constant and OLS yield the BLUE. The results are in table 3.

4.5.1. Spot rates

Significance of a t statistic for β_i , $i=1, 2, \dots, 12$, parameters (months) in equation (4.3) is an indication of a significant increase or decrease in monthly freight rate growth at a particular month compared to the average over the sample period. For example, in (4.3), the spot rates for capesize bulk carriers increase significantly by 15.3% during April compared to the average of zero ($\beta_0 = 0$) over the period. Similarly, panamax spot rates increase by 8.6% in

March, while there is a significant seasonal increase in handysize spot rates in both March and April by 4.3% and 3.3%, respectively.

The rise in the level of dry bulk spot rates in those months could be explained by the surge in demand from Japanese importers for all commodities (grain, coal, iron ore, etc.) because of the end of the fiscal (tax) year in Japan at the end of March⁴. Also, the harvest season in the Southern Hemisphere (February to March in Australia and Argentina) increases the demand for handysize and panamax dry bulk carriers (during March and April). Due to the shortage of storage facilities and the port structure in these countries grains harvested are exported immediately using mostly smaller vessels that can approach these shallow ports. In contrast, large inventories of grains are held during the year in the Northern Hemisphere. These stock levels are reduced during March and April to make way for storage space required for the forthcoming harvest. Thus, the increase in demand for freight services in the Handy and Panamax sizes affect rates positively. Capesize freight rates are also influenced by the shift of the handysize and panamax tonnage to grain transportation. This, in turn, causes an under-supply of these types of vessels in transportation of other major and/or minor dry bulk commodities.

Panamax spot rates also show a combined increase of 14.4% during October and November. Since panamax bulk carriers are heavily involved in coal and grain transportation from the US Gulf, this upsurge in their spot rates may be explained by the increase in US grain exports (harvested between June and October) as well as the increase in demand for coal to stock up for the winter requirements.

The results also show a seasonal decline in rates during June and July across all the three sizes of vessels. This decline is more pronounced in July compared to June and in larger vessels compared to smaller ones. The combined mid summer (June and July) decline in capesize, panamax and handysize rates are 26%, 21.3% and 13.8%, respectively, which seem

⁴ Japanese importers try to stock up their inventories (inputs in production) before the end of the year so as to show them as expenses in their books.

Table 4.4: Deterministic seasonality in dry bulk freight rate series

$$\Delta X_t = \beta_0 + \sum_{i=2}^{12} \beta_i Q_{i,t} + \varepsilon_t \quad \text{Equation (4.3)}$$

Coef	Spot Rates			1-year Time-charter			3-year Time-charter		
	CSZ	PMX	HSZ	CSZ	PMX	HSZ	CSZ	PMX	HSZ
Const. β_0	-0.001 (0.07)	-0.002 (-0.21)	-0.002 (-0.37)	-0.003 (-0.27)	-0.002 (-0.27)	-0.001 (-0.22)	-0.002 (-0.31)	-0.002 (-0.29)	-0.001 (-0.20)
Jan β_1	0.032 (1.02)	-0.058 (-0.92)	-0.004 (-0.23)	-0.002 (-0.19)	0.020 (1.21)	0.013 (0.77)	-0.010 (-0.97)	0.010 (1.45)	0.013 (1.00)
Feb. β_2	-0.044 (-0.89)	0.049 (1.24)	0.005 (0.36)	-0.030 (-1.56)	-0.000 (-0.00)	-0.004 (-0.47)	-0.024 (-1.27)	-0.003 (-0.41)	-0.016 (-1.11)
Mar β_3	0.021 (0.32)	0.086 (2.43)	0.043 (1.79)	0.030 (1.90)	0.023 (1.53)	0.029 (3.07)	0.023 (2.12)	0.021 (2.10)	0.005 (0.48)
Apr. β_4	0.153 (2.57)	-0.008 (-0.28)	0.033 (2.10)	0.026 (1.12)	0.007 (0.44)	0.026 (2.08)	0.009 (0.52)	0.004 (0.41)	-0.001 (-0.04)
May β_5	-0.009 (-0.20)	0.011 (0.35)	0.023 (1.09)	-0.006 (-0.30)	0.024 (2.12)	0.006 (0.51)	0.001 (0.08)	0.013 (1.63)	0.040 (1.25)
June β_6	-0.078 (-2.18)	-0.100 (-4.91)	-0.040 (-1.88)	-0.042 (-2.80)	-0.041 (-3.20)	-0.039 (-4.51)	-0.021 (-1.85)	-0.021 (-2.40)	-0.030 (-2.25)
July β_7	-0.182 (-3.33)	-0.113 (-3.75)	-0.098 (-4.19)	-0.042 (-2.08)	-0.056 (-3.87)	-0.045 (-4.50)	-0.021 (-1.68)	-0.022 (-3.18)	-0.019 (-3.12)
Aug. β_8	0.020 (0.30)	-0.002 (-0.03)	-0.009 (-0.44)	0.020 (1.01)	0.013 (1.07)	-0.006 (-0.77)	0.029 (1.85)	0.008 (0.77)	0.018 (1.19)
Sept. β_9	0.157 (1.49)	-0.002 (-0.04)	0.013 (0.51)	0.036 (1.57)	0.002 (0.13)	0.006 (0.63)	0.028 (2.18)	0.007 (0.87)	0.009 (1.29)
Oct. β_{10}	-0.040 (-1.05)	0.095 (2.61)	0.021 (0.86)	-0.001 (-0.03)	-0.006 (-0.56)	0.009 (1.17)	0.001 (0.09)	-0.021 (-2.56)	0.001 (0.25)
Nov. β_{11}	0.019 (0.33)	0.049 (1.91)	0.099 (0.41)	0.019 (0.96)	0.012 (0.92)	0.006 (0.63)	-0.006 (-0.37)	-0.006 (-0.63)	-0.014 (-1.35)
Dec. β_{12}	-0.051 (-1.47)	-0.009 (-0.27)	0.003 (0.13)	-0.011 (-0.76)	0.002 (0.17)	-0.002 (-0.23)	-0.012 (-1.21)	0.008 (1.15)	-0.009 (-1.25)
R^2	0.081	0.130	0.095	0.021	0.076	0.111	0.010	0.042	0.030
Wald-test	55.75 [0.000]	63.06 [0.000]	52.76 [0.000]	33.45 [0.000]	56.36 [0.000]	54.77 [0.000]	45.61 [0.000]	67.36 [0.000]	26.03 [0.006]
Q(1)	7.520 [0.006]	4.897 [0.027]	3.851 [0.051]	34.49 [0.000]	28.03 [0.000]	28.49 [0.000]	25.88 [0.000]	37.11 [0.000]	4.492 [0.034]
Q(12)	3.43 [0.002]	37.88 [0.000]	10.52 [0.569]	65.49 [0.000]	59.07 [0.000]	58.49 [0.000]	39.88 [0.000]	108.1 [0.000]	21.4 [0.042]
ARCH(12)	1.74 [0.063]	4.08 [0.000]	0.90 [0.549]	0.68 [0.763]	2.02 [0.025]	0.80 [0.626]	0.72 [0.731]	2.15 [0.016]	4.76 [0.000]
White-test	2.209 [0.137]	0.103 [0.749]	0.005 [0.945]	0.002 [0.964]	0.008 [0.927]	0.627 [0.429]	0.005 [0.942]	0.212 [0.645]	6.279 [0.013]
JB	1.89 [0.387]	226.9 [0.000]	1009 [0.000]	7.752 [0.020]	28.22 [0.000]	29.46 [0.000]	5884 [0.000]	29.86 [0.000]	60.97 [0.000]

- See notes in Tables 4.1 and 4. 3 and the following.
- t statistics are corrected for heteroscedasticity and serial correlation using the Newey-West method where appropriate.
- Coefficients in bold show significance at the 10% level.
- Wald-test is a joint test for the significance of coefficients of dummy variables. This is a $\chi^2(11)$ statistic.
- Q(1) and Q(12) are the Ljung-Box tests for 1st and 12th order serial correlation in the residuals, 5% critical values for these statistics are 3.84 and 21.03, respectively.
- J-B is the Jarque- Bera (1980) test for normality. 5% critical value for this test is $\chi^2(2)=5.99$.
- The coefficient for January dummy, β_1 , is calculated as $\beta_1 = -\sum_{i=2}^{12} \beta_i$. Standard errors for January dummies are calculated from variance-covariance matrix of the coefficients, see chapter 3, footnote 1, for details.

to be higher than the spring increase (15.3%, 8.6% and 7.6% for capesize, panamax and handysize respectively). The significant seasonal decline in the dry bulk spot markets at mid summer is caused by the start of the summer holidays and a drop in the industrial output⁵ of the industrialised countries.

The weaker seasonal increase or decline in average freight rates for smaller size vessels may be attributed to their flexibility, which enables them to switch between trades and routes more easily compared to the larger ships. In addition, most capesize vessels are mainly engaged in long term charter contracts leaving relatively fewer tonnage to trade in the spot market. As a result “shocks” to spot rates have a much greater effect on capesize rates compared to smaller vessels. These results are in line with the more general pattern (not only seasonality) of freight rate volatility discussed in Kavussanos (1996a), which suggest that freight rates for larger vessels are more volatile than smaller ones.

4.5.2. One-year time-charter rates

In the dry bulk time-charter market, 1-year time-charter rates for handysize vessels show a significant rise of 5.5% during March and April, while the rates for panamax and capesize vessels show a significant increase of 2.4% in May and 3% in March, respectively. The higher upswing in 1-year time-charter rates for handysize vessels may be explained by the increase in the demand for time-charter contracts for handysize vessels in order to transport grain cargoes, during and after the harvest season, over a period of time between small ports (mainly in the Southern Hemisphere and developing countries) with draught restrictions. In contrast to the spot market and one year time-charter rates for handysize vessels, the significant seasonal increase in 1-year time-charter rates for panamax and capesize vessels during spring is lower than the increase in handysize rates. This is because charterers who need to fix time-charter contracts in order to lift their grain cargoes over a period of time prefer smaller rather than larger dry bulk carriers⁶. Restrictions in some loading and

⁵ The decrease in the level of industrial output in North America during June and July is documented by Beaulieu and Miron (1991), among others.

⁶ Grain is imported by a large number of countries in contrast to iron ore and coal, which are imported by industrialised countries. The storage of grain is also quite expensive relative to other major bulk commodities. Therefore, there might be a lack of large storage silos as well as shore cargo-handling facilities in many of the grain importing regions and countries. Such importers try to optimise their inventory (cost) by importing the purchased grain cargo (e.g. 1 million tons of wheat from Australia or the U.S) in small shipments using

discharging ports (depth of berth and amount of cargo available for shipment) also dictate the use of smaller vessels available in the time-charter market during the harvest season.

The reduction of the positive spring effect on 1-year time-charter rates compared to spot rates is higher compared to the significant seasonal decline in June and July in time-charter rates for all vessel sizes. The combined spring increase in time-charter rates is, 3% for capesize, 2.4% for panamax and 5.5% for handysize vessels, whereas the combined summer decline in rates for the same size vessels are, 8.4%, 9.7% and 8.4%, respectively. These are more or less the same between sectors. The decline in the time-charter rates during June and July may be due to two reasons; the reduction in the level of industrial production and trade in mid summer or switch of spot operators to time-charter operation after the end of the Japanese and harvest led spring upsurge, which causes an over-supply in the time-charter market. Also, since time-charter rates are linked to the current and expected spot rates, a drop in the spot market is transmitted to the time-charter market accordingly. In line with spot markets, the net seasonal effect on 1-year time-charter rates is negative for each sector; the summer fall in rates is higher than the corresponding spring rises.

4.5.3. Three-year time-charter rates

The pattern of seasonal decline in 3-year time-charter rates for dry bulk carriers is similar to 1-year rates. That is, there is a seasonal increase in 3-year time-charter rates during spring (2.3% for capesize and 2.1% for panamax) and decline in rates for all the sizes during June and July. The combined decline in rates during the summer months is 4.2%, 4.3% and 4.9% in capesize, panamax and handysize markets, respectively, which are almost half of those for 1-year time-charter rates. Both the increase and the decline in 3-year time-charter rates are less pronounced compared to 1-year rates. Panamax rates also show a further decline of 2.1% during October, while rates for capesize bulk carriers recover by a combined 5.5% during August and September. The seasonal fluctuations in 3-year time-charter rates for larger vessels during August and September coincide with the time that Japanese and Korean steel

handysize vessels equipped with cargo handling gear. At the same time, due to their draught restrictions and lack of cargo handling gear, the employment of larger dry bulk carriers in long term grain transportation is very limited, if it exists at all. Hence, time-charter rates for large dry bulk carriers are not so responsive to fluctuations in the grain trade.

mills negotiate (or re-negotiate) and renew their long term imports (iron ore and coal) and the associated charter contracts.

The seasonal movement of dry bulk time-charter rates suggests that, on average, the levels of freight rates increase in certain months (March and April) and drop in others (June and July). Shipowners (and charterers) can base tactical operations on such movements, in order to maximise their revenue (minimise their transportation costs). For example, the best time for a shipowner to fix (renew) a dry bulk time-charter contract or switch from spot to time-charter operation might be March and April. Taking such opportunity, he may well be able to “ride the seasonal cycle” until the next year⁷. On the other hand, the best time for a charterer to fix a dry bulk vessel for one year is June and July. Also, these regular seasonal movements in dry bulk rates suggest that, if cleaning and repositioning costs permit, shipowners operating combined carriers might be able to switch between sectors (tanker and dry bulk) in order to exploit these short-run fluctuations.

4.5.4. Comparison of seasonality across sector and contract durations

Whether we focus on the spring rises or summer decline in rates, the results suggest that the degree of seasonal fluctuation of shipping freight rates varies across vessel sizes and duration of contract. For example, in the case of capesize rates, the combined June and July decline falls from 26% for spot rates to 8.4% and 4.2% for 1 year and 3 years time-charter rates, respectively. The spring increase is also reduced from 15.3% for spot to 8.6% and 7.6% for 1-year and 3-year time-charter rates, respectively. Charter rates for the other two classes of dry bulk carriers also show a similar relationship between seasonal fluctuations and duration of the charter contract.

In addition, it can be seen that as one moves from spot to longer term contracts, the seasonality effect on charter rates is more or less the same (equalised) between different size vessels. That is, while for spot rates there is a marked difference across the size in the

⁷ In a simple bootstrap simulation exercise for renewing 1-year time-charter contracts, it is found that hiring out a vessel (handysize, panamax or capesize) during April and May every year, for 17 years, generates approximately 2% to 10% significantly higher earnings than other months of the year. This, amounts to a 0.5% higher return every year on average. The results are available from the authors on request.

summer months (26%, 21.3% and 14.8%), for 1-year contracts the seasonal effects for these months become 8.4%, 9.7% and 8.4% while for 3-year contracts the difference in the seasonal effects across vessel sizes is equalised (and reduced) further to 4.2%, 4.3% and 4.9%.

Both these facts, the reduction in seasonality and the equalisation of seasonality across vessels as the duration of contract rises are expected. This is because 1-year time-charter rates, say, are formed as the expected future spot rates over the year (see e.g. Beenstock and Vergottis, 1989 and Kavussanos, 1996). Therefore, one would expect that 1-year time-charter rates would have already incorporated expected future seasonal variations and are smoother than spot rates. In addition, spot rate seasonalities are expected to be higher than time-charter rate ones to incorporate possible periods of unemployment⁸. As a consequence differences in freight rate seasonalities between sectors are eliminated since they depend less on the idiosyncratic factors influencing rates in sub-markets and more on the length (type) of the contract involved. These arguments extend to longer duration, 3-year time-charter contracts.

The higher seasonal fluctuations of spot rates compared to time charter rates may be further explained as the result of the chartering strategy of industrial charterers (e.g. power stations and still mills). These type of charterers use long term charter contracts not only to fulfil their long term requirements in terms of supply of raw materials, but also to secure and maintain their transportation cost at a relatively fixed level over a long period. They use the spot market then in order to meet their seasonal or cyclical requirements. Therefore, they may enter the spot market at certain seasons, which leads to an increase in demand in the spot market and consequently the freight rates at those periods.

Comparing the significant drop in freight rates during the summer months and the significant rise in time-charter rates for the spring months, it seems that there is an asymmetric reaction to positive and negative moods in these markets. The positive seasonal effects are less pronounced and are not significant in all vessel sizes (e.g. 3-year contract for Handysize) as one moves from spot to time-charter contracts. However, negative seasonal effects still

⁸ For a more formal analysis of the factors driving the relationship between short and long term charter contracts see Kavussanos and Alizadeh (2000).

persist as the duration of charter contract increases (the summer decline in rates is significant in all sectors for 1 and 3-year contracts).

A comparison between the coefficients of determination, \bar{R}^2 , of the regression equations reveals that the longer the duration of the contract the lower is the proportion of the rate fluctuations explained by seasonal factors. For example, in the case of capesize vessels, these coefficients are 8.1%, 2.1% and 1% for spot, 1-year and 3-year time-charter rates. The corresponding \bar{R}^2 's for panamax vessels are respectively 13%, 7.6% and 4.2%. In the handysize markets these \bar{R}^2 's are 8.4%, 11.1% and 3%, respectively. It can be inferred then that, as expected, spot markets are much more seasonal than freight markets of longer duration contracts. Comparison of \bar{R}^2 's between vessel sizes for each contract reveals that, although the overall variation in freight rates for smaller vessels is less than larger ones (as indicated by the summary statistics of the series in table 1 as well as Kavussanos (1996a and 1997) on dynamic volatilities), the contribution of seasonal movements to rate fluctuations seem to be broadly higher for smaller vessels.

4.6. Seasonality Under Different Market Conditions

The possibility that seasonal pattern in freight rates differ under different market conditions is investigated through equation (3.10) reported here.

$$\Delta X_t = \beta_{1,0}d_{1,t} + \sum_{i=2}^{12} \beta_{1,i}(d_{1,t}Q_{i,t}) + \beta_{2,0}d_{2,t} + \sum_{i=2}^{12} \beta_{2,i}(d_{2,t}Q_{i,t}) + \varepsilon_t, \quad \varepsilon_t \sim \text{iid}(0, \sigma^2) \quad (4.4)$$

where state dummies $d_{1,t}$ and $d_{2,t}$ are

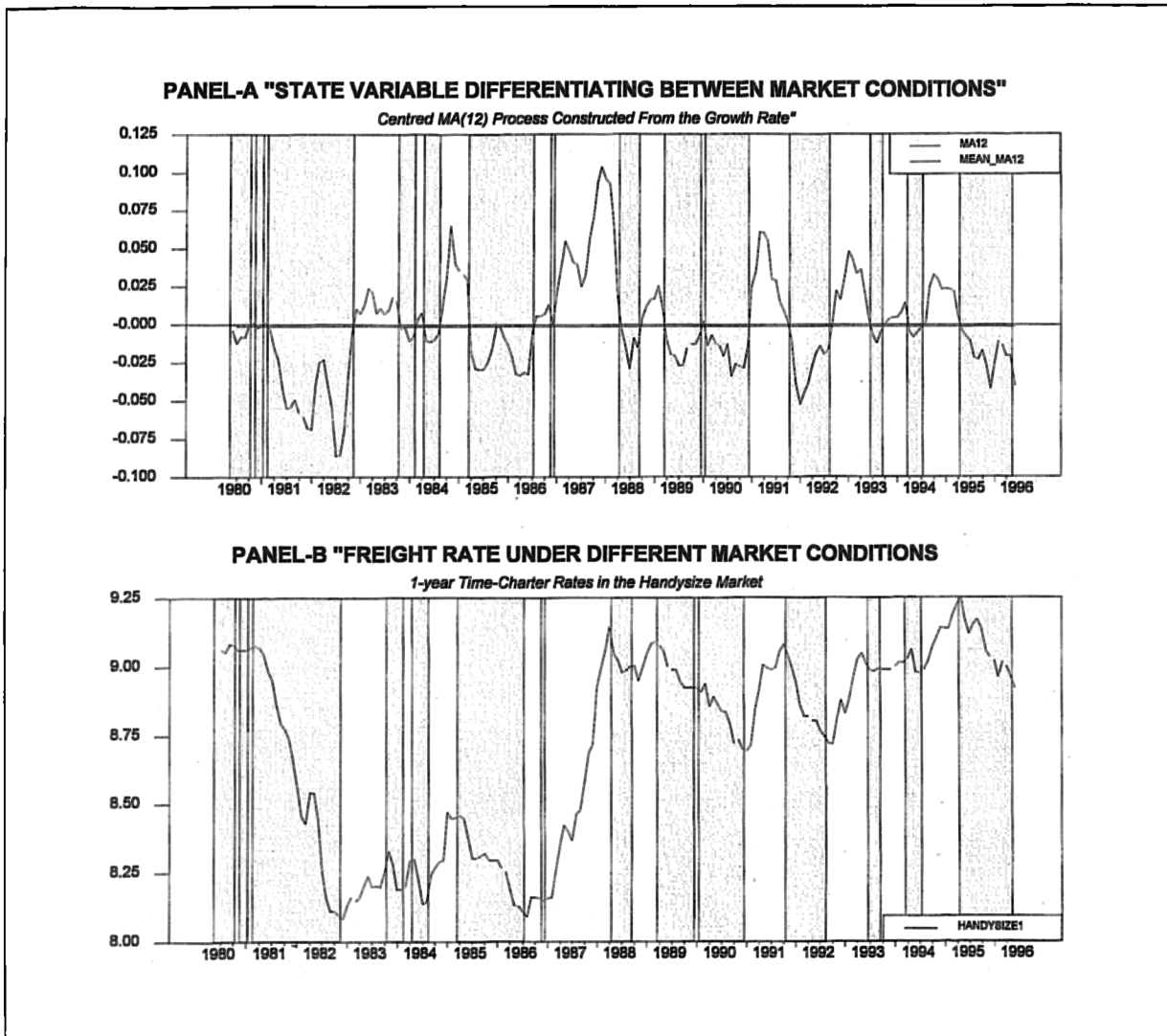
$$\begin{cases} d_{1,t} = 1 \text{ and } d_{2,t} = 0 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} > 0 \quad \text{upturn} \\ d_{1,t} = 0 \text{ and } d_{2,t} = 1 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} \leq 0 \quad \text{downturn} \end{cases}$$

In the above threshold switching seasonal model, two dummy variables, $d_{1,t}$ and $d_{2,t}$, allow estimation of different seasonal coefficients according to the prevailing market conditions.

Threshold switching seasonal models of equation (4.4) are estimated next to investigate the possibility that seasonal patterns vary under different market conditions. The state variable for the threshold switching model is set to be a centred moving average, MA(12), process constructed from the growth rate of each freight rate series. The threshold level is set to zero, since average growth rates over the sample period are zero. Therefore, a positive (negative) MA(12) process indicates that the market is expanding (contracting)⁹. As an example, Figure 4.10 panel A illustrates the behaviour of the state variable, centred MA(12) process, in the case of 1-year time-charter rates for handysize vessels. Comparison of identified market conditions between panels A and B in Figure 4.10 indicates that the centred MA(12) process successfully identifies different market conditions for handysize 1-year time-charter rate. The same is also true for the other eight series under investigation.

⁹ We also estimated two-state Markov switching model under which the state of the market is determined simultaneously with the estimated model (see Hamilton, 1989). However, due to the nonlinear nature of these models, high volatility of freight rate series and the large number of coefficients (dummies) to be estimated, convergence could not be achieved for four out of nine models (spot series, which display higher volatility and handysize 3-year time-charter rates). The results of those models for which convergence could be achieved are similar to the results from the switching model with the MA(12) latent variable.

Figure 4.10: Distinction between different market conditions using MA(12) process
Handysize 1-year time-charter rates



The results of threshold switching seasonal model of equation (4.4) are presented in Table 4.5 to 4.7 for spot, 1-year and 3-year time-charter rates, respectively. Under each heading, two columns are designated as "good" and "bad" in order to distinguish, expansion and contraction periods, respectively. Wald-tests for parameter equality of model (4.4); that is, $\beta_{1,i} = \beta_{2,i}$, $i=0, 2, \dots, 12$, is rejected in every case, supporting the conjecture that the seasonal behaviour of freight rates is related to market conditions. This is also in line with higher \bar{R}^2 values observed (with the exception of panamax spot rates), compared to the general model, becoming as large as 28.9% in cases like the 3-year time charter rates for panamax size vessels.

Regression constants represent the average growth or decline rates of freight rate series over the estimation period under different market conditions. They are significant in every case. For example, in the case of capesize spot rates, the average growth rate of the series during expansion periods is found to be 3.3% whereas the average decline during contraction periods is 3.5%. These positive and negative coefficient values over different phases of the market cycle are consistently significant for all vessel sizes and contract duration. Broadly, irrespective of market condition, rates of larger vessels within the same contract duration exhibit higher averages, positive or negative, compared to smaller ones. This is consistent with earlier results.

Table 4.5: Seasonal variations in spot rates under different market conditions

$$\Delta X_t = \beta_{1,0}d_{1,t} + \sum_{i=2}^{12} \beta_{1,i}(d_{1,t}Q_{i,t}) + \beta_{2,0}d_{2,t} + \sum_{i=2}^{12} \beta_{2,i}(d_{2,t}Q_{i,t}) + \varepsilon_t$$

where state dummies $d_{1,t}$ and $d_{2,t}$ are

$$\begin{cases} d_{1,t} = 1 \text{ and } d_{2,t} = 0 & \text{if } \frac{1}{12} \sum_{j=6}^5 \Delta X_{t+j} > 0 \\ d_{1,t} = 0 \text{ and } d_{2,t} = 1 & \text{if } \frac{1}{12} \sum_{j=6}^5 \Delta X_{t+j} \leq 0 \end{cases} \quad \text{Equation (4.4)}$$

	Capesize		Panamax		Handysize	
	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)
Const.	0.033 (3.234)	-0.035 (-2.614)	0.026 (2.251)	-0.028 (-2.564)	0.022 (4.058)	-0.019 (-3.147)
Jan.	0.019 (0.319)	0.039 (0.923)	-0.045 (-0.532)	-0.084 (-1.072)	0.006 (0.149)	-0.015 (-0.631)
Feb.	-0.015 (-0.356)	-0.089 (-0.950)	0.054 (1.727)	0.049 (0.801)	-0.012 (-0.502)	0.017 (1.065)
Mar.	-0.040 (-0.601)	0.100 (0.735)	0.055 (2.306)	0.115 (1.548)	0.036 (1.060)	0.037 (1.277)
Apr.	0.201 (2.619)	0.051 (0.691)	-0.018 (-0.534)	-0.004 (-0.105)	0.038 (1.770)	0.020 (1.078)
May.	-0.054 (-1.115)	0.036 (0.531)	0.018 (0.368)	-0.008 (-0.230)	-0.014 (-0.631)	0.054 (1.778)
June	-0.070 (-1.764)	-0.077 (-1.399)	-0.150 (-4.400)	-0.062 (-2.731)	-0.055 (-1.967)	-0.032 (-0.971)
July	-0.187 (-2.611)	-0.147 (-1.881)	-0.122 (-3.962)	-0.135 (-2.281)	-0.149 (-6.073)	-0.054 (-1.586)
Aug.	0.146 (2.903)	-0.106 (-1.176)	-0.024 (-0.486)	0.049 (1.529)	-0.035 (1.318)	0.002 (0.057)
Sept.	0.069 (1.336)	0.269 (1.511)	0.048 (0.621)	-0.008 (-0.233)	0.062 (1.959)	-0.010 (-0.326)
Oct.	-0.091 (-1.639)	0.004 (0.076)	0.141 (2.195)	0.076 (2.252)	0.050 (2.086)	-0.010 (-0.305)
Nov.	0.034 (0.461)	-0.012 (-0.157)	0.045 (1.463)	0.020 (0.602)	0.027 (0.855)	0.005 (0.145)
Dec.	-0.011 (-0.341)	-0.066 (-1.065)	0.001 (0.026)	-0.013 (-0.319)	0.044 (1.380)	-0.013 (-0.615)
R^2	0.093		0.105		0.140	
Wald-test	120.9	[0.000]	123.3	[0.000]	378.8	[0.000]
Wald-1	44.09	[0.000]	23.44	[0.024]	66.86	[0.000]
Q(1)	17.37	[0.000]	11.12	[0.001]	17.37	[0.000]
Q(12)	17.15	[0.144]	41.57	[0.000]	17.15	[0.144]
ARCH(12)	0.700	[0.749]	4.385	[0.000]	0.700	[0.749]
White test	0.201	[0.654]	0.046	[0.829]	0.201	[0.654]
J-B	1.358	[0.507]	284.8	[0.000]	1.358	[0.507]

- See notes in Table 4.4 and the following.
- Wald-test is a joint test for the significance of coefficients of dummy variables. This is a $\chi^2(22)$ statistic.
- Wald-1 is a joint test for the equality of coefficients of dummy variables under different market conditions. This is a $\chi^2(11)$ statistic.

Next we turn to a comparison of seasonality between different market conditions in the spot market. Although the pattern of seasonality remains broadly the same as before, there are notable differences over market conditions. For example, it can be seen that seasonal fluctuations are or become significant in “good” market conditions when supply is inelastic compared to “bad” markets; under the latter market conditions rates display either lower or no significant seasonality in the flat portion of supply curve. This can be seen, for instance, in

the case of capesize spot rates. Capesize rates show a significant rise of 20.1% in April in strong markets, but no significant increase during weak market contractions. Panamax rates also show significant increases of 5.4% and 5.5% in February and March when the market is “good”, but no significant rise when the market is depressed. The difference between seasonal movements under different market conditions is even more transparent during the mid summer decline in rates. The magnitude of this decline is 25.7%, 27.2% and 20.4% for capesize, panamax and handysize rates, respectively, under rising market conditions, as opposed to 14.7%, 19.7% and 0% for the respective size categories when the market is falling. The October increase in panamax rates is reduced from 14.1% in rising markets to 7.6% in falling markets, while significant increases of 6.2% and 5.0% are estimated for handysize spot rates during September and October only in rising market conditions. This increase in handysize spot rates, which is due to the increase in the US grain export, was not observed in Table 4.3.

Tables 4.6 and 4.7 report seasonal results for one and three-year time-charter rates under different market conditions for each size bulk carrier. Estimates of the threshold switching seasonal models lead to similar conclusions as in the case of spot rates; that is, the seasonal fluctuations (positive or negative) are stronger for periods of market expansion as opposed to periods of market contraction. However, such differences become smaller as the duration of the contract rises from one to three years. For three-year contracts it seems that seasonality is mainly attributable to periods of expansion, with the majority of seasonal coefficients becoming insignificant in depressed markets. This points to the conclusion that the supply for shipping services schedule is less and less steep (more and more elastic) at the top end of the curve as the contract duration rises. This supply curve is almost flat for 3-year time-charter rates in “bad” markets, see Figure 4.11.

This is an important issue in the cyclical shipping freight markets since the elasticity of supply is high during troughs and low in peaks of the shipping business cycle as in Figure 4.11. As a result, changes in demand during the recovery period in the cycle produce seasonal reactions in freight rates which are higher compared to the low reactions in market downturns, see for an illustration.

Table 4.6: Seasonal variations in 1-year time-charter rates under different market conditions

$$\Delta X_t = \beta_{1,0}d_{1,t} + \sum_{i=2}^{12} \beta_{1,i}(d_{1,t}Q_{i,t}) + \beta_{2,0}d_{2,t} + \sum_{i=2}^{12} \beta_{2,i}(d_{2,t}Q_{i,t}) + \varepsilon_t$$

where state dummies $d_{1,t}$ and $d_{2,t}$ are
$$\begin{cases} d_{1,t} = 1 \text{ and } d_{2,t} = 0 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} > 0 \\ d_{1,t} = 0 \text{ and } d_{2,t} = 1 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} \leq 0 \end{cases} \quad \text{Equation (4.4)}$$

	Capesize		Panamax		Handysize	
	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)
Const.	0.034 (5.808)	-0.043 (-5.811)	0.025 (4.486)	-0.029 (-4.394)	0.020 (3.684)	-0.023 (-5.663)
Jan.	0.001 (0.043)	-0.002 (-0.093)	0.036 (1.072)	0.003 (0.267)	0.035 (1.058)	0.001 (0.047)
Feb.	0.023 (0.119)	-0.079 (-3.349)	0.020 (1.281)	-0.020 (-1.507)	0.001 (0.085)	-0.018 (-1.394)
Mar.	0.036 (2.001)	-0.001 (-0.027)	0.030 (1.689)	0.007 (0.286)	0.028 (1.769)	0.024 (2.376)
Apr.	0.032 (1.523)	0.012 (0.273)	-0.004 (-0.423)	0.015 (0.480)	0.032 (3.479)	0.012 (0.513)
May.	0.024 (0.906)	-0.032 (-2.102)	0.025 (1.746)	0.016 (0.998)	0.024 (0.112)	0.013 (1.423)
June	-0.059 (-2.890)	-0.017 (-1.016)	-0.050 (-2.091)	-0.036 (-3.246)	-0.049 (-3.922)	-0.023 (-2.288)
July	-0.068 (-2.424)	-0.015 (-0.800)	-0.067 (-6.705)	-0.046 (-1.954)	-0.055 (-5.195)	-0.033 (-2.267)
Aug.	0.011 (0.381)	0.018 (0.778)	0.016 (0.756)	0.015 (1.144)	-0.009 (-1.147)	-0.005 (-0.392)
Sept.	0.055 (1.642)	0.029 (1.141)	0.002 (0.075)	0.002 (0.172)	0.006 (0.526)	0.005 (0.439)
Oct.	-0.021 (-1.315)	0.027 (1.094)	-0.013 (-0.961)	0.003 (0.188)	0.001 (0.045)	0.018 (2.985)
Nov.	0.015 (0.791)	0.029 (1.274)	-0.003 (-0.236)	0.017 (1.421)	0.010 (0.813)	-0.004 (-0.464)
Dec.	-0.028 (-1.851)	0.030 (1.161)	0.008 (0.527)	0.007 (0.549)	-0.003 (-0.207)	0.009 (1.157)
R^2	0.246		0.230		0.257	
Wald-test	134.9	[0.000]	129.95	[0.000]	149.7	[0.000]
Wald-1	124.2	[0.000]	58.62	[0.000]	75.81	[0.000]
Q(1)	11.00	[0.001]	5.069	[0.024]	17.37	[0.000]
Q(12)	28.05	[0.005]	20.00	[0.067]	16.88	[0.154]
ARCH(12)	0.915	[0.532]	1.753	[0.059]	1.181	[0.300]
White test	0.046	[0.829]	1.871	[0.171]	8.417	[0.004]
J-B	4.171	[0.124]	19.83	[0.000]	11.88	[0.003]

- See notes in Table 4.4 and the following.
- Wald-test is a joint test for the significance of coefficients of dummy variables. This is a $\chi^2(22)$ statistic.
- Wald-1 is a joint test for the equality of coefficients of dummy variables under different market conditions. This is a $\chi^2(11)$ statistic.

Table 4.7: Seasonal variations in 3-year time-charter rates under different market conditions.

$$\Delta X_t = \beta_{1,0}d_{1,t} + \sum_{i=2}^{12} \beta_{1,i}(d_{1,i}Q_{i,t}) + \beta_{2,0}d_{2,t} + \sum_{i=2}^{12} \beta_{2,i}(d_{2,i}Q_{i,t}) + \varepsilon_t$$

where state dummies $d_{1,t}$ and $d_{2,t}$ are $\begin{cases} d_{1,t} = 1 \text{ and } d_{2,t} = 0 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} > 0 \\ d_{1,t} = 0 \text{ and } d_{2,t} = 1 & \text{if } \frac{1}{12} \sum_{j=-6}^5 \Delta X_{t+j} \leq 0 \end{cases}$ Equation (4.4)

	Capesize		Panamax		Handysize	
	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)	Good ($\beta_{1,i}$)	Bad ($\beta_{2,i}$)
Const.	0.024 (5.091)	-0.030 (-5.313)	0.021 (4.413)	-0.021 (-4.319)	0.017 (3.355)	-0.020 (-5.106)
Jan.	-0.021 (-1.295)	0.003 (0.155)	0.007 (0.388)	0.004 (0.617)	0.021 (0.749)	0.013 (1.320)
Feb.	-0.021 (-0.789)	-0.026 (-1.129)	-0.002 (-0.170)	-0.014 (-1.891)	-0.003 (-0.305)	-0.028 (-1.118)
Mar.	0.035 (2.278)	0.012 (0.933)	0.044 (2.691)	0.004 (0.630)	0.005 (0.538)	-0.000 (-0.003)
Apr.	0.027 (1.679)	-0.008 (-0.303)	0.011 (0.683)	-0.006 (-0.681)	-0.015 (-0.476)	0.015 (1.217)
May.	0.021 (1.128)	-0.017 (-0.773)	0.013 (1.520)	0.007 (0.727)	0.070 (1.178)	0.012 (1.685)
June	-0.027 (-2.141)	-0.014 (-0.824)	-0.035 (-2.487)	-0.008 (-0.994)	-0.057 (-2.166)	-0.006 (-0.492)
July	-0.029 (-2.315)	-0.012 (-0.615)	-0.032 (-4.304)	-0.010 (-1.213)	-0.027 (-3.285)	-0.011 (-1.555)
Aug.	0.020 (0.895)	0.026 (1.369)	0.015 (0.722)	0.011 (0.990)	0.028 (1.200)	0.002 (0.256)
Sept.	0.024 (1.482)	0.023 (1.256)	0.006 (0.694)	0.013 (1.266)	0.010 (1.227)	0.011 (0.981)
Oct.	0.0001 (0.006)	0.007 (0.355)	-0.021 (-3.477)	-0.021 (-1.710)	0.0005 (0.064)	0.007 (1.152)
Nov.	-0.0003 (-0.028)	-0.0002 (-0.010)	-0.015 (-1.292)	0.003 (0.204)	-0.012 (-1.323)	-0.019 (-3.679)
Dec.	-0.028 (-1.330)	0.008 (0.705)	0.007 (0.584)	0.015 (2.683)	-0.018 (-2.174)	0.003 (0.389)
R^2	0.158		0.289		0.107	
Wald-test	96.41	[0.000]	142.1	[0.000]	78.48	[0.000]
Wald-1	57.04	[0.000]	99.03	[0.000]	49.99	[0.000]
Q(1)	9.728	[0.002]	8.290	[0.004]	17.37	[0.000]
Q(12)	27.80	[0.006]	14.49	[0.270]	22.17	[0.035]
ARCH(12)	0.749	[0.701]	1.655	[0.080]	5.710	[0.000]
White test	1.108	[0.292]	6.296	[0.012]	24.29	[0.000]
J-B	57.61	[0.000]	14.37	[0.001]	4984	[0.000]

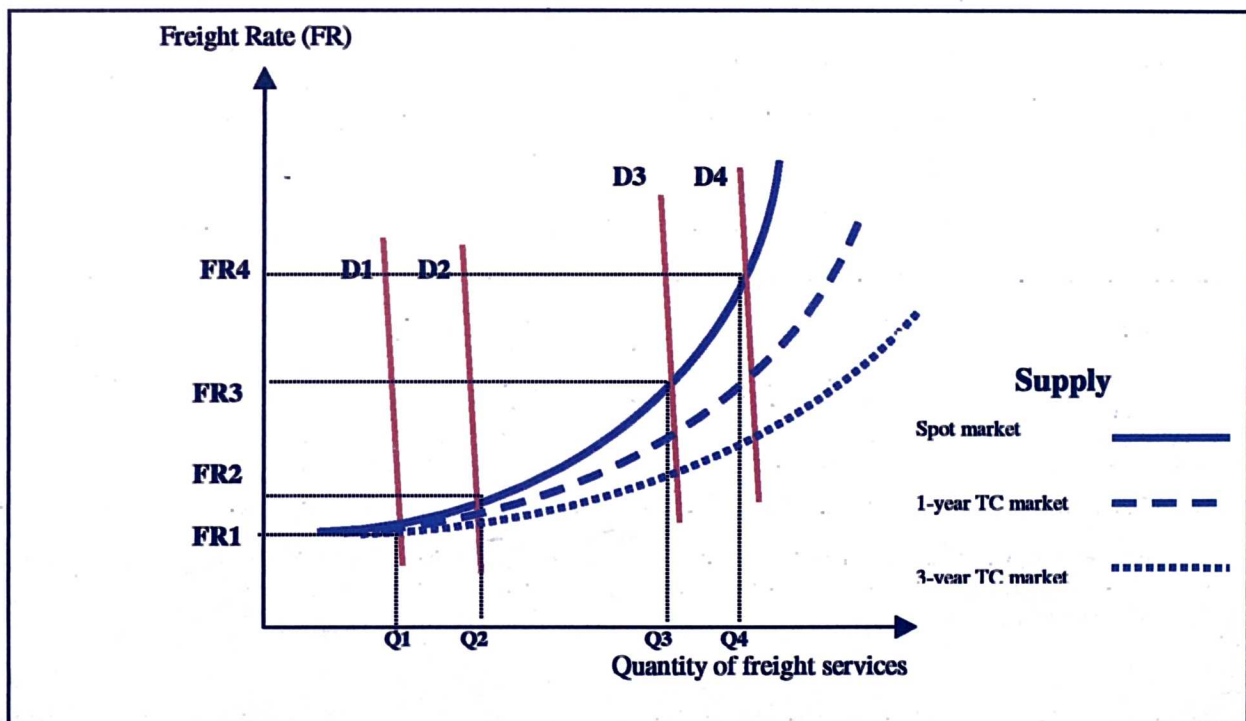
- See notes in Table 4.4 and the following.
- Wald-test is a joint test for the significance of coefficients of dummy variables. This is a $\chi^2(22)$ statistic.
- Wald-1 is a joint test for the equality of coefficients of dummy variables under different market conditions. This is a $\chi^2(11)$ statistic.

In general, the results for the dry bulk shipping sector suggest that, seasonality in freight rates is deterministic rather than stochastic. Rejection of the existence of stochastic seasonal behaviour across freight rates highlights the fact that the pattern of seasonal demand for shipping services or international seaborne trade in dry bulk commodities has not changed. Deterministic seasonality is identified to be a result of weather and calendar effects; that is,

harvest seasons, holiday periods and change of accounting year in Japan. As it turns out these have been regular events. Had any of these shifted within the year then seasonality patterns would have become irregular, giving rise to stochastic seasonality.

Regular-deterministic seasonality is quite different across the size of vessels and duration of the charter contract as well as different market conditions. More specifically: 1) the levels of freight rates for different sizes of dry bulk carriers increase during the spring and autumn months and drop sharply in June and July, 2) seasonal changes are asymmetric, in that rises (during spring and autumn) are less pronounced over all sectors compared to falls (in the summer), 3) spot rate seasonality seems to be more pronounced for freight rates of larger tonnage than smaller ones, 4) differences in seasonality amongst sectors are broadly eliminated as the duration of contract increases indicating less curvature in the supply function of longer duration contracts, and 5) seasonal movements in dry bulk freight series are also found to be asymmetric under different market conditions; that is, seasonal variations are more pronounced during market expansions than under market contractions.

Figure 4.11: The Shipping Freight Market



4.7. Conclusions

This Chapter has examined the existence and type of seasonality that may be present in dry bulk freight rates of different duration as well as the stochastic properties of these series. Tramp freight rates seem to have a unit root at zero frequency, but not at seasonal frequencies for the period examined. This by itself suggests that ARIMA and VAR models are appropriate when modelling the series. In addition, having rejected the existence of stochastic seasonality, i.e. non-stationarity at seasonal frequencies, it is found that there is significant deterministic seasonality, i.e. regular seasonal patterns. It is also found that, while deterministic seasonal movements show similarities across vessel size and duration of contract, there are conspicuous differences too. Regular seasonal patterns in dry bulk freight rates are attributed to the nature and pattern of the trade in commodities transported by these ships, while the differences emanate from the factors that sub-divide the dry bulk sector and commodities such as ship size, flexibility, route and commodity parcel size.

Broadly, the results reveal that freight rates increase during early spring, i.e. March and April, and drop sharply in June and July. Panamax and handysize spot rates also show a rise in the autumn months. The contrast between seasonal variations in freight rates for different size carriers provides an incentive for multi-vessel companies to diversify and extend their investments to vessels of different sizes, as well as operate vessels under contracts of different duration. Such strategies reduce their exposure to seasonal fluctuations of the freight market during the year. The results also provide evidence in favour of an asymmetric effect of the seasonal behaviour of freight rate series under different market conditions. It is found that seasonal fluctuations are sharper and more pronounced during market recovery as opposed to the periods when the market is deteriorating. This is argued to be in line with the theory of shipping freight rate formation and is caused by the shape of the supply schedule in the market equilibrium model.

Other important implications of the results regarding the economic operation of ships, in the presence of seasonal fluctuations in shipping markets, are as follows. First, shipowners may use information on the seasonal movements of freight markets in order to make decisions such as sending the ship to dry-dock in seasons that freight rates are expected to fall (e.g. July and August in the dry bulk market). They can also adjust the speed to increase productivity

during peak seasons (e.g. March, April and May in the dry bulk market). Second, shipowners (charterers) might be able to secure their cash flow (transportation costs) against the seasonal movements in the market using futures contracts such as the BIFFEX. Third, shipowners might be able to maximise their revenue, in the long run, by entering into the time-charter market during peak seasons (for example, March, April and May). The results also suggest that, in the long run, for a shipowner operating in the time-charter market, renewing time-charter contracts in peak seasons (e.g. March and April and May for handysize dry bulk carriers) may increase the shipowners' revenue. However, to what extent these type of decisions and short run speculative strategies, based on the seasonal movements of the freight rates, can be implemented and increase the shipowners wealth is a matter of further research.

5. CHAPTER FIVE

THE EXPECTATIONS HYPOTHESIS OF THE TERM STRUCTURE AND RISK PREMIA IN FREIGHT RATE FORMATION

5.1 Introduction

Having investigated the stochastic behaviour of dry bulk freight series, this chapter examines the relationship between spot and time-charter rates and the efficient market hypothesis in the determination of period rates. In particular, the validity of the expectations hypothesis of the term structure, EHTS, for 1-year and 3-year time-charter rates is investigated across three different sizes of dry bulk carriers. The motivation for this study stems from the importance of understanding the term structure relationship, which is not only of interest to agents involved in the shipping industry, but also is essential for modelling and forecasting period rates. For instance, uncovering the true relationship between short and long term shipping contracts is important in timing chartering activities and entering shipping contracts of different duration. Furthermore, understanding the dynamics of short and long term shipping freight rates, the interaction between them and the impact of risk in the formation of period rates is essential in enhancing the accuracy of forecasting models for predicting freight rates.

Different testing procedures such as “*perfect foresight spread*”, cointegration, and non-linear restrictions on the VAR model (tests proposed by Campbell and Shiller 1987 and 1991) are used in this study. These testing methods take into account the univariate properties of the series under study as pointed out by Campbell and Shiller (1987). The results do not provide any support for the EHTS in dry bulk markets. However, failure of the EHTS is attributed to the existence of risk elements in the formation of long-term rates in such a volatile industry.

This chapter is organised as follows. Section 5.2 presents the theory of the EHTS and its importance as well as a brief review of the literature in shipping markets, while section 5.3 reviews the evidence on the EHTS in money markets. Section 5.4 discusses implications of the EHTS for shipping markets and different methods of testing the EHTS in the formation of period rates. Section 5.5 presents a model for time-varying risk premia. Properties of the data are considered in section 5.6, while section 5.7 presents the empirical results for different tests of the EHTS and models the time-varying risk premia. Implications of the results are discussed in section 5.8 and conclusions are drawn in the last section.

5.2 The Theory of the Expectations Hypothesis of the Term Structure

The existence of freight contracts with different duration in the shipping industry offers both shipowners and charterers flexibility in their decisions regarding chartering and operational activities. Short term or spot charter rates are thought to be determined by current supply and demand for shipping services (see for e.g. Stopford, 1997 and McConville, 1999), whereas long term period rates are believed to be determined through agents' expectations about future short term rates. As a consequence, spot and time charter markets have distinct risk/return characteristics (see Kavussanos, 1996, 1998), which enable agents involved in freight markets to diversify risks by opting for different duration contracts. For instance, risk-averse shipowners may choose to operate vessels on a time charter rather than a spot contract to reduce risks, or avoid time charter markets when they expect rates to increase.

As mentioned in chapter 1, an implication of the efficient market hypothesis (EMH) for shipping freight markets is that short term and long term freight contracts should be related in such a way that any opportunity to generate excess profit by switching between different contracts is eliminated. This implication can be formulated into a testable hypothesis, known as the EHTS. According to the EHTS discounted earnings from a long term time-charter contract, say for 12 months, should be equal to the discounted expected earnings from a series of freight contracts over the next 12 months. Thus, if shipping freight markets operate efficiently this relationship should hold. Failure of the relationship may be a result of the malfunctioning (inefficiency) of the spot and/or time-charter markets, incorrect expectations of agents or an incorrect underlying model that governs the relationship between the two markets.

Investigating the validity of the term structure relationship of shipping freight contracts is important because uncovering the true nature of such a relationship has several implications both for practitioners and academics. Such implications include amongst others: decisions about entering shipping contracts of different duration according to whether time-charters are over or underpriced with respect to expected spot contracts; operational strategies by hiring in and out vessels based on the degree of mis-pricing; modelling freight rate movements; information on risk return relationships in shipping operations in different segments of the

dry bulk freight market; inferences about the efficient pricing of freight markets, since if markets are efficient, then there is no opportunity for agents to make excess profit, and *visa versa*.

A relatively limited number of papers have been devoted to examining the EHTS relationship in shipping freight markets. Zannetos (1966), Glen et al (1981) and Strandenes (1984), while recognising that there is a term structure relationship between spot and time charter rates, did not test for the validity of the relationship, as we have seen it being tested in bond and money markets in the finance literature. The only studies actually testing for the EHTS are those of Hale and Vanags (1989) and Veenstra (1999) for the dry bulk market, who broadly reject the validity of the relationship. This evidence may be influenced by the following problems, which can lead to potentially wrong inferences. First, the former study utilises the Mankiw-Summers (1984) test, which is less powerful compared to more recent alternatives such as the Campbell-Shiller (1987, 1991) tests. Second, only a short period, 1980:10 to 1986:12, is used which only covers part of the shipping business cycle. Third, while Veenstra (1999) uses the Campbell-Shiller method to test the EHTS, his formulation of the test is not appropriate¹. Finally, although both studies while recognising that failure may be a result of the existence of risk premia, they do not attempt to model them or provide further insight. These risk premia may be a consequence of the perception held by agents that long term contracts are less risky than a series of short term ones, and as a result a discount may be offered to secure such longer term contracts.

This chapter aims to address these issues; first, by utilising modern econometric techniques to take into account the stochastic properties of the series in testing the EHTS through a battery of tests derived from the underlying theoretical relationship of the EH (see, Campbell and Shiller 1987 and 1991); and second, by explaining failure of the EHTS as a consequence of the existence of time-varying risk premia, which are modelled in EGARCH-M frameworks. Other distinguishing features of this study include the relatively long period of monthly data used (January 1980 – August 1997) thus covering a complete cycle of the industry, and the use of contracts of different maturities for various vessel sizes which allows investigation of the relationship between contract maturity and shipping sectors.

¹ See chapter 2 for details of problems with re-parameterisation of the EHTS in Veenstra (1999), and Appendix A and Section 5.4 for the appropriate formulation.

5.3 Evidence on the EHTS in Money Markets

The term structure relationship of money instruments is developed in papers such as those of Mankiw and Summers (1984), Mankiw and Miron (1986) and Campbell and Shiller (1987), and for time-varying risk premia in Simon (1989) and Engle et al (1987) among others. Several studies are devoted to testing the EHTS in various bonds and interest rate markets with different terms to maturity, sample periods, frequencies and geographical locations².

More recent studies on the validity of the EHTS in money markets follow Campbell and Shiller (1987 and 1991) and use the VAR methodology to test the theory. This is because the VAR methodology takes into account the stochastic properties of data. For example, Cuthbertson et al (1995) find evidence in favour of the EHTS in the UK certificates of deposits based on monthly data. Cuthbertson (1996a) using weekly (1 to 52 weeks) LIBOR series finds support for the EHTS at the short end of the maturity spectrum (1 to 13 weeks). Hurn et al (1995a) do not reject the EH using the UK monthly LIBOR. Guest and McLean (1998) report evidence against the EHTS in the Australian Treasury bills market and suggest the existence of a time-varying risk premium in that market.

Overall, the evidence on the validity of the theory in money markets seems to be mixed and inconclusive. Most authors attribute failures of the EHTS to the existence of (time-varying) risk premia. This is regarded as an alternative hypothesis to the EHTS, which relates the deviations from the pure expectations hypothesis³ (PEH) and the EH to investors' perceptions of risk. Studies such as Jones and Roley (1983), Simon (1989), Engle et al (1987) and Bollerslev et al (1988), among others, are devoted to identifying and measuring an appropriate variable for market risk and time-varying risk premia. For example, Simon (1989) uses the square of excess holding period returns on a long term bond over a short term bond as a proxy for the market risk, whereas Jones and Roley (1983) use the weighted average of absolute changes in the short term rate for this purpose. Other studies which find

² For example, Campbell and Shiller (1987 and 1991) investigate the term structure of US government bonds for the period 1946-87 using monthly returns and report mixed results. Taylor (1992) finds no support for the EHTS across the UK long term government bonds and three month Treasury Bills using weekly data over the period January 1985-November 1989. He also rejects the existence of time-varying risk premia and concludes that some form of market segmentation drives the UK bond market. Mills (1991) also finds mixed results for the term structure of UK interest rates using a very long annual data set dating back to 1870's. MacDonald and Speight (1991) also report mixed results for the validity of the hypothesis for long term government bonds across five countries, the UK, the US, Germany, Belgium and Canada, using quarterly data for the period 1964 to 1986.

³ The PEH asserts that long term rates are determined solely by the weighted average of the current and expected short term rates; that is, the liquidity premium is zero.

the conditional variance of the excess return forecast errors to be a reasonable proxy for the term premia in the term structure models include; Engle et al (1987), Taylor (1992), Engle and Ng (1993a), Hurn et al (1995b) and Brunner and Simon (1996), among others.

The shipping freight markets and the money (bond and interest rate) markets share some common features, as noticed by Zannetos (1966) for the first time. For example, investors in bond or interest rate markets have the option to invest in long or short-term rates and bonds with different times to maturity. Similarly, in shipping markets, shipowners (or charterers) have the option to enter into shipping contracts with different duration, namely time-charter (long term) and single voyage (short-term) contracts. There are also notable differences between the money markets and freight markets. First, shipping freight rates relate to a service industry and unlike money markets, contracts in shipping markets are not tradable (liquid) and must be adhered to until maturity. This means that once a charterer hired a vessel for one year, he/she can not sell the contract a month later, say, for the next eleven months. Second, from the risk-averse shipowners' point of view, long term contracts are considered to be more secure (less risky) than short term ones (see the discussion in section 5.8). This is exactly opposite to what is noted in money markets, in which risk-averse investors are in favour of shorter term instruments (liquidity preference) compared to longer ones. Finally, shipping is an international service industry exposed to the cyclicalities created by political events, world economic activity and multilateral trade commodity economics around the world. This increases considerably the risk in shipping markets compared to other financial markets.

Since most studies on the term structure theory are concentrated on money markets, testing the EHTS in freight rate markets contributes to the literature in a number of ways. The EHTS is examined for a service market with a number of properties, which are distinct compared to money markets. The non-tradability of freight contracts, the opposite relationship expected a priori between short and long term contracts compared to money markets, and the cyclicalities evident in the shipping industry are special features of this market which make it worth investigating. The investigation and modelling of risk premia in the EGARCH-M framework is also an innovation for freight markets.

5.4 The Theoretical Framework for Investigating the EHTS in Freight Markets

The EHTS in shipping freight markets postulates that the discounted present value of earnings (\$/day) from an n period time-charter contract should be equal to the discounted expected earnings from a series of m period spot contracts within the life of the time-charter contract⁴ plus a term premium⁵, τ . Mathematically,

$$\sum_{i=0}^{k-1} \frac{TC_t^n}{(1+r)^i} = \sum_{i=0}^{k-1} \frac{E_t(FR_{t+im}^m)}{(1+r)^i} + \tau \quad k = n/m \quad (5.1)$$

where, TC_t^n is the earnings of n period time-charter contract rate at time t , $E_t FR_{t+im}^m$ is the expected earnings of spot charter rate at time t of a contract which lasts over m periods from $t+im$ to $t+(i+1)m$, and $k=n/m$ is a positive integer indicating the number of spot charter contracts in the life of a time-charter contract. Letting $\delta = 1/(1+r)$ and $FR_t^m = FR_t$, where ($m=1$), equation (5.1) can be re-parameterised to yield time-charter earnings as a function of expected future spot earnings as follows

$$TC_t^n = \sum_{i=0}^{k-1} \frac{(1-\delta)}{(1-\delta^k)} \delta^i E_t(FR_{t+im}) + \frac{(1-\delta)\tau}{(1-\delta^k)} \quad (5.2)$$

or

$$TC_t^n = \theta \sum_{i=0}^{k-1} (1-\delta) \delta^i E_t(FR_{t+im}) + \phi \quad (5.3)$$

where $\theta = 1/(1-\delta^k)$ and $\phi = (1-\delta)(1-\delta^k)^{-1}\tau$. In this setting, ϕ is a constant term premium indicating the price of risk. Two main assumptions are made in this formulation. First, the duration of the spot contract (trip or voyage) is assumed to be constant⁶, m . Second, it is assumed that the probability of failing to fix the vessel on a spot contract during the n period (unemployment risk) is zero or reflected in ϕ ⁷. If ϕ is zero, then the EHTS reduces to the

⁴ Note that in order to test this relationship, spot and time-charter rates must be comparable; that is they should have the same units of measurement. Therefore, we use earnings from spot and time-charter operations.

⁵ When $\tau=0$ then only the series of spot earnings are relevant in determining the long term rate. This is the PEH version of the EH.

⁶ Since we are using average of monthly spot rates, the duration for a trip-charter is assumed to be one month.

⁷ Apart from unemployment risk, there are other risks associated with the spot market operation. For example, the excess administration involved in operating in the spot market and possible relocation costs for commencement of a new trip-charter contract.

PEH, which posits that the earnings of long term contracts are solely determined through weighted average of the expected (future) earnings of spot contracts.

For example, according to equation (5.3), earnings from a 1-year time-charter contract ($n=12$) can be written as a weighted average of the discounted expected earnings from a series of one month spot contracts ($m=1$) as follows:

$$TC_t^{12} = \theta \sum_{i=0}^{11} (1-\delta) \delta^i E_t (FR_{t+i}) + \phi \quad (5.4)$$

Since variables in (5.3) are nonstationary, direct tests for the validity of the EHTS may result in invalid inferences. Following Campbell and Shiller (1987 and 1991), (5.3) can be transformed to utilise the cointegrating relationship between earnings from short and long term contracts and result in a model with stationary variables. This is done by subtracting FR_t from both sides of equation (5.3) and rearranging, to obtain the spread between earnings from time-charter and spot contracts, $S_t^{(n,m)}$, as a weighted average of the expected future changes in spot earnings in the following form (see Appendix A for more details),

$$S_t^{(12,1)} = TC_t^{12} - FR_t = \theta \sum_{i=1}^{11} (\delta^i - \delta^{12}) E_t (\Delta FR_{t+i}) \quad (5.5)$$

where, $S_t^{(12,1)} = TC_t^{12} - FR_t$ is the spread between 1-year time-charter and 1-month spot earnings at time t , $E_t \Delta FR_{t+i} = E_t FR_{t+i} - E_t FR_{t+i-1}$ is the first difference operator of the expected spot rates, and $E_t \Delta^{11} FR_{t+i} = E_t FR_{t+i} - E_t FR_{t+i-11}$, is the expected difference between two freight rates which are 11 periods apart.

Equation (5.5) states that, the spread between 1-year time-charter and monthly spot earnings is equal to the weighted average of the expected future changes in spot earnings in the next 11 months. To convert the EHTS into an empirically testable form, the values of the expected future changes in spot earnings on the RHS of the equation should be determined. When data on expectations are not available, a forecasting scheme must be selected, which normally incorporates Rational Expectations (RE). Different methods proposed in the literature for this purpose include use of AR models as in Hale and Vanags (1989) or use of the PFS and the VAR model in Campbell and Shiller (1987 and 1991). Once the best forecasting model is

chosen, the EHTS may be tested through a number of methods outlined in the following subsections.

5.4.1 The Perfect Foresight Spread (PFS) approach

Assuming shipowners and charterers know exactly the RE values of the future expected changes of spot earnings in equation (5.5), where the RE of future changes in spot earnings is:

$$E_t \Delta FR_{t+i} = \Delta FR_{t+i} + \varepsilon_{t+i} \quad (5.6)$$

where, $E_t(\varepsilon_{t+i})=0$; $E_t(\varepsilon_{t+i}, \varepsilon_{t+j})=0$, $i \neq j$, $i=1,2,\dots,T$, then the 12 month *PFS*, $S_t^{(12,1)}$, can be written as⁸

$$S_t^{(12,1)} = \theta \sum_{i=1}^{11} (\delta^i - \delta^{12}) \Delta FR_{t+i} + \sum_{i=1}^{11} \zeta_i \varepsilon_{t+i} \quad (5.7)$$

Now, if the EHTS holds, the actual spread, $S_t^{(12,1)}$, of equation (5.5) and the *PFS*, $S_t^{(12,1)}$, of equation (5.7) should move close together over time. Therefore, the EHTS plus RE can be tested by regressing the *PFS*⁹ on a constant, the actual spread and an information set, Λ_t , which is a subset of the full information set, Ω_t .

$$S_t^{(12,1)} = \alpha + \beta S_t^{(12,1)} + \gamma \Lambda_t + \eta_t \quad (5.8)$$

where, $\eta_t = \sum_{i=1}^{11} \zeta_i \varepsilon_{t+i}$. That is, the error terms, η_t , are a combination of the RE forecast errors, inducing a MA(10) structure. Thus, one can estimate equation (5.8)¹⁰ and test the validity of the joint EHTS and RE^{11,12} through the restrictions $\alpha=0$, $\beta=1$ and $\gamma=0$.

⁸ Campbell and Shiller (1991) use this *PFS* term to indicate that if agents had perfect foresight about future rates, the model would be predicting the spread.

⁹ Note that here the *PFS* term is moved to the LHS of the regression equation. This is done to eliminate the possible problem of correlation between the error terms and the *PFS* series.

¹⁰ Assuming RE the RHS variables of equation (5.8) are orthogonal to the errors, η_t , thus, there is no need to use IV estimation methods. A GMM estimator is used to correct for the MA(10) and MA(34) term in the errors, η_t , for 12- and 36-months time-charter rate equations, respectively, and possible heteroscedasticity (Hansen, 1982; Newey-West, 1987).

5.4.2 The cointegration approach

If FR_t and TC_t^{12} are integrated series of order one, $I(1)$, then the RHS of equation (5.5) is stationary since it is a linear combination of $I(0)$ series, ΔFR_t . This implies that the LHS of the equation (5.5), that is the spread, $S_t^{(12,1)} = TC_t^{12} - FR_t$, must also be stationary (i.e. TC_t^{12} and FR_t are cointegrated) for the EHTS to hold, with cointegrating vector $[1, -1]$ (see, for example Hall et al 1991). Cointegration tests can be performed using the Johansen (1988) multivariate cointegration approach. The advantages of Johansen over the single equation tests of Engle-Granger (1987) and Phillips-Hansen (1990) is that the former can reveal the existence of more than one cointegrating relations among a number of non-stationary variables, and it is more powerful in determining those relationships as well as testing restrictions on the cointegrating parameters.

Following Granger's representation theorem, two non-stationary cointegrated variables, such as spot and time-charter earnings can be modelled in an error correction model (VECM) of the following form, which captures the short-run dynamics between the variables.

$$\begin{aligned}\Delta TC_t^{12} &= \gamma_{1,0} + \sum_{i=1}^q \gamma_{1,i} \Delta TC_{t-i}^{12} + \sum_{i=1}^q \lambda_{1,i} \Delta FR_{t-i} + \delta_1 (TC_{t-1}^{12} + \beta_0 + \beta FR_{t-1}) + \varepsilon_{1,t} \\ \Delta FR_t &= \gamma_{2,0} + \sum_{i=1}^q \gamma_{2,i} \Delta TC_{t-i}^{12} + \sum_{i=1}^q \lambda_{2,i} \Delta FR_{t-i} + \delta_2 (TC_{t-1}^{12} + \beta_0 + \beta FR_{t-1}) + \varepsilon_{2,t}\end{aligned}\quad (5.9)$$

Restrictions on the cointegrating vector can be tested using Likelihood Ratio (LR) tests¹³. If TC_t^{12} and FR_t are cointegrated, with cointegrating vector $[1, 0, -1]$ in the system of equations (5.9), then the error correction term, $(TC_{t-1}^{12} + \beta_0 + \beta FR_{t-1})$, represents the spread, which can be regarded as weak evidence for the EHTS. This suggests that although the earnings from spot and time-charter operation may diverge in the short run, the earnings will adjust when the spread deviates from its equilibrium value. In other words, earnings from spot and time-charter operations move together in the long run.

¹¹ Both variables, $S_t^{(12,1)}$ and $S_t^{(12,1)}$, in equation (5.8) are stationary. The actual spread is stationary because spot and time-charter rates are cointegrated (see section 2.2) and PFS is stationary because it is a linear combination of the stationary ΔFR_{t+i} terms.

¹² Notice that $\beta_0=0$ implies the PEH in which the risk premium is assumed to be zero, whereas, $\beta_0 \neq 0$ implies the EH with a constant risk premium.

5.4.3 VAR methodology

An alternative test for the EHTS proposed by Campbell and Shiller (1987), uses a bivariate VAR model to predict the future changes in spot earnings, $E_t \Delta FR_{t+i}$, required for testing in equation (5.5). In this framework, the spread, $S_t^{(12,1)}$ and changes in spot earnings, ΔFR_t , are modelled in a bivariate system of equations of the following form:

$$\begin{aligned} S_t^{(12,1)} &= \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(12,1)} + \sum_{i=1}^p \mu_{2,i} \Delta FR_{t-i} + \varepsilon_{1,t} \\ \Delta FR_t &= \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(12,1)} + \sum_{i=1}^p \varphi_{2,i} \Delta FR_{t-i} + \varepsilon_{2,t} \end{aligned} \quad (5.10)$$

To confirm the effectiveness of the spread in forecasting future changes in spot rates, Granger-causality tests can be performed on the significance of the coefficients of lagged spread values, $\varphi_{1,i}$, in the second equation of the VAR model.

Forecasts of changes in spot earnings, $E_t \Delta FR_{t+i}$, are then obtained from the estimated model by writing equation (5.10) in the following compact form known as the *companion matrix* representation (see Appendix B for more details):

$$\mathbf{Z}_t = \mathbf{A} \mathbf{Z}_{t-1} + \boldsymbol{\varepsilon}_t \quad (5.11)$$

where $\mathbf{Z}'_t = [S_t^{(12,1)}, \Delta FR_t, \dots, S_{t-p}^{(12,1)}, \Delta FR_{t-p}]$ is a $(3p \times 1)$ vector of current and lagged spread and changes in spot earnings. p is the order of the VAR model. \mathbf{A} is a $(2p \times 2p)$ companion matrix which contains the coefficients of the VAR system and $\boldsymbol{\varepsilon}_t$ is a $(2p \times 1)$ vector of zeros and innovations. Following the Campbell and Shiller notation, the individual elements in \mathbf{Z}_t , i.e. $S_t^{(12,1)}$ and ΔFR_t , can be written using the selection vectors¹⁴, $\mathbf{e1}$ and $\mathbf{e2}$, as,

$$S_t^{(12,1)} = \mathbf{e1}' \mathbf{Z}_t, \quad \Delta FR_t = \mathbf{e2}' \mathbf{Z}_t$$

¹³ The null hypothesis that the cointegrating vector is the spread, $\phi=0$ and $\beta=-1$, can be tested using the test statistic $-T \ln[(1 - \hat{\lambda}_1^*) / (1 - \hat{\lambda}_1)] \sim \chi^2(2)$, where $\hat{\lambda}_1^*$ and $\hat{\lambda}_1$ are the largest eigenvalues of the restricted and the unrestricted model, respectively, see Johansen and Juselius (1990) and Johansen (1991).

¹⁴ $\mathbf{e1}' = [1, 0, \dots, 0, 0]$ is a $(2p \times 1)$ selection vector with its first element equal to one and zeros elsewhere, $\mathbf{e2}' = [0, 1, 0, \dots, 0]$ is a $(2p \times 1)$ vector of zeros with its 2nd element equal to one.

Now using the chain rule of forecasting it is possible to find the optimal predictor of the expected future changes of spots earnings, k step ahead, using the VAR model.

$$E\Delta FR_{t+k} = \mathbf{e}2' E\mathbf{Z}_{t+k} = \mathbf{e}2' \mathbf{A}^k \mathbf{Z}_t \quad ; \quad k = 1, \dots, K \quad (5.12)$$

Substituting the forecast values of the expected future changes in spot earnings from the VAR model in the term structure equation (5.5), we can write

$$S_t^{(12,1)} \equiv \mathbf{e}1' \mathbf{Z}_t = \theta \sum_{i=1}^{11} (\delta^i - \delta^{i2}) \mathbf{e}2' \mathbf{A}^i \mathbf{Z}_t = S_t^{*(12,1)} \quad (5.13)$$

The RHS of the above equation is the weighted average of the predicted values of future changes in spot earnings, and is known as the *theoretical spread*, $S_t^{*(12,1)}$. The EHTS implies that the *theoretical spread* and the actual spread should move close together over time. Hence a testable implication of the EHTS is that the regression of the *theoretical spread* on a constant and the actual spread should satisfy the restrictions that $\alpha=0$ and $\beta=1$ in the following regression.

$$S_t^{*(12,1)} = \alpha + \beta S_t^{(12,1)} + \varepsilon_t \quad , \quad \varepsilon_t \sim iid(0, \sigma^2) \quad (5.14)$$

However, Campbell and Shiller (1987) point out to another test of the EHTS directly through the VAR model by placing restrictions on its parameters. This test can be constructed by using the selection vectors, $\mathbf{e}1$ and $\mathbf{e}2$, and the forecast values of future changes in spot earnings from equation (5.12) and substituting them in equation (5.5) as follows,

$$S_t^{(12,1)} = \mathbf{e}1' \mathbf{Z}_t = \theta \mathbf{e}2' (\mathbf{I} - \delta \mathbf{A})^{-1} (\mathbf{I} - \delta^{12} \mathbf{A}^{12}) \mathbf{Z}_t - \theta \delta^{12} \mathbf{e}2' (\mathbf{I} - \mathbf{A})^{-1} (\mathbf{I} - \mathbf{A}^{12}) \mathbf{Z}_t \quad (5.15)$$

For the EHTS to hold (eliminating \mathbf{Z}_t from both sides of equation (5.15)), the following set of restrictions should be valid.

$$\mathbf{e}1' = \theta \mathbf{e}2' (\mathbf{I} - \delta \mathbf{A})^{-1} (\mathbf{I} - \delta^{12} \mathbf{A}^{12}) - \theta \delta^{12} \mathbf{e}2' (\mathbf{I} - \mathbf{A})^{-1} (\mathbf{I} - \mathbf{A}^{12}) \quad (5.16)$$

Since it is difficult to estimate the restricted VAR model needed for likelihood ratio (LR) or Lagrange Multiplier (LM) tests, Wald tests may be used to test the validity of these non-linear cross equation restrictions on the unrestricted VAR model¹⁵.

5.4.4 Variance Ratio test

Campbell and Shiller (1991) utilise another implication of the EHTS by arguing that if the theoretical spread, $S_t^{*(12,1)}$, is the best forecast of future changes in spot earnings, then the variance of the theoretical spread, $Var(S_t^{*(12,1)})$, must be equal to the variance of the actual spread, $Var(S_t^{(12,1)})$. As a consequence, the ratio of the variances of these two spread series should be close to unity, $VR = Var(S_t^{(12,1)}) / Var(S_t^{*(12,1)}) = 1$. The empirical distribution of the VR (or the ratio of standard deviations) test is constructed in this paper using bootstrap methods. Thus, 10,000 independent samples, with replacements, are drawn from the actual and theoretical spread series, $S_t^{(12,1)}$ and $S_t^{*(12,1)}$ and variance ratios are formed. 90% confidence intervals for the empirical distributions are then computed using 10,000 VRs. The null hypothesis that the VR equals unity is rejected if the 90% confidence band does not include 1.

¹⁵ The Wald statistic for testing restrictions (5.16) on the VAR model takes the form: $W = f(\Theta)' \{Var[f(\Theta)]\}^{-1} f(\Theta) \sim \chi^2(r)$ where $f(\Theta)$ and $Var[f(\Theta)]$ represent the non-linear restrictions (5.16) on the VAR model and their variance, while r indicates the number of restrictions. The latter can be estimated using the first derivative of the non-linear restrictions with respect to the estimated parameters, $d f(\Theta)$, and the variance covariance matrix of the estimated coefficients, $Cov(\Phi)$, as follows: $Var[f(\Theta)] = d f(\Theta)' [Cov(\Phi)] d f(\Theta)$

5.5 Time-varying risk premia

The possible failure of the EHTS in the term structure models is mainly attributed in the literature to the existence of (time-varying) risk premia; see for example, Engle et al (1987), Engle and Ng (1993a), Hurn et al (1995b) and Brunner and Simon (1996). To investigate the issue empirically consider a time varying risk premium, ϕ_t , in equation (5.3), and substituting the expected values of future spot earnings, $E_t FR_{t+i}$, by their RE values, $E_t FR_{t+i} = FR_{t+i} + \varepsilon_{t+i}$, results in

$$TC_t^{12} = \theta \sum_{i=0}^{12-1} (1-\delta) \delta^i (FR_{t+i}) + \phi_t + \eta_t, \quad \eta_t = \varepsilon_t + \sum_{i=1}^{12-1} \zeta_i \varepsilon_{t+i} \quad (5.17)$$

where η_t is MA(11), representing the accumulated RE errors. The time-varying risk premium (discount), ϕ_t , may be modelled as the square root of the conditional variance of the forecast errors, which in turn are modelled as an Exponential GARCH (EGARCH) (see Nelson, 1991) of the following form

$$\begin{aligned} exr_t &= TC_t^{12} - \theta \sum_{i=0}^{11} (1-\delta) \delta^i (FR_{t+i}) = \phi_0 + \phi_1 \sigma_t + \eta_t \\ \eta_t &= \varepsilon_t + \sum_{i=1}^{11} \zeta_i \varepsilon_{t+i}, \quad \varepsilon_t \sim \text{iid}(0, \sigma_t^2) \\ \sigma_t^2 &= \exp(a_0 + \sum_{i=1}^p b_i \ln \sigma_{t-i}^2 + \sum_{i=1}^q c_i g_{1,t-i} + \sum_{i=1}^q d_i g_{2,t-i}) \\ g_{1,t} &= (\varepsilon_t / \sigma_t), \quad g_{2,t} = [(\varepsilon_t / \sigma_t) - E(\varepsilon_t / \sigma_t)] \end{aligned} \quad (5.18)$$

where exr_t represents the excess earnings from operation in the time-charter market over the spot market, σ_t^2 is the conditional variance and $g_{1,t}$ and $g_{2,t}$ are standardised residuals, ε_t / σ_t , and the difference between ε_t / σ_t and the expected value of ε_t / σ_t , respectively. In the above EGARCH-M framework, the coefficient of the time-varying volatility in the mean equation, ϕ_1 , reflects the impact of market risk on the earnings differential between operating in the time-charter or spot markets. Therefore, in shipping markets, one would expect ϕ_1 to be negative. The form in which the time varying variance enters the specification of the mean to determine the risk premium is a matter of empirical evidence. For example, in different

applications, Engle et al (1987) use the log of the variance, while Bollerslev, Engle and Wooldridge (1988) and French et al (1987) find that the square root of the variance performs better.

Advantages of the EGARCH formulation include; First, innovations are allowed to have an asymmetric impact on future volatility depending on their sign and magnitude, and captured by the coefficients of $g_{1,t-i}$ and $g_{2,t-i}$ terms. For example, if coefficients of $g_{1,t-i}$ terms, c_i , are negative, then negative shocks will increase the ex-ante variance proportionately more than positive shocks. Significance of coefficients of the $g_{2,t-i}$ terms, d_i , implies that shocks with larger (smaller) magnitude than the expected value of innovations will have a larger (smaller) impact on the ex-ante variance. Second, the EGARCH-M specification also relaxes the non-negativity restrictions on the conditional variance parameters required by GARCH models, for the variance to be positive at all times. Estimation of parameter values is achieved by maximising the log-likelihood function using the Berndt, Hall, Hall and Hausman (1974), BHHH, algorithm.

5.6 Description of the Data

In order to test the EHTS, we need comparable spot and time-charter rates¹⁶, i.e. series with the same units of measurement (preferably in earnings per day or month)¹⁷. Such data are constructed and reported by Clarkson Research Studies for three different size dry bulk carriers. Monthly one-year and three-year time-charter rates (\$/day) are available from January 1977. However, monthly spot rates (voyage charter rates converted to time-charter equivalents, TCE^{18,19}), on earnings per day basis, are only compiled and reported since January 1990. Two problems may arise when using this common shorter period (post January 1990) to test the defined hypothesis. First degrees of freedom are lost, thereby reducing the power of the tests²⁰. Second, period specific biases may arise when testing the null over a short period covering only part of the shipping cycle. This may result in wrong conclusions being drawn on the validity of the theory. However, monthly spot rate indices on a trip-charter basis for the three size vessels are available from the Institute of Shipping Economics and Logistics (ISL), Bremen, since January 1980. Comparison of the ISL trip-charter indices and Clarksons, voyage rates over the common period, post 1990, reveals that the series are very-very close²¹. Thus, the Clarksons' series are used to re-scale the ISL spot series in order to produce a longer data set²². In this way, data for all variables of interest are available from January 1980 to August 1997 providing a reasonable sample size of 212 observations.

¹⁶ Spot and time-charter rates should have the same units of measurement, otherwise the spread between the two rates will represent the difference in units of measurement instead of the operational premium of one market over the other.

¹⁷ Earnings per day (\$/day) are preferred to voyage rates (\$/ton), since the former excludes voyage costs and can be regarded as a true representative of the return on shipowners' investment and operational activities.

¹⁸ TCE of the spot rates are defined as the revenues net of voyage costs (on earnings per day basis) from spot market operations. Therefore, if the vessel specifications, route, cargo (tons), bunker prices, port charges and canal dues are known, the time-charter equivalents of the spot rates can be calculated using the revenue function $TCE = ((FR * W) - VC) / N$, where FR , W , VC are the spot rate (in \$/ton), the volume of cargo (in tons) and voyage costs (in \$), respectively. N is the number of days from the start to the end of the contract. The voyage costs can be calculated as $VC = (Co * N * BP) + Cd + Pc$, where, Co is the vessel's daily fuel consumption and BP is the price of bunkers in that particular route. Cd and Pc are the canal dues and port charges incurred during the voyage, respectively. Therefore, each spot contract can be converted to a time-charter equivalent. Once all the time-charter equivalents are obtained, they are grouped by vessel size and averaged to produce a monthly series, for each size vessel (dwt).

¹⁹ Stranden (1984) also uses time-charter equivalents of the spot rates in her study. She estimates time-charter equivalents directly using voyage and vessel particulars. In her calculations, she also takes into account unemployment possibilities and ballast legs.

²⁰ For example, a perfect foresight spread test for 3 years time-charter rates will reduce the number of observations by 36 and leave $(92-36=56)$ 56 observations for estimation.

²¹ The correlation coefficients between ISL tramp trip-charter indices and TCE of spot rate series from Clarkson Research Studies are 91%, 90% and 94% for handysize, panamax and capesize, respectively.

²² This is, basically, a re-scaling of the ISL index into \$/day. However, the effect of this, effectively using trip-charters to represent the spot market, is the elimination of the effect of voyage cost fluctuations in trading in spot versus time-charter markets.

Figure 5.1: Spot, 1-year and 3-year TC earnings for handysize vessels

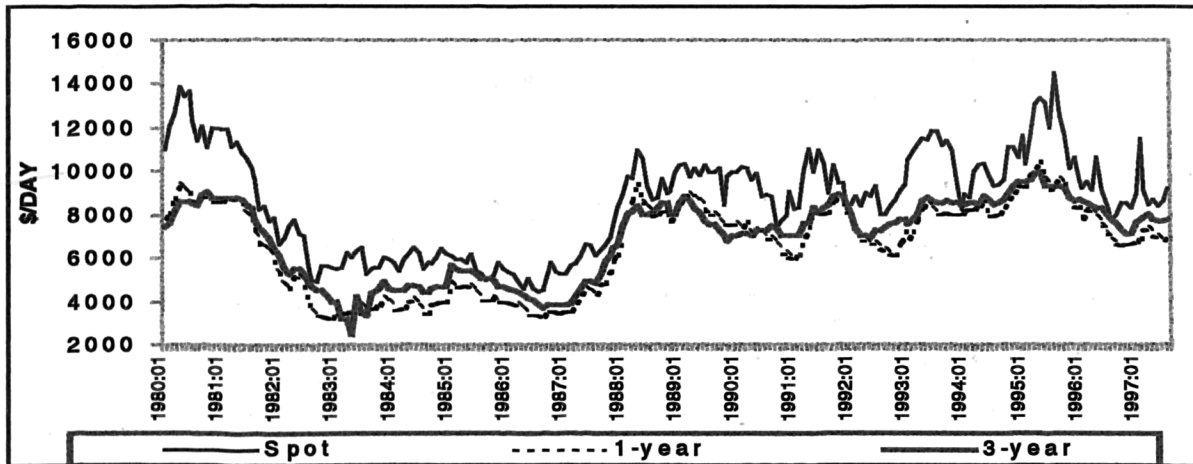


Figure 5.2: Spot, 1-year and 3-year TC earnings for panamax vessels

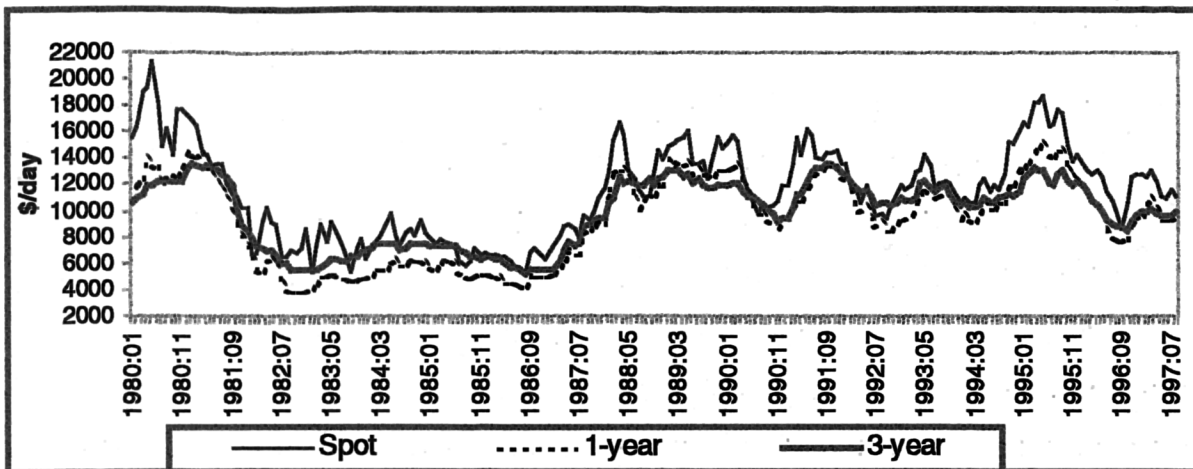
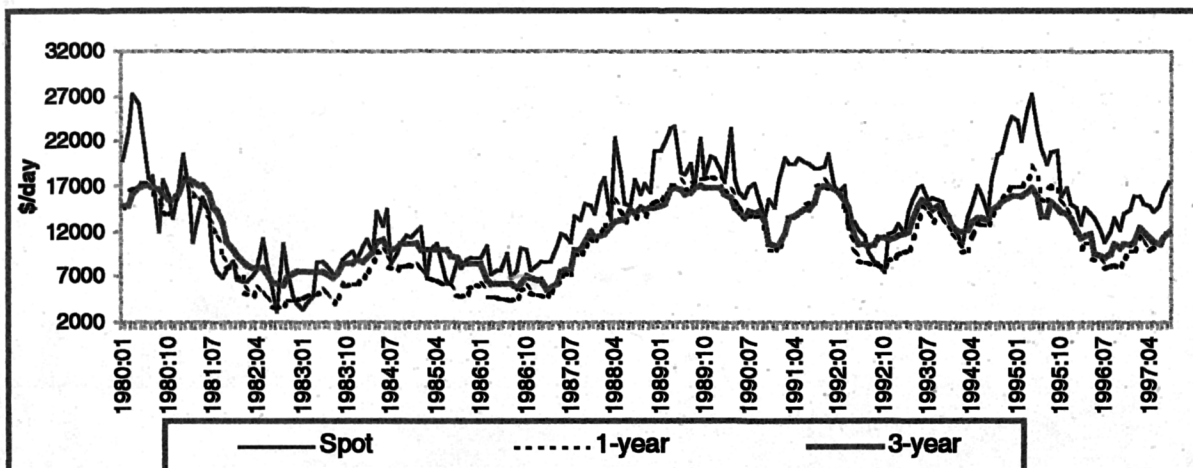


Figure 5.3: Spot, 1-year and 3-year TC earnings for capesize vessels



Figures 5.1 to 5.3 plot the earnings per day (\$/day) for spot, 1-year and 3-year time-charter rates for each vessel size. It can be seen that for each sector, earnings from these types of contracts move together in the long run, while, their short run dynamics are different. Summary statistics of the variables (in \$000s) are shown in Table 5.1. As expected, the mean values of earnings per day are higher for larger vessels, while time-charter earnings seem to be lower than spot earnings. The latter may be interpreted as a sign of existence of negative premium in the period market (see Zannetos 1966). A comparison between sample standard deviations (or variances) of spot and time-charter earnings reveals that earnings for larger vessels fluctuate more than the smaller ones, both in spot and time charter markets. Insignificant coefficients of skewness across series indicate that the distributions of these series are symmetric, the only exception being 3-year time-charter earnings in the handy market. The centralised coefficients of kurtosis indicate negative excess kurtosis for all series except for panamax and handysize spot earnings. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests for the log of each variable, its first difference and the spreads²³ are in Table 5.2. Results indicate that levels of log spot and time-charter earnings are non-stationary, I(1) variables²⁴. All the spread series are found to be stationary, I(0), indicating a possible cointegration relationship between spot and time-charter rates.

Table 5.1: Descriptive Statistics of Log-Earnings in the Dry Bulk Freight Market
Figures are in \$000s

	Handysize			Panamax			Capesize		
	Spot	1-year	3-year	Spot	1-year	3-year	Spot	1-year	3-year
Mean	8.585 [0.000]	6.544 [0.000]	6.915 [0.000]	11.469 [0.000]	9.357 [0.000]	9.849 [0.000]	13.964 [0.000]	10.940 [0.000]	11.975 [0.000]
S.D.	2.349	2.015	1.082	3.502	3.239	2.553	5.186	4.337	3.367
Variance	5.521	4.062	3.247	12.266	10.492	6.516	26.898	18.808	11.336
Skewnes	0.063 [0.710]	-0.315 [0.063]	-0.503 [0.003]	0.185 [0.275]	-0.181 [0.284]	-0.377 [0.026]	0.234 [0.167]	0.002 [0.988]	-0.110 [0.514]
Kurtosis	0.870 [0.011]	-1.303 [0.000]	-1.108 [0.001]	0.719 [0.036]	-1.289 [0.001]	-1.244 [0.005]	-0.536 [0.117]	-1.290 [0.004]	-1.148 [0.001]

Sample: January 1980 to August 1997.

Figures in [] are significance levels. Coefficients of kurtosis are centralised (Ku-3).

²³ Note that $S_t^{(n,1)} = TC_t^n - FR_t$, where $n=12, 36$ months.

²⁴ Capesize spot earnings seem to be stationary according to the result of ADF test. However, results of seasonal unit root tests of Beaulieu and Miron (1993), which is more appropriate as we are dealing with monthly data indicate that all series, including capesize earnings, are I(1) at zero frequency with no seasonal unit roots at any other frequency.

Table 5.2: Unit root tests for levels and first differences of variables

	Variables levels				First Differences			
	ADF test		PP test		ADF test		PP test	
	LAGS	STAT	LAGS	STAT	LAGS	STAT	LAGS	STAT
Handysize								
Spot earnings (FRH)	1 ^b	-2.28	1 ^b	-2.30	0 ^c	-16.47***	0 ^c	-16.47***
1- year time-charter (TCH1)	1 ^b	-1.85	1 ^b	-1.44	4 ^c	-4.67***	4 ^c	-9.57***
3- year time-charter (TCH3)	1 ^b	-1.53	1 ^b	-1.20	4 ^c	-4.42***	4 ^c	-9.94***
1- year spread (TCH1 - FRH)	1 ^b	-5.06***	1 ^b	-6.10***				
3- year spread (TCH3 - FRH)	0 ^b	-5.31***	0 ^b	-5.31***				
Panamax								
Spot earnings (FRP)	4 ^b	-2.98*	4 ^b	-2.59	0 ^c	-14.27***	0 ^c	-14.27***
1- year time-charter (TCP1)	1 ^b	-2.02	1 ^b	-1.59	0 ^c	-10.40***	0 ^c	-10.40***
3- year time-charter (TCP3)	4 ^b	-2.73	4 ^b	-1.76	3 ^c	-4.58***	0 ^c	-9.78***
1- year spread (TCP1 - FRP)	0 ^b	-6.77**	0 ^b	-6.77***				
3- year spread (TCP3 - FRP)	4 ^b	-5.34***	4 ^b	-4.72***				
Capesize								
Spot earnings (FRC)	4 ^b	-2.88*	4 ^b	-3.07**	2 ^c	-13.51***	2 ^c	-17.79***
1- year time-charter (TCC1)	1 ^b	-2.50	1 ^b	-1.83	0 ^c	-8.80***	0 ^c	-8.80***
3- year time-charter (TCC3)	1 ^b	-2.44	1 ^b	-1.92	0 ^c	-9.56***	0 ^c	-9.56***
1- year spread (TCC1 - FRC)	1 ^b	-5.76***	1 ^b	-7.44***				
3- year spread (TCC3 - FRC)	1 ^b	-4.44***	1 ^b	-5.25***				

- Sample: January 1980 to August 1997.
- The maximum lag length in each test is chosen to eliminate the residual serial correlation using LM test. SBIC is also considered when determining the optimum lag length.
- The window for the Phillips and Perron nonparametric correction is chosen by the order of the residual autocorrelation as determined by the LM statistics in the ADF test (see, Harris 1996, p. 33).
- Superscripts a, b and c indicate that the unit root test includes both constant and trend (equation (3.4^a), constant and no trend (equation (3.4), and no deterministic term (equation (3.3^a), respectively.
- For tests with no deterministic term, 1%, 5% and 10% critical values are -2.58, -1.94 and -1.62, respectively. For tests with a constant deterministic component, 1%, 5% and 10% critical values are -3.45, -2.88 and -2.57, respectively. For tests with a constant and a trend, 1%, 5% and 10% critical values are -3.99, -3.43 and -3.13, respectively.
- The symbols ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

5.7 Estimation Results

This section presents the results from different testing procedures for the EHTS outlined in section 5.4. The constant discount rate is set to 10%, which is the mean of the 12-month LIBOR over the sample period²⁵.

5.7.1 Perfect foresight spread tests

To avoid the associated problems of non-consistency and lack of efficiency of the parameter estimates arising in the presence of MA(p) error terms in equation (5.8), Hansen's (1982) GMM is used for estimating this equation (see Appendix C for more details). The null hypothesis of the EHTS plus RE amounts to testing $\alpha=0$, $\beta=1$, $\gamma=0$. Results for 1-year and 3-year time-charter rates are in Table 5.3. In each case, lagged values of the spread and changes in spot rates are used as supplementary information. The null hypothesis of $\alpha=0$, $\beta=1$, $\gamma=0$ is rejected in all six cases at the 5% significance level. The joint test for $\alpha=0$, $\beta=1$ also rejects H_0 in all cases. The slope coefficients, β , vary from 0.432 to 0.886 and Wald tests reject the hypothesis that $\beta=1$ in every case, except the 3-year time-charter rates for handysize and panamax markets. The constant term, α , seems to be significant in four out of six regression equations; these are the equations for handysize and panamax 1-year and 3-year time-charter rates. The null of $\gamma=0$ for the supplementary information set could not be rejected at the 5% level for all combinations of spot and 1-year contracts. The null of $\gamma=0$ is rejected at the 5% level for combinations of spot and 3-year time-charter contracts for panamax and handysize markets. The results from the PFS tests reject the joint hypothesis of the EHTS and RE of the term structure in time-charter formation.

Plots of perfect foresight and actual spreads between spot and 1-year, and spot and 3-year, earnings in the handysize market are shown in figures 5.4 and 5.7, respectively. Similar graphs for panamax markets are produced in figures 5.5 and 5.8 and for capesize markets in figures 5.6 and 5.9. Consideration of these graphs reveals that the actual spread series follow the PFS series closely in some periods but diverge in others. It seems that the series diverge during market swings (upturns or downturns), for example, 1980 to 1982, and move together

²⁵ However, simulations have shown that results are not sensitive to different discount rates such as 5% and 15%.

during less volatile periods, for example, 1982 to 1986. This may be interpreted as a result of the mismatch between expectations and realised values when the market is going towards expansions or recessions. Freight rate volatilities during market swings are much higher than when the market is at its peak or trough (see, Kavussanos 1996a) and this may be priced by agents as we find later when we estimate the EGARCH-M models.

Table 5.3: Perfect foresight spread test

Sample period; 1980:1 to 1996:8 for 1-year rates and 1980:1 to 1994:8 for 3-year rates

Equation (5.8)							
$S_t^{(n,m)} = \alpha + \beta S_t^{(n,m)} + \gamma \Lambda_t + \eta_t \quad ; \quad m=1, n=12,36$							
	<i>Coefficients</i>		<i>Wald test</i>				
	α	β	$H_0: \alpha=0$ $\chi^2(1)$	$H_0: \beta=1$ $\chi^2(1)$	$H_0: \gamma=0$ $\chi^2(4)$	$H_0: \alpha=0, \beta=1$ $\chi^2(2)$	$H_0: \alpha=0, \beta=1, \gamma=0$ $\chi^2(6)$
Handysize (spot and 1-year)	1.331 (0.312) [0.000]	0.699 (0.140) [0.000]	19.35 [0.000]	8.61 [0.003]	3.37 [0.497]	60.16 [0.000]	148.40 [0.000]
Handysize (spot and 3-year)	2.390 (0.459) [0.000]	0.819 (0.141) [0.000]	27.07 [0.000]	1.65 [0.198]	9.69 [0.046]	47.58 [0.000]	54.88 [0.000]
Panamax (spot and 1-year)	1.495 (0.634) [0.018]	0.614 (0.128) [0.000]	5.55 [0.018]	9.04 [0.003]	1.18 [0.882]	21.43 [0.000]	98.96 [0.000]
Panamax (spot and 3-year)	2.105 (0.566) [0.000]	0.886 (0.116) [0.000]	13.85 [0.000]	0.96 [0.326]	14.56 [0.006]	18.50 [0.000]	20.56 [0.006]
Capesize (spot and 1-year)	0.874 (1.321) [0.508]	0.437 (0.144) [0.002]	0.438 [0.508]	15.35 [0.000]	4.35 [0.360]	34.72 [0.000]	61.07 [0.000]
Capesize (spot and 3-year)	1.267 (1.063) [0.233]	0.432 (0.175) [0.013]	1.422 [0.233]	10.58 [0.001]	3.24 [0.519]	21.73 [0.000]	24.14 [0.000]

- The regression equation of the actual spread, $S_t^{(n,1)} = TC_t^n - FR_t$, $n=12,36$, on the PFS (constructed through (5.7)), for each case is estimated by GMM and a correction for serial correlation and/or heteroscedasticity is applied where appropriate.
- Figures reported in (.) and [.] are standard errors and p-values, respectively.
- Λ_t is the supplementary information set, which includes 2 lags of ΔFR_t and $S_t^{(n,1)}$, $n=12,36$, in each equation.

Figure 5.4: Perfect foresight and actual spread series, the case of spot and 1-year time-charter rates for handysize vessels

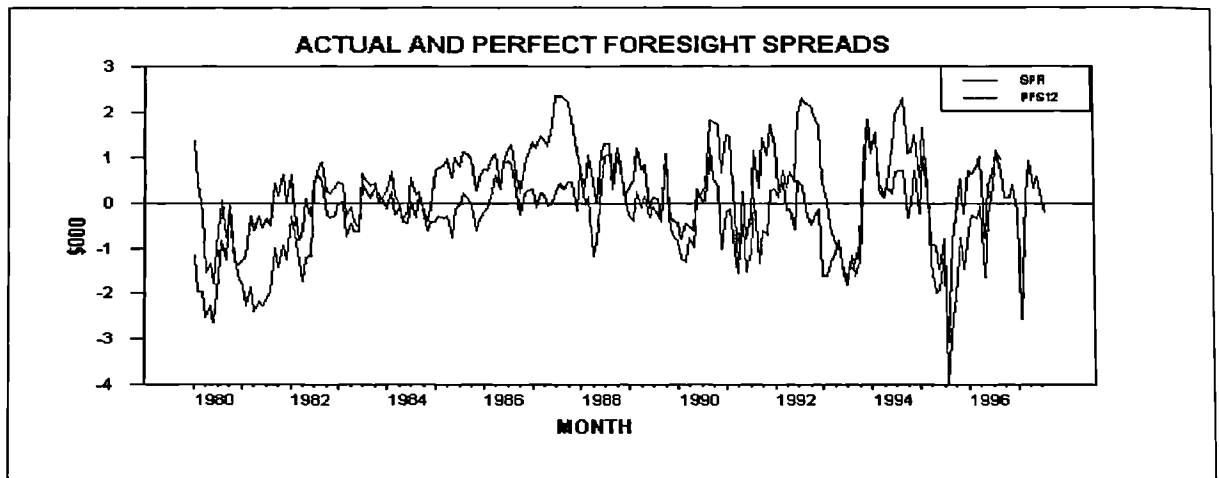


Figure 5.5: Perfect foresight and actual spread series, the case of spot and 1-year time-charter rates for panamax vessels

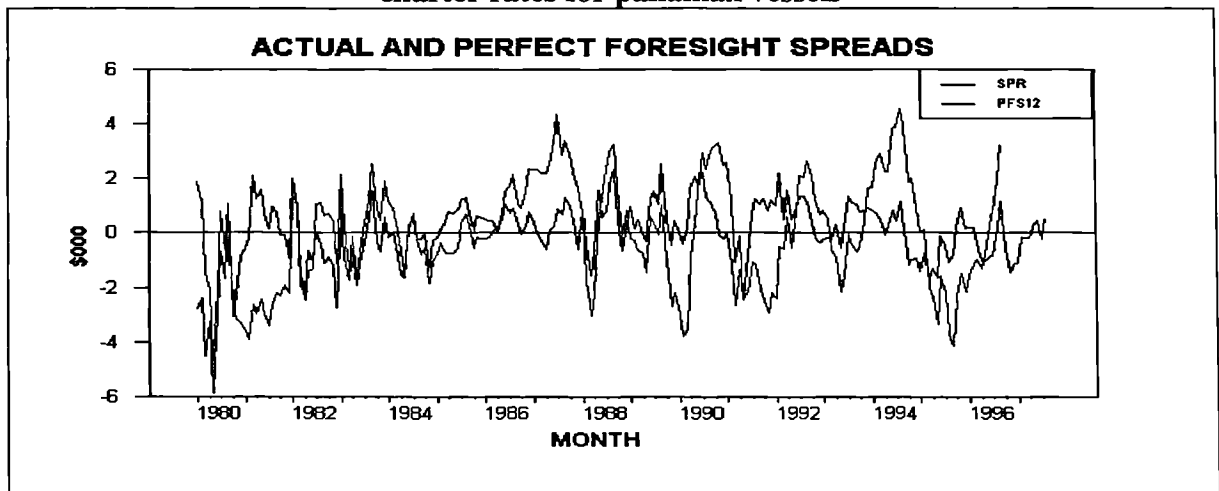


Figure 5.6: Perfect foresight and actual spread series, the case of spot and 1-year time-charter rates for capesize vessels

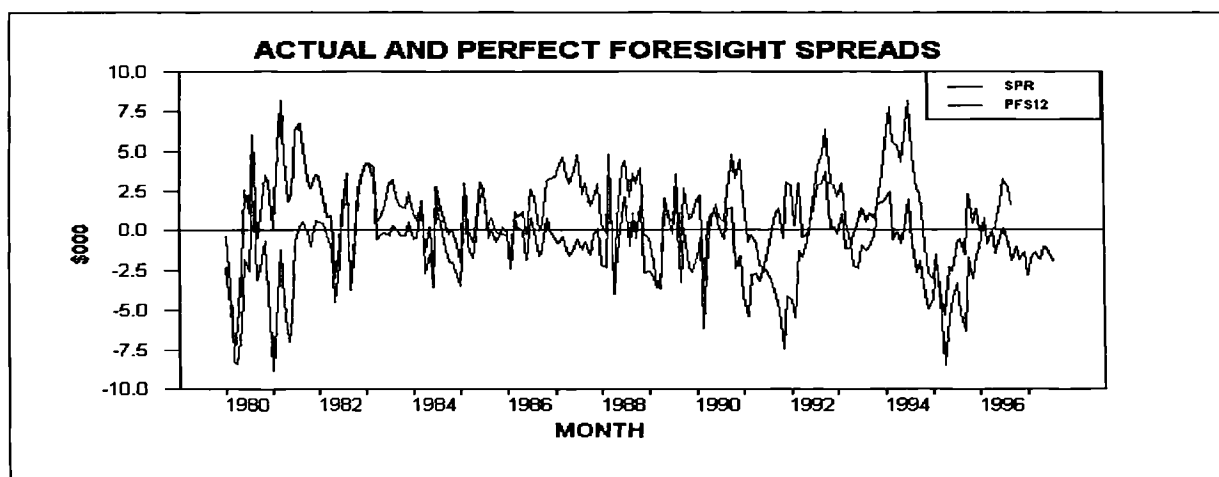


Figure 5.7: Perfect foresight and actual spread series, the case of spot and 3-year time-charter rates for handysize vessels

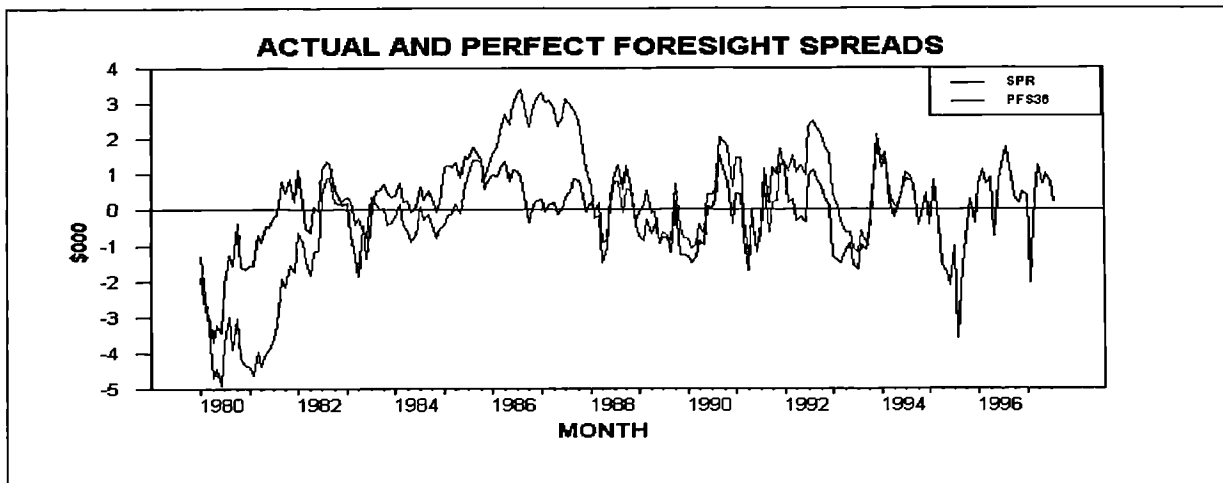


Figure 5.8: Perfect foresight and actual spread series, the case of spot and 3-year time-charter rates for panamax vessels

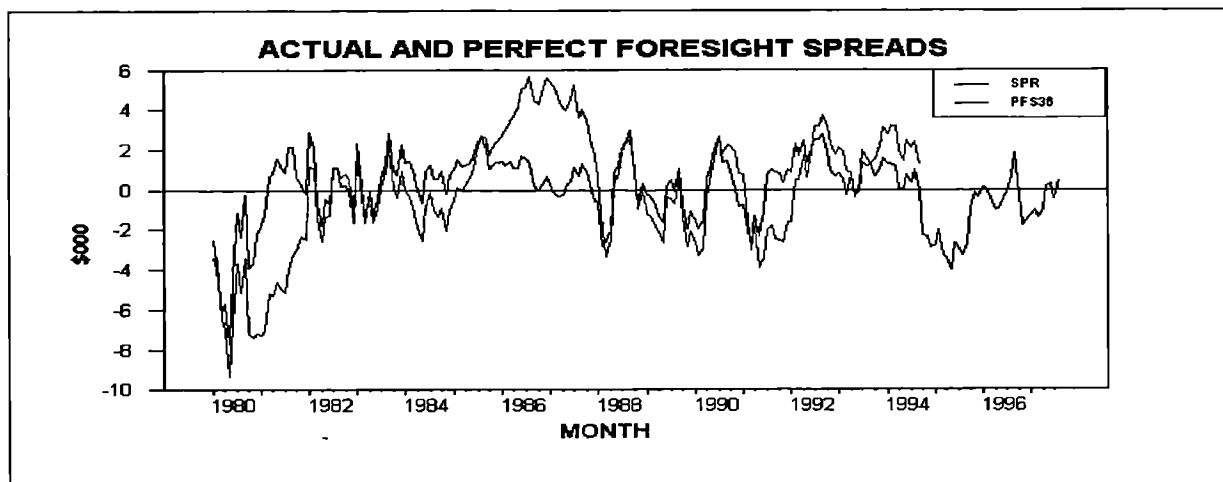
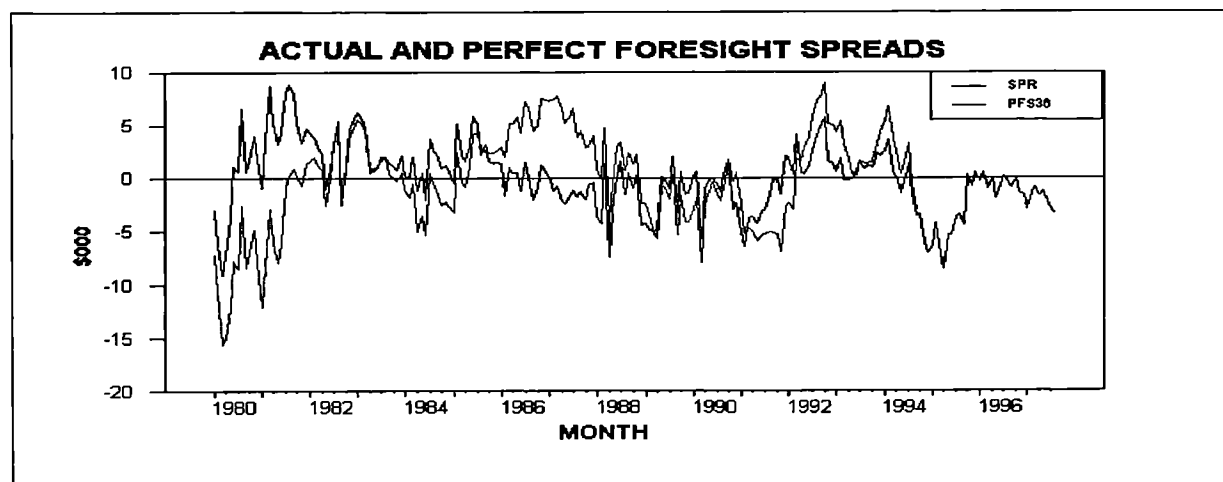


Figure 5.9: Perfect foresight and actual spread series, the case of spot and 3-year time-charter rates capesize vessels



To obtain further insight into the validity of the EHTS over time, we estimate the *PFS* model (equation (5.8)) using a rolling regression method with a 3-year rolling window. As an example, figures 5.10 and 5.11 show the estimated coefficients of β and its two standard error bands for 1-year and 3-year time-charter contracts in the handysize market. In the case of 1-year time-charter contracts, the estimates of β are not close to one most of the time, therefore rejecting the EHTS over the sample period. The results for 3-year rates are somewhat different; the estimates of β seem to move along the line drawn for unity more often, suggesting that the validity of the hypothesis may depend on the sample period examined. Similar results are obtained for the other size categories of bulk carriers. This points to the possibility that the one to one relationship between the actual and perfect foresight spread, required by the EHTS, may be time dependent.

Figure 5.10: Rolling estimates of β in the perfect foresight spread test (equation (5.8)), the case of spot and 1-year time-charter rates

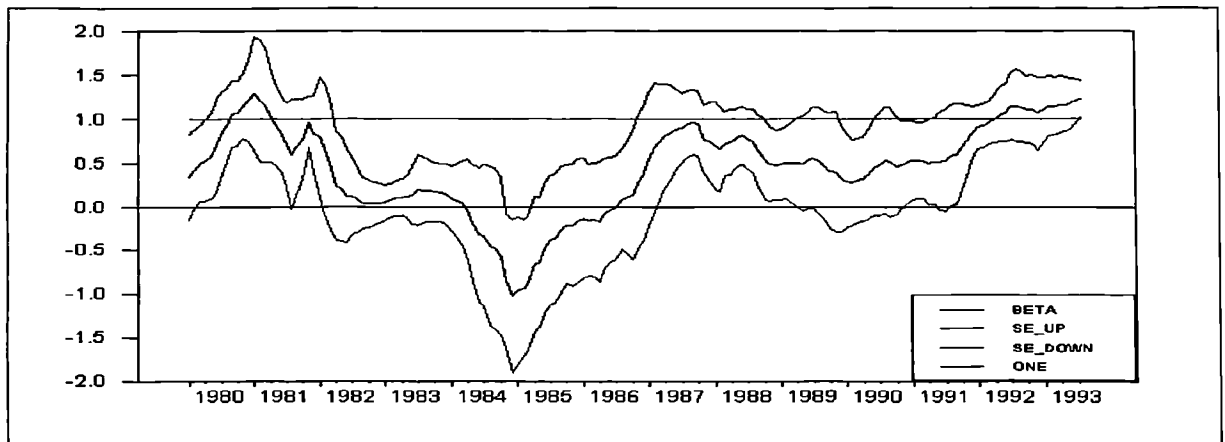
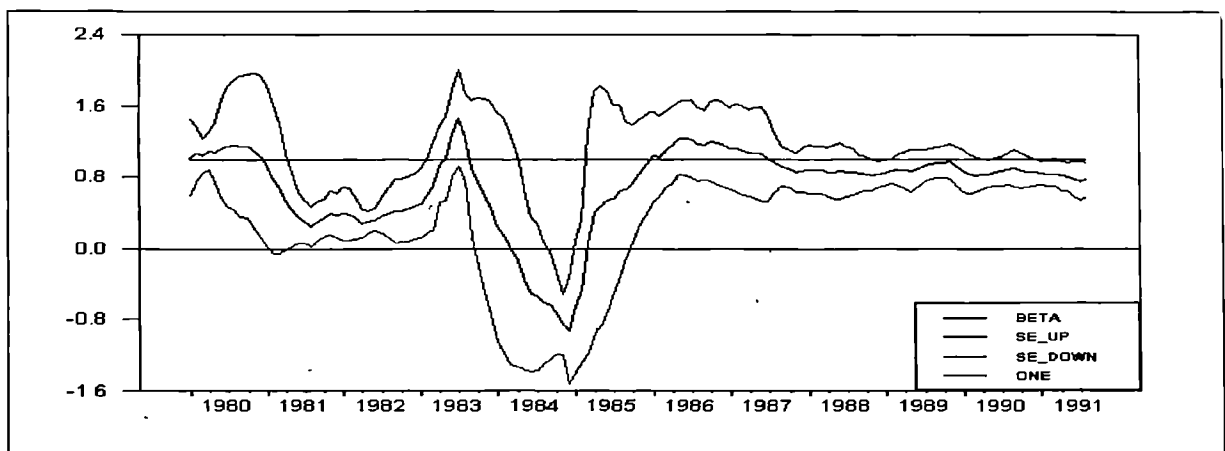


Figure 5.11: Rolling estimates of β in the perfect foresight spread test (equation (5.8)), the case of spot and 3-year time-charter rates



5.7.2 Johansen Cointegration tests

The existence of a long run cointegrating relationship between spot and time-charter earnings across each size dry bulk carrier is investigated next using the Johansen (1988) cointegration method. Results are in Table 5.4. The reported lag length of the six VECM models of equation (5.9) are determined alongside the deterministic parts (constant and trend) using AIC and SBIC criteria. In all pair-wise cointegrating tests, λ_{\max} and λ_{trace} test statistics reject the null hypothesis of there being no cointegrating vector, against the alternative of there being one cointegrating vector.

Table 5.4: Johansen Cointegration Tests

Sample period, 1980:1 to 1997:8

Equation (5.9)

$$\Delta TC_t^n = \gamma_{1,0} + \sum_{i=1}^q \gamma_{1,i} \Delta TC_{t-i}^n + \sum_{i=1}^q \lambda_{1,i} \Delta FR_{t-i} + \delta_1 (TC_{t-1}^n + \beta_0 + \beta FR_{t-1}) + \varepsilon_{1,t}$$

$$\Delta FR_t = \gamma_{2,0} + \sum_{i=1}^q \gamma_{2,i} \Delta TC_{t-i}^n + \sum_{i=1}^q \lambda_{2,i} \Delta FR_{t-i} + \delta_2 (TC_{t-1}^n + \beta_0 + \beta FR_{t-1}) + \varepsilon_{2,t}$$

$n=12,36$

Pairs Of Rates	Lag	Cointegration test				95% CV		Normalized Vector	LR test H_0 :		
		H_0	H_1	λ_{trace}	λ_{\max}	λ_{trace}	λ_{\max}		(1, 0, β)	(1, β_0 , -1)	(1, 0, -1)
Handysize (1-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	30.012 3.757	26.256 3.757	20.18 9.16	15.87 9.16	[1, 1453 ^a , -0.94 ^a]	6.761 [0.009]	0.760 [0.383]	22.242 [0.000]
Handysize (3-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	29.035 2.462	26.574 2.462	20.18 9.16	15.87 9.16	[1, 372.4 ^a , -0.86 ^a]	0.341 [0.559]	2.332 [0.127]	18.610 [0.000]
Panamax (1-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	41.764 4.999	37.610 4.154	20.18 9.16	15.87 9.16	[1, 2457 ^a , -1.03 ^a]	14.161 [0.000]	0.359 [0.549]	29.804 [0.000]
Panamax (3-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	35.282 4.126	31.152 4.126	20.18 9.16	15.87 9.16	[1, -152.7, -0.85 ^a]	0.027 [0.870]	2.325 [0.127]	16.253 [0.000]
Capesize (1-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	56.335 8.224	48.111 8.224	20.18 9.16	15.87 9.16	[1, 2433 ^a , -0.96 ^a]	8.660 [0.003]	0.395 [0.530]	34.831 [0.000]
Capesize (3-year / spot)	2	$r=0$ $r \leq 1$	$r \geq 1$ $r=2$	36.938 8.176	28.764 8.176	20.18 9.16	15.87 9.16	[1, -945.4, -0.77 ^a]	0.319 [0.572]	2.228 [0.136]	11.555 [0.003]

- Johansen's reduced rank cointegration tests for each pair are estimated using a model with a constant in the cointegrating vector and no trend as selected by SBIC, (see chapter 3)
- The appropriate number of lags in each case is chosen so as to minimise SBIC.
- $\lambda_{\text{trace}} = -T \sum_{i=r+1}^n \log(1 - \hat{\lambda}_i)$ and $\lambda_{\max} = -T \log(1 - \hat{\lambda}_{r+1})$ are tests for determining the number of cointegrating vectors, r , in a cointegrating system which consists of n variables.
- The Likelihood Ratio, LR tests for testing restrictions on the cointegration relationships is calculated using $-T \ln[(1 - \hat{\lambda}_1^*) / (1 - \hat{\lambda}_1)] \sim \chi^2(r)$, where $\hat{\lambda}_1^*$ and $\hat{\lambda}_1$ are the largest eigenvalues of the restricted and the unrestricted model, respectively, and r is the number of restrictions.
- The above LR test for [1, 0, β] and [1, β_0 , -1] are distributed as $\chi^2(1)$, with 5% critical value equal to 3.84. The LR test for [1, 0, -1] is distributed as $\chi^2(2)$, with 5% critical value equal to 5.99.
- Superscript "a" on elements of cointegrating vectors means significant at 5% level.

Once the existence of this long run relationship is established, the restrictions derived in section 5.4.2 are imposed on the cointegration vector to test the PEH and the EHTS. LR test statistics in the last column of Table 5.4 testing the $[1, 0, -1]$ EHTS restriction on the cointegrating vector, reject the restrictions in all cases. To investigate whether failure of the EHTS is due to failure of $\beta=-1$, the restriction $[1, \beta_0, -1]$ is tested in the second column from the right of Table 5.4 (β_0 indicates that the constant term is not restricted, i.e. testing whether $\beta=-1$). This restriction is not rejected any case. It seems then that failure of the EHTS is due to the joint rejection of $\beta_0=0$ and $\beta=-1$ but not of the individual coefficient of slope, β . The third column from the right considers whether β_0 is responsible for the rejection of the joint hypothesis $\beta_0=0, \beta=-1$, by testing the restriction $[1, 0, \beta]$; that is, that $\beta_0=0$. This restriction is not rejected for all spot and 3-year time-charter combinations but is rejected for the spot and 1-year combinations.

5.7.3 VAR model results

Following Campbell and Shiller (1987), a bivariate VAR model is defined in order to utilise the information in the spread series for forecasting future changes in spot earnings needed in equation (5.10). The general VAR model of equation (5.10) is estimated for 1-year and 3-year rates for three different sectors of the market, using GMM, while standard errors of the estimated parameters are corrected for serial correlation and/or heteroscedasticity using the Newey-West (1987) method. The lag length in each model is selected using the SBIC. Results are in Table 5.5. Wald type Granger causality tests in the first and second rows of the table indicate significant causality from the spread, $S_t^{(n,m)}$, to ΔFR_t in all cases. There seem to be no feedback effects from ΔFR_t on spread, the exceptions being cases of spot and 1-year earnings in the panamax and handysize markets. Such a pattern in Granger-causality tests implies that the spread between spot and time-charter contracts contains information for predicting future changes in spot market earnings and justifies use of the VAR model.

Table 5.5: Granger-Causality, Wald and Variance Ratio tests test on VAR model

Sample period: 1980:1 to 1997:8

Equation (5.10)

$$S_t^{(n,m)} = \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(n,m)} + \sum_{i=1}^p \mu_{2,i} \Delta FR_{t-i} + \varepsilon_{1,t} \quad m=1, n=12,36$$

$$\Delta FR_t = \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(n,m)} + \sum_{i=1}^p \varphi_{2,i} \Delta FR_{t-i} + \varepsilon_{2,t}$$

	Handysize		Panamax		Capesize	
	(1-year/spot)	(3-year/spot)	(1-year/spot)	(3-year/spot)	(1-year/spot)	(3-year/spot)
$\mu_{1,1}$	0.829 (0.039)	0.732 (0.046)	0.653 (0.117)	0.555 (0.207)	0.375 (0.148)	0.449 (0.224)
$\mu_{1,2}$			0.072 (0.088)	-0.123 (0.130)	-0.140 (0.107)	-0.156 (0.185)
$\mu_{2,1}$	0.193 (0.046)	-0.024 (0.092)	0.206 (0.117)	0.163 (0.193)	0.315 (0.140)	0.314 (0.207)
$\mu_{2,2}$			0.200 (0.073)	0.87 (0.064)	0.159 (0.088)	0.153 (0.083)
$\varphi_{1,1}$	0.124 (0.047)	0.132 (0.054)	0.510 (0.192)	0.706 (0.229)	0.924 (0.175)	0.816 (0.246)
$\varphi_{1,2}$			0.266 (0.110)	0.472 (0.172)	0.527 (0.153)	0.498 (0.205)
$\varphi_{2,1}$	-0.021 (0.077)	-0.012 (0.083)	-0.409 (0.180)	-0.468 (0.207)	-0.731 (0.166)	-0.644 (0.216)
$\varphi_{2,2}$			-0.189 (0.090)	-0.074 (0.091)	-0.234 (0.124)	-0.196 (0.112)
Granger-Causality						
S_t on ΔFR_t ($\varphi_{1,i}=0$) p-value	7.096 [0.008]	5.982 [0.014]	7.107 [0.029]	14.324 [0.001]	27.83 [0.000]	11.309 [0.002]
ΔFR_t on S_t ($\mu_{2,i}=0$) p-value	17.880 [0.000]	0.068 [0.794]	7.884 [0.019]	2.245 [0.325]	4.227 [0.121]	3.512 [0.173]
Wald test						
Wald Statistics	$\chi^2(2)$ 11.485	$\chi^2(2)$ 3.869	$\chi^2(4)$ 13.971	$\chi^2(4)$ 43.409	$\chi^2(4)$ 48.157	$\chi^2(4)$ 38.905
DF	2	2	4	4	4	4
p-value	[0.003]	[0.144]	[0.030]	[0.000]	[0.000]	[0.000]
VAR(S)/VAR(S*)						
Observed	1.977	2.526	1.688	1.306	1.666	1.674
90%CI	1.572 2.466	1.838 3.475	1.041 2.061	1.031 1.695	1.031 1.991	1.174 2.63
VAR Lag						
\bar{R}^2 S_t equation	1 0.666	1 0.573	2 0.621	2 0.511	2 0.381	2 0.503
\bar{R}^2 ΔFR_t equation	0.033	0.042	0.077	0.103	0.198	0.148
Q(12) S_t equation	12.58	13.15	18.62	24.14	12.63	18.45
p-value	[0.400]	[0.358]	[0.098]	[0.020]	[0.396]	[0.102]
Q(12) ΔFR_t equation	8.09	8.87	17.969	16.97	15.65	22.31
p-value	[0.778]	[0.714]	[0.125]	[0.151]	[0.110]	[0.034]

- The figures in [.] are probability values.
- VAR models estimated by non-linear GMM. The standard errors are corrected for serial correlation and/or heteroscedasticity using the Newey-West method (see chapter 3, section 3.5).
- The lag length for each model is chosen in order to minimise the SBIC.
- Granger-Causality tests are Wald statistics distributed as $\chi^2(r)$, where r is the number of the restricted parameters. This is equal to the number of lags, p , included in the model.
- Wald tests, testing the EHTS are, $e1' = \theta e2'(I - \delta A)^{-1}(I - \delta^n A^n) - \theta \delta^n e2'(I - A)^{-1}(I - A^n)$ for $m=1, n=12$ and 36 (see, equation (5.16)). They have chi-square distributions with degrees of freedom equal to the number of restrictions in each case; that is, 2 for handysize 1-year and 3-year rates equations and 4 for panamax and capesize 1year and 3-year rates equations.
- VAR(S)/VAR(S*) is variance ratio test for actual and theoretical spread series, where the null and alternative are $VAR(S)/VAR(S*) \leq 1$ and $VAR(S)/VAR(S*) > 1$, respectively.
- 90% confidence intervals are bootstrap intervals for variance ratio test. When the interval includes 1 the EH is not rejected.
- Q(12) is the Ljung-Box tests for 12th order serial correlation in the residuals, 5% critical values for these statistics are 3.84 and 21.03, respectively.

The interpretation of this causal relationship is that when the spread widens, either earnings from spot operation or both earnings from spot and period market operations will move in the next period in a direction which reduces this divergence and brings back the system to equilibrium. This is expected since earnings from spot and time-charter operations are found to be cointegrated and move together in the long-run.

Table 5.5 also contains Wald test results from imposing the non-linear restrictions implied by (5.16) the EHTS on the VAR model of equation (5.10). The EHTS is rejected in all cases, with the exception of the spot and 3-year time-charter rate combination in the handysize market.

5.7.4 Variance Ratio test results

Results from variance ratio tests are also in Table 5.5. Point estimates of the variance of the actual spread over the variance of the theoretical spread are shown in each case. Figures below the point estimates of the VRs are 90% bootstrap confidence interval bounds. It can be seen that the VRs are far from unity in all cases. Thus, overall actual spread series show excess volatility over the theoretical spread series, a result which is not consistent with the EH of the term structure.

5.7.5 The time-varying risk premia model

Overall, the results of different tests for the EHTS reject the validity of the hypothesis. Such rejection can be due to the existence of a risk premium, which may also be time varying. In this section, we relax the assumption of constant risk premia in the EHTS and investigate the possibility that they are time-varying through the EGARCH-M model²⁶ of equation (5.18). To ensure convergence in maximising log-likelihood functions, each model is estimated using a wide range of initial values with a tight convergence criterion.

²⁶ GARCH models have also been tried but EGARCH models are preferred since they capture the asymmetric response of the conditional variance to shocks with different sign and magnitude.

Results are in Tables 5.6 and 5.7, for 1-year and 3-year time-charter rates, respectively. The order of the MA terms is set to 10, since it is found to be enough to capture the serial correlation. Diagnostic tests confirm that all models are well specified and the sign and size bias tests do not indicate any asymmetric variance effects (see, Engle and Ng 1993b) in the selected models.

For the 3-year capesize and 1-year and 3-year handysize models failure of normality and its consequences on the efficiency of the parameters is remedied by using the Bollerslev and Wooldridge (1992) corrected standard errors. The adjusted R-square values vary from 96% for 3-year panamax model to 84% for 3-year handysize model, which indicate a good fit for each model.

Significant coefficients of lagged standardised error terms, c_i , in all variance models suggest that negative forecast errors (shocks) have greater impact than positive shocks on the conditional variance of excess earnings. This asymmetric behaviour of market volatilities with respect to shocks may reflect the uneasiness of the agents involved in the industry regarding the possibility of market downturns. Also significant size effects (measured by d_i) indicate that larger (above average) shocks have greater impact on volatilities compared to smaller shocks. This is not the case for 3-year excess returns in the case of panamax vessels. The earlier argument regarding the sensitivity of agents to possible market downturns is also reflected partly in their significant asymmetric response to the magnitude of the shock; that is, larger shocks increase the volatility relatively more than smaller shocks.

In the case of 1-year time-charter and spot earnings, negative and significant parameters of the standard deviation terms in the mean equation for all size vessels indicate the existence of negative time-varying risk premia. The coefficients of time-varying risk premium are -8.203, -7.449 and -4.061 for capesize, panamax and handysize, respectively. These coefficients can be interpreted as the elasticity of excess earnings with respect to the standard deviation of forecast errors. The same argument also holds for 3-year time-charter models. Negative and significant coefficients of lagged standard error terms of -10.16, -6.759 and -3.799 for capesize, panamax and handysize models, respectively, support the importance of risk in the relationship between spot and 3-year charter earnings in the respective markets. The decline (in absolute terms) in the coefficient of the standard deviation in the mean equation for smaller size vessels, for both 1-year and 3-year time-charter equations, indicates that the risk

premium is positively related to the size. That is, the larger the vessel, the greater the impact of conditional volatility on the difference between the earnings from spot and time charter markets. This is because owners operating larger vessels are more exposed to freight market uncertainty compared to those operating smaller vessels, and as a result require larger sums to compensate for the higher risks of trading in spot markets, see Kavussanos (1996a).

Table 5.6: EGARCH-M model of excess earnings of 12-month time-charter over spot operations

Equation (5.18)									
$exr_t = TC_t^{12} - \theta \sum_{i=0}^{11} (1 - \delta) \delta^i (FR_{t+i}) = \phi_0 + \phi_1 \sigma_t + \eta_t, \quad \eta_t = \varepsilon_t + \sum_{i=1}^{11} \zeta_i \varepsilon_{t+i}, \quad \varepsilon_t \sim \text{iid}(0, \sigma_t^2)$ $\sigma_t^2 = \exp(a_0 + \sum_{i=1}^p b_i \ln \sigma_{t-i}^2 + \sum_{i=1}^q c_i g_{1,t-i} + \sum_{i=1}^q d_i g_{2,t-i}), \quad g_{1,t} = (\varepsilon_t / \sigma_t), \quad g_{2,t} = [(\varepsilon_t / \sigma_t) - E(\varepsilon_t / \sigma_t)]$									
	HANDYSIZE			PANAMAX			CAPE SIZE		
ϕ_0	-0.065	(0.018)	[0.000]	0.252	(0.026)	[0.000]	0.314	(0.035)	[0.004]
ϕ_1	-4.061	(0.200)	[0.000]	-7.449	(0.094)	[0.000]	-8.203	(0.268)	[0.000]
ζ_1	0.919	(0.095)	[0.000]	0.820	(0.017)	[0.000]	0.852	(0.196)	[0.000]
ζ_2	0.851	(0.066)	[0.000]	0.843	(0.041)	[0.000]	0.880	(0.148)	[0.000]
ζ_3	0.652	(0.044)	[0.000]	0.745	(0.017)	[0.000]	0.715	(0.113)	[0.000]
ζ_4	0.561	(0.068)	[0.000]	0.680	(0.018)	[0.000]	0.674	(0.092)	[0.000]
ζ_5	0.603	(0.070)	[0.000]	0.493	(0.013)	[0.000]	0.568	(0.066)	[0.000]
ζ_6	0.499	(0.063)	[0.000]	0.372	(0.015)	[0.000]	0.578	(0.065)	[0.000]
ζ_7	0.285	(0.037)	[0.000]	0.272	(0.022)	[0.000]	0.658	(0.067)	[0.000]
ζ_8	0.173	(0.023)	[0.000]	0.198	(0.031)	[0.000]	0.694	(0.062)	[0.000]
ζ_9	-0.015	(0.032)	[0.629]	0.108	(0.034)	[0.002]	0.450	(0.053)	[0.000]
ζ_{10}	-0.005	(0.043)	[0.910]	0.042	(0.024)	[0.081]	0.199	(0.060)	[0.001]
a_0	-1.131	(0.266)	[0.000]	-1.116	(0.104)	[0.000]	-0.697	(0.032)	[0.000]
b_1	0.816	(0.044)	[0.000]	0.802	(0.020)	[0.000]	0.866	(0.006)	[0.000]
c_1	-0.160	(0.049)	[0.001]	-0.126	(0.005)	[0.000]	-0.109	(0.053)	[0.039]
d_1	0.098	(0.043)	[0.022]	0.064	(0.04)	[0.000]	0.058	(0.025)	[0.019]
\bar{R}^2	0.904			0.838			0.933		
Kurtosis	0.428	[0.235]		2.817	[0.000]		0.103	[0.774]	
Q(12)	18.74	[0.095]		10.46	[0.576]		11.20	[0.511]	
ARCH(12)	0.516	[0.726]		0.417	[0.430]		0.564	[0.868]	
J-B Normality	4.105	[0.128]		75.85	[0.000]		0.265	[0.875]	
SBIC	-835.03			-720.82			-658.77		
Sign Bias	-0.023	[0.981]		-0.073	[0.941]		-0.148	[0.882]	
Negative Size Bias	0.255	[0.891]		-0.220	[0.826]		-0.224	[0.822]	
Positive Size Bias	-0.084	[0.933]		-0.139	[0.889]		1.530	[0.128]	
Joint test	0.015	[0.997]		0.065	[0.977]		1.322	[0.268]	

- Sample period; 1980:1 to 1996:8
- Figures in (.) and [.] are standard errors and p-values, respectively.
- Coefficients of kurtosis are centralised (Ku-3).
- Q(12) is the Ljung-Box tests for 12th order serial correlation in the residuals, which has a $\chi^2(12)$ distribution.
- ARCH(12) is the F test for 12th order autoregressive conditional heteroscedasticity.
- J-B is the Jarque- Bera (1980) test for normality. The 5% critical value for this statistic is $\chi^2(2)=5.99$.
- The test statistic for the Engle and Ng (1993a) tests is the t-ratio of b in the regressions; $u_t^+ = a + b S_{t-1}^- \varepsilon_{t-1} + e_t$ (sign bias test); $u_t^- = a + b S_{t-1}^- \varepsilon_{t-1} + e_t$ (negative size bias test); $u_t^+ = a + b S_{t-1}^+ \varepsilon_{t-1} + e_t$ (positive size bias test) where u_t^2 are the squared standardised residuals, ε_t^2/h_t , S_{t-1}^- is a dummy variable taking the value of one when ε_{t-1} is negative and zero otherwise, and $S_{t-1}^+ = 1 - S_{t-1}^-$. The joint test is based on the regression $u_t^2 = a + b_1 S_{t-1}^- + b_2 S_{t-1}^- \varepsilon_{t-1} + b_3 S_{t-1}^+ \varepsilon_{t-1} + e_t$. The joint test $H_0: b_1 = b_2 = b_3 = 0$, is an F test with 95% critical value of 2.60.

Table 5.7: EGARCH-M model of excess earnings of 36-month time-charter over spot operations

Equation (5.18)

$$Exret_t = TC_t^{36} - \theta \sum_{i=0}^{35} (1-\delta)\delta^i FR_{t-i} = \phi_0 + \phi_1 \sigma_t + \eta_t, \quad \eta_t = \varepsilon_t + \sum_{i=1}^q \zeta_i \varepsilon_{t-i}, \quad \varepsilon_t \sim iid(0, \sigma_t^2)$$

$$\sigma_t^2 = \exp(a_0 + \sum_{i=1}^p b_i \ln \sigma_{t-i}^2 + \sum_{i=1}^q c_i g_{1,t-i} + \sum_{i=1}^q d_i g_{2,t-i})$$

$$g_{1,t} = (\varepsilon_t / \sigma_t), \quad g_{2,t} = [(\varepsilon_t / \sigma_t) - E(\varepsilon_t / \sigma_t)]$$

	HANDYSIZE			PANAMAX			CAPESIZE		
ϕ_0	-0.127	(0.018)	[0.001]	0.094	(0.021)	[0.001]	0.429	(0.072)	[0.000]
ϕ_1	-3.799	(0.386)	[0.000]	-6.759	(0.305)	[0.000]	-10.16	(0.993)	[0.000]
ζ_1	0.562	(0.050)	[0.000]	0.486	(0.084)	[0.001]	0.292	(0.090)	[0.001]
ζ_2	0.615	(0.056)	[0.000]	0.661	(0.052)	[0.000]	0.630	(0.047)	[0.000]
ζ_3	0.637	(0.055)	[0.000]	0.830	(0.040)	[0.000]	0.752	(0.069)	[0.000]
ζ_4	0.692	(0.061)	[0.000]	0.986	(0.068)	[0.000]	0.654	(0.158)	[0.000]
ζ_5	0.782	(0.066)	[0.000]	0.912	(0.065)	[0.000]	0.550	(0.193)	[0.004]
ζ_6	0.634	(0.039)	[0.000]	0.724	(0.051)	[0.000]	0.451	(0.111)	[0.000]
ζ_7	0.460	(0.042)	[0.000]	0.531	(0.042)	[0.000]	0.370	(0.037)	[0.000]
ζ_8	0.295	(0.033)	[0.000]	0.342	(0.022)	[0.000]	0.250	(0.060)	[0.000]
ζ_9	0.049	(0.027)	[0.062]	0.123	(0.028)	[0.000]	0.076	(0.062)	[0.224]
ζ_{10}	-0.063	(0.029)	[0.184]	0.085	(0.032)	[0.009]	0.016	(0.041)	[0.693]
a_0	-0.164	(0.123)	[0.184]	-0.391	(0.057)	[0.000]	-0.520	(0.100)	[0.000]
b_1	0.969	(0.021)	[0.000]	0.942	(0.009)	[0.000]	0.910	(0.019)	[0.000]
c_1	-0.354	(0.027)	[0.000]	-0.239	(0.028)	[0.000]	-0.236	(0.017)	[0.000]
d_1	0.312	(0.030)	[0.000]	0.019	(0.028)	[0.478]	0.039	(0.021)	[0.060]
\bar{R}^2	0.841			0.965			0.960		
D-W	2.722			1.753			2.641		
Kurtosis	2.220	[0.000]		-0.012	[0.975]		2.603	[0.000]	
Q(12)-statistic	8.224	[0.767]		11.26	[0.507]		5.533	[0.892]	
ARCH(12)	1.039	[0.416]		1.379	[0.182]		0.518	[0.900]	
J-B Normality	34.14	[0.000]		1.234	[0.539]		52.78	[0.000]	
SBIC	-714.22			-792.80			-633.77		
Sign Bias	-1.745	[0.083]		-0.201	[0.841]		0.470	[0.639]	
Negative Size Bias	-0.532	[0.595]		0.763	[0.447]		-0.354	[0.723]	
Positive Size Bias	0.233	[0.816]		1.286	[0.200]		1.006	[0.316]	
Joint test	3.183	[0.038]		0.979	[0.404]		1.148	[0.331]	

- Sample period; 1980:1 to 1994:8
- See notes in Table 5.6.

5.8 Discussion

Although authors, such as Beenstock and Vergottis (1989a), impose the assumption of RE and the EH in their general equilibrium industry model to model period rates, our results do not seem to support those assumptions in dry bulk shipping freight markets. This failure is attributed to the existence of time-varying risk premia, which we model through EGARCH-M specifications. The following arguments aim to provide some explanation for this.

International evidence on the EHTS in interest rate and bond markets displays mixed results. Authors such as Engle et al (1987), Hurn et al (1995b) and Guest and McLean (1998) argue that failure of the theory is due to the existence of time-varying risk premia. It is argued in the literature that the relationship between long and short term freight rate contracts in shipping markets is similar to those in money markets based on the term structure relationship and expectations theory according to the EMH (e.g. Zannetos, 1966, Strandenæs, 1984, and Hale and Vanags, 1989, among others). Investigating the EMH in determination of period rates is important since failure of the hypothesis, in the absence of risk, may signal excess profit making opportunities and has implications on chartering and operational activities of the agents involved in the shipping industry.

Shipowners operating in the spot market are generally exposed to four types of risk²⁷ in comparison to those operating in the time-charter market. First, spot rates show higher fluctuations compared to time-charter rates. Risk-averse shipowners will respond to this by choosing alternative forms of shipping contracts to eliminate the risk, e.g. by fixing their vessels in the period market, see Kavussanos (1996a and 1998). The second type of risk for a shipowner operating in the spot market is that there is always a chance that the owner may not be able to fix a contract for a period of time (unemployment risk) even when operation and chartering is well planned. Thirdly, there are cases when the owner has to relocate the vessel from one port to the other for a new spot charter contract which involves substantial time and costs. Finally, if voyage spot rates (rather than trip-charter spot rates) are compared to time-charter rates, shipowners are also exposed to voyage (mainly bunker) cost

²⁷ Although these types of risks can be eliminated to some extent through hedging tools, such as through the BIFFEX, the owners or operators are still reluctant to use such tools, see Kavussanos and Nomikos (2000a and b).

fluctuations. Thus, shipowners operating in the time-charter market are prepared to offer a discount to cover the risk, which they are exposed to when operating in the spot market. Therefore, the charterer will take the risk of operating in the spot market during the life of the time-charter contract subject to a discount over the spot rates. Our results suggest that the magnitude of this discount is time dependent and reflects the degree of uncertainty in the market.

The sentiment of the banks and lenders in shipping finance is another important factor in shipowners' decision to operate in the spot or the time-charter market. Financiers view differently clients (shipowners) who are committed to long term shipping contracts when financing a ship purchase or newbuilding, since this ensures a relatively more secure stream of income for the shipowner and reduces the probability of loan default. Thus, shipowners may be prepared to offer a discount when fixing their vessel on a long term contract, as opposed to short term ones, in order to fulfil the lender's requirements for the loan. This argument can be quite important during periods of market uncertainty, supporting further the existence of time-varying risk premia in shipping freight markets.

Negative coefficients of time-varying risk premia in our model suggest that there is a negative relationship between the agents' perception of risk and price of long term shipping contracts, which are thought to be more secure than short (spot) contracts. This is opposite to money markets in which short term rates are thought to be more secure and investors are rewarded when taking risk in investing in long term financial instruments. Our results indicate that in every market, investors price the uncertainty and are prepared to pay for security.

Implications of the fact that time charter rates can deviate from their theoretical values for considerable time periods are the following: Risk neutral or risk prone operators can make excess profits by hiring vessels in the time-charter market, when time-charter rates are under priced, and operate them in the spot market. Agents involved in freight carriage can utilise the difference between actual and theoretical time-charter rates (the spread) as an indicator of which contract to choose at any point in time. Thus, risk neutral shipowners may choose to operate in the spot market when actual time-charter rates are below their theoretical values and switch to the time-charter market when actual time-charter rates are greater than their theoretical values. Furthermore, our results on the VAR model suggest that the information

contained in time-charter rates and dynamics between the spot and time-charter rates can be used to improve forecasts of earnings in the spot market. Thus, based on the results of the Granger-causality from the spread to spot rates, it can be argued that the dynamic relationship between spot and period rates may be taken into account when predicting future spot rates. Also, results based on EGARCH-M models suggest that risk dynamics in the spot market (forecast errors) should be considered when defining models for pricing period rates. Finally, it seems that risk-averse agents who want to avoid large spreads between spot and time charter contracts should invest in smaller size vessels.

5.9 Conclusions

The validity of the EHTS in the formation of period rates in the dry bulk shipping markets is examined in this chapter. In general, the results do not support the EHTS for the period 1980 to 1997. However, this failure is attributed to shipowners perceptions of risk regarding their decision to operate in spot or time-charter markets. Existence of negative risk premia in the formation of period rates suggests that shipowners take into account the future uncertainty in the spot market and are prepared to offer a discount in time-charter fixtures in order to secure a contract with longer duration. This inverse spot market uncertainty over time-charter contracts is thought to emanate from higher freight rate volatilities in spot markets, relocation costs, risk of unemployment and fluctuations in voyage costs. Comparison of risk premia across vessel sizes suggests that larger premia are required in the market for larger vessels to compensate the higher risks involved in operating these vessels in the spot market, as the sums involved are larger compared to smaller ships. No pattern is evident on risk premia across contracts of different duration.

Results are opposite to money markets in which short term rates are thought to be more secure and investors are rewarded when taking risks in investing in long term rates. Thus, whatever the market, investors price the uncertainty and are prepared to pay for security. From the econometric point of view, our findings suggest that in modelling and forecasting shipping period rates on the basis of the PEH and the EHTS it is appropriate to incorporate factors which account for agents' perception of risk and future market conditions.

The results on the relationship between spot and time-charter rates for each size vessel indicate that spot and time-charter rates move together in the long run. However, due to risk factors, the relationship between two rates is not in line with what the EHTS would lead us to expect. The fact that earnings from short term and long term contracts are closely related suggest that the spread between them contains information in predicting the future movement of earnings in at least one of these contracts. Therefore, shipowners, operators and charterers might be able to base their chartering strategies on the spread between the short and long term earnings or rates. For example, when the spread is above its long run average, it is an indication that either spot earnings (rates) are too high or period earnings (rates) is too low.

Therefore, it is likely that either spot or period charter rates or both may respond in future periods to bring back the spread to its long run average; that is, to restore the long run equilibrium relationship between long term and short term contracts. This means that either period rates may increase or spot rates may decrease. Hence, risk neutral agents, depending on their operational needs, can choose between the two types of contracts to optimise their costs and revenues over time.

Appendix 5.A

Transformation of the present value model for spot and time-charter rates

Expanding the RHS of equation (5.3) in the text results in

$$TC_t^n = \theta \left[(E_t FR_t - \delta E_t FR_t) + (\delta E_t FR_{t+1} - \delta^2 E_t FR_{t+1}) + \dots + (\delta^{k-1} E_t FR_{t+k-1} - \delta^k E_t FR_{t+k-1}) \right] \quad (5.A.1)$$

where the terms inside brackets in equation (5.A.1) can be rearranged further to obtain

$$TC_t^n = \theta \left[E_t FR_t + (\delta E_t FR_{t+1} - \delta E_t FR_t) + \dots + (\delta^{k-1} E_t FR_{t+k-1} - \delta^{k-1} E_t FR_{t+k-2}) - \delta^k E_t FR_{t+k-1} \right] \quad (5.A.2)$$

Subtracting FR_t from both sides of equation (5.A.2) and using the difference operator, $\Delta E_t FR_{t+i} = E_t FR_{t+i} - E_t FR_{t+i-1}$, it can be seen that the spread between time charter and spot earnings, $S_t^{(n,m)}$, can be written in terms of the expected future changes in the spot earnings, $\Delta E_t FR_{t+i}$, plus an extra term, which is the difference between $k-1$ period ahead and current spot earnings, in the following form

$$S_t^{(n,m)} = TC_t^n - FR_t = \theta \sum_{i=1}^{k-1} \delta^i E_t (\Delta FR_{t+i}) - \theta \delta^k E_t (\Delta^{k-1} FR_{t+k-1}) \quad , \quad k = n/m \quad (5.A.3)$$

However, the last term in (5.A.3) can be written in terms of expected earnings of one period contracts, as

$$\begin{aligned} E_t (\Delta^{k-1} FR_{t+k-1}) &= E_t (FR_{t+k-1}) - E_t (FR_t) \\ &= E_t (FR_{t+k-1}) - E_t (FR_{t+k-2}) + E_t (FR_{t+k-2}) + \dots - E_t (FR_t) \end{aligned} \quad (5.A.4)$$

or

$$E_t (\Delta^{k-1} FR_{t+k-1}) = E_t (\Delta FR_{t+k-1}) + E_t (\Delta FR_{t+k-2}) + \dots - E_t (\Delta FR_{t+1}) = \sum_{i=1}^{k-1} E_t (\Delta FR_{t+i}) \quad (5.A.5)$$

therefore, substituting (5.A.5) in (5.A.3) results in

$$S_t^{(n,m)} = TC_t^n - FR_t = \theta \sum_{i=1}^{k-1} \delta^i E_t (\Delta FR_{t+i}) - \theta \delta^k \sum_{i=1}^{k-1} E_t (\Delta FR_{t+i}) \quad (5.A.6)$$

Equation (5.A.6) can be simplified further to

$$S_t^{(n,m)} = TC_t^n - FR_t = \theta \sum_{i=1}^{k-1} (\delta^i - \delta^k) E_t(\Delta FR_{t+i}) \quad (5.A.7)$$

For example, when $n=12$ and $m=1$, (5.A.7) becomes

$$S_t^{(12,1)} = TC_t^{12} - FR_t = \theta \sum_{i=1}^{11} (\delta^i - \delta^{12}) E_t(\Delta FR_{t+i}) \quad (5.A.8)$$

And when $n=36$ and $m=1$, (5.A.7) becomes

$$S_t^{(36,1)} = TC_t^{36} - FR_t = \theta \sum_{i=1}^{35} (\delta^i - \delta^{36}) E_t(\Delta FR_{t+i}) \quad (5.A.9)$$

Appendix 5.B

Restrictions on the VAR model

Following Campbell and Shiller (1987), a covariance stationary VAR model can be used in order to forecast expected future values of changes in spot earnings.

$$\begin{aligned} S_t^{(n,m)} &= \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(n,m)} + \sum_{i=1}^p \mu_{2,i} \Delta FR_{t-i} + \varepsilon_{1,t} \\ \Delta FR_t &= \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(n,m)} + \sum_{i=1}^p \varphi_{2,i} \Delta FR_{t-i} + \varepsilon_{2,t} \end{aligned} \quad (5.B.1)$$

The above bivariate VAR model can be written in a more compact form using companion (matrix) notation as

$$\mathbf{Z}_t = \mathbf{A} \mathbf{Z}_{t-1} + \boldsymbol{\varepsilon}_t \quad (5.B.2)$$

Or

$$\begin{bmatrix} S_t^{(n,m)} \\ \Delta FR_t \\ \vdots \\ S_{t-p}^{(n,m)} \\ \Delta FR_{t-p} \end{bmatrix} = \begin{bmatrix} \mu_{1,1} & \mu_{2,1} & \cdots & \mu_{1,p} & \mu_{2,p} \\ \varphi_{1,1} & \varphi_{2,1} & \cdots & \varphi_{1,p} & \varphi_{2,p} \\ 1 & 0 & \cdots & & \\ 0 & 1 & & & \\ \vdots & & \ddots & & \\ & & & 0 & 1 & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} S_{t-1}^{(n,m)} \\ \Delta FR_{t-1} \\ \vdots \\ S_{t-p-1}^{(n,m)} \\ \Delta FR_{t-p-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (5.B.3)$$

where $\mathbf{Z}_t = [S_t^{(n,m)}, \Delta FR_t, \dots, S_{t-p}^{(n,m)}, \Delta FR_{t-p}]$ is a $(2p \times 1)$ matrix of current and lagged values of stationary variables, \mathbf{A} is a $(2p \times 2p)$ matrix of parameters and zero and one elements, and $\boldsymbol{\varepsilon}_t$ is a $(2p \times 1)$ vector of residuals and zeros elements. Individual elements in \mathbf{Z}_t , i.e. $S_t^{(12,1)}$ and ΔFR_t , can be written using the selection vectors, $\mathbf{e1}$ and $\mathbf{e2}$ as,

$$S_t^{(n,m)} = \mathbf{e1}' \mathbf{Z}_t, \quad \Delta FR_t = \mathbf{e2}' \mathbf{Z}_t$$

Now using the chain rule of forecasting it is possible to find the optimal predictor of the expected future changes of spot earnings using the VAR model.

$$E \Delta FR_{t+k} = \mathbf{e2}' E \mathbf{Z}_{t+k} = \mathbf{e2}' \mathbf{A}^k \mathbf{Z}_t \quad ; \quad k=1, \dots, K \quad (5.B.4)$$

Substituting the forecast values of the expected future changes in spot earnings from the VAR model in the term structure equation (5.5), considering 12-month time-charter rates, we can write

$$S_t^{(12,1)} = \mathbf{e1}'\mathbf{Z}_t = \theta \sum_{i=1}^{11} (\delta^i - \delta^{12}) \mathbf{e2}'\mathbf{A}^i \mathbf{Z}_t \equiv S_t^{*(12,1)} \quad (5.B.5)$$

The RHS of the above equation is the weighted average of the predicted values of expected 1 period changes in spot earnings, known as the *theoretical spread*, $S_t^{*(12,1)}$.

An example of implementing VAR restrictions (spot and 3-period time-charter)

Using present value relationship derived in Appendix A, we can write the following spot and 3-month time-charter earnings relationship,

$$\begin{aligned} S_t &= \theta \sum_{i=1}^{3-1} (\delta^i - \delta^3) E_t \Delta FR_{t+i} \\ &= \theta (\delta - \delta^3) E_t \Delta FR_{t+1} + \theta (\delta^2 - \delta^3) E_t \Delta FR_{t+2} \end{aligned} \quad (5.B.6)$$

It has also been mentioned that a VAR model can be used to predict future changes in spot earnings. Thus, a first order VAR can be specified as

$$\begin{pmatrix} S_t^{(3,1)} \\ \Delta FR_t \end{pmatrix} = \begin{pmatrix} \mu_{1,1} & \mu_{2,1} \\ \phi_{1,1} & \phi_{2,1} \end{pmatrix} \begin{pmatrix} S_{t-1}^{(3,1)} \\ \Delta FR_{t-1} \end{pmatrix} \quad (5.B.7)$$

Projecting the VAR model to obtain individual, one and two period ahead forecast results in

$$\begin{aligned} S_{t+1}^{(3,1)} &= \mu_{11} S_t^{(3,1)} + \mu_{12} \Delta FR_t \\ \Delta FR_{t+1} &= \phi_{11} S_t^{(3,1)} + \phi_{12} \Delta FR_t \end{aligned} \quad (5.B.8)$$

and

$$\begin{aligned} S_{t+2}^{(3,1)} &= \mu_{11}^2 S_t^{(3,1)} + \mu_{11} \mu_{12} \Delta FR_t + \mu_{12} \phi_{11} S_t^{(3,1)} + \mu_{12} \phi_{12} \Delta FR_t \\ \Delta FR_{t+2} &= \phi_{11} \mu_{11} S_t^{(3,1)} + \phi_{11} \mu_{12} \Delta FR_t + \phi_{12} \phi_{11} S_t^{(3,1)} + \phi_{12}^2 \Delta FR_t \end{aligned} \quad (5.B.9)$$

Note that the one period ahead forecasts in (5.B.9) are replaced by the RHS of (5.B.8). The restriction implied on the VAR model by the present value relationship for the case of 2-month time-charter and spot earnings is

$$S_t^{(3,1)} = \mathbf{e1}' \mathbf{Z}_t = \theta \sum_{i=1}^{3-1} (\delta^i - \delta^3) \mathbf{e2}' \mathbf{A}^i \mathbf{Z}_t \equiv S_t^{*(3,1)} \quad (5.B.10)$$

The above restriction can be simplified to

$$\mathbf{e1}' \mathbf{Z}_t = \theta(\delta - \delta^3) \mathbf{e2}' \mathbf{A} \mathbf{Z}_t + \theta(\delta^2 - \delta^3) \mathbf{e2}' \mathbf{A}^2 \mathbf{Z}_t \quad (5.B.11)$$

Or

$$\mathbf{e1}' = \theta(\delta - \delta^3) \mathbf{e2}' \mathbf{A} + \theta(\delta^2 - \delta^3) \mathbf{e2}' \mathbf{A}^2 \quad (5.B.12)$$

Expanding the restriction yields

$$\begin{aligned} (1 \ 0) = & \theta(\delta - \delta^3) \begin{pmatrix} 0 & 1 \end{pmatrix} \begin{pmatrix} \mu_{1,1} & \mu_{2,1} \\ \varphi_{1,1} & \varphi_{2,1} \end{pmatrix} + \\ & \theta(\delta^2 - \delta^3) \begin{pmatrix} 0 & 1 \end{pmatrix} \begin{pmatrix} \mu_{1,1}\mu_{1,1} + \mu_{1,2}\varphi_{1,1} & \mu_{1,1}\mu_{2,1} + \mu_{2,1}\varphi_{2,1} \\ \mu_{1,1}\varphi_{1,1} + \varphi_{1,2}\varphi_{1,1} & \mu_{2,1}\varphi_{1,1} + \varphi_{2,1}\varphi_{2,1} \end{pmatrix} \end{aligned} \quad (5.B.13)$$

Which is equivalent to the following set of restrictions

$$\begin{aligned} \theta(\delta - \delta^3)\varphi_{11} + \theta(\delta^2 - \delta^3)(\mu_{1,1}\varphi_{1,1} + \varphi_{1,2}\varphi_{1,1}) &= 1 \\ \theta(\delta - \delta^3)\varphi_{21} + \theta(\delta^2 - \delta^3)(\mu_{2,1}\varphi_{1,1} + \varphi_{2,1}\varphi_{2,1}) &= 0 \end{aligned} \quad (5.B.14)$$

On the other hand, substituting the projected values from the VAR model (5.B.8) in the present value relationship of (5.B.6), the following equation can be obtained

$$S_t^{(3,1)} = \theta \sum_{i=1}^{3-1} (\delta^i - \delta^3) E_t \Delta FR_{t+i} = \theta(\delta - \delta^3) E_t \Delta FR_{t+1} + \theta(\delta^2 - \delta^3) E_t \Delta FR_{t+2} \quad (5.B.15)$$

Substituting for expected values of changes in spot earnings in (5.B.15) using prediction from the VAR model (see, equations (5.B.8) and (5.B.9)) and rearranging the terms, spread can be written as

$$\begin{aligned} S_t^{(3,1)} &= \theta(\delta - \delta^3) (\varphi_{11} S_t^{(3,1)} + \varphi_{21} \Delta FR_t) + \theta(\delta^2 - \delta^3) (\varphi_{11} S_{t+1}^{(3,1)} + \varphi_{21} \Delta FR_{t+1}) \\ &= \theta(\delta - \delta^3) \varphi_{11} S_t^{(3,1)} + \theta(\delta - \delta^3) \varphi_{21} \Delta FR_t + \\ &\quad \theta(\delta^2 - \delta^3) (\varphi_{11} (\mu_{11} S_t^{(3,1)} + \mu_{21} \Delta FR_t) + \varphi_{21} (\varphi_{11} S_t^{(3,1)} + \varphi_{21} \Delta FR_t)) \end{aligned} \quad (5.B.16)$$

which can be simplified further to

$$S_t^{(3,1)} = \left(\theta(\delta - \delta^3)\varphi_{11} + \theta(\delta^2 - \delta^3)(\varphi_{11}\mu_{11} + \varphi_{21}\varphi_{11}) \right) S_t + \left(\theta(\delta - \delta^3)\varphi_{21} + \theta(\delta^2 - \delta^3)(\varphi_{11}\mu_{21} + \varphi_{21}\varphi_{21}) \right) \Delta FR_t \quad (5.B.17)$$

The above equation implies that, for the above equality to hold (RHS equals LHS), the coefficient of the spread term on the RHS should be one and coefficient for the current and lagged FR should be zero.

$$\begin{aligned} \left(\theta(\delta - \delta^3)\varphi_{11} + \theta(\delta^2 - \delta^3)(\varphi_{11}\mu_{11} + \varphi_{21}\varphi_{11}) \right) &= 1 \\ \left(\theta(\delta - \delta^3)\varphi_{21} + \theta(\delta^2 - \delta^3)(\varphi_{11}\mu_{21} + \varphi_{21}\varphi_{21}) \right) &= 0 \end{aligned} \quad (5.B.18)$$

These are exactly the same as restrictions derived in (5.B.14).

6. CHAPTER SIX

DYNAMIC INTERRELATIONSHIPS BETWEEN DRY BULK FREIGHT RATES AND THEIR VOLATILITIES

6.1. Introduction

The aim of this chapter is to examine the dynamic interrelationships between freight rate levels and between freight rate volatilities for three size dry bulk carriers in the spot and period markets. In particular, we investigate the interaction and the direction of information flow between freight rates for different size vessels in the spot, 1-year and 3-year time-charter markets. We set up a vector error correction model (VECM) which captures both the long run relationships and the short run dynamics of freight rate series in each market. Granger-causality tests and impulse response analyses are then performed on VECM models to examine the direction of information flow and the degree of interdependence between freight rates in each market.

The degree of substitution between different size dry bulk carriers in spot and time-charter markets is also analysed. This is done by examining the persistence profile of the long-run equilibrium relationships among three size categories in each market, in the presence of a system wide shock to the freight market. The speed at which the system returns to the long run equilibrium after a shock, suggests how fast freight rates for each size class react to restore the long run equilibrium and can be viewed as an indication of the degree of substitution between different size vessels in the market.

Finally, we investigate the possibility of transmission of freight rate volatilities from one dry bulk sector to others within the spot and time-charter markets. This can be regarded as the second step of the analysis of the interrelationship between freight rates. The aim of this part is to detect any spillover effects between freight rate volatilities, in order to trace the direction of the information flow between different sectors of the dry bulk market. This is done through a VECM-GARCH model, which has a VECM specification in the mean and a multivariate GARCH specification for the variance. This type of model has been used extensively in the financial economics literature to assess the interaction between levels and volatilities of capital, interest rates, bond and commodity markets in different geographical locations. For example, Koutmos and Booth (1995) find volatility spillovers between international capital markets using a multivariate EGARCH model and Koutmos and Tucker (1996) report dynamic interactions between spot and future stock markets using a multivariate GARCH model. Other studies, investigating the spillover effects in means and volatilities of different

financial markets include; Booth et al (1997) on price and volatility spillovers in Scandinavian stock markets, Liu and Shiun Pan (1997) on the mean and volatility spillover effects in the U.S. and Pacific-Basin stock markets and Tse (1998) on spillover effects in Euroyen and Eurodollar future markets, and Lin and Tamvakis (2001) on spillovers between petroleum futures markets, among many others.

Analysis of the interaction between freight markets for different size bulk carriers may be important for the following reasons. First, it can provide insight on the causality and direction of information flow among dry bulk shipping sectors, which is important to agents involved in shipping. For example, the instantaneous impact and lagged effects of shocks to freight rates for a particular size on freight rates for other size categories can be of interest to shipowners and charterers, since such information may be used in their decision making regarding hedging, chartering activities and budget planning. Furthermore, if there is a long run relationship between two freight series, then the spread between the two series can be used as an indicator of future freight rate movements. Second, analysis of freight markets in a multivariate framework, in which information on freight rates including spreads between freight rates for different vessel sizes are efficiently and fully utilised, ensures correct and efficient econometric models and better market analysis and forecasts.

Furthermore, we investigate and compare the interrelationships between freight rate levels and volatilities for different segments (vessel sizes) of the dry bulk sector over contracts with different time to maturity; that is, spot, 1-year and 3-year time-charter contracts. Comparison of the interrelation between segments of the dry bulk sector over duration of contract is interesting since such analysis can reveal valuable information on the degree of substitution and interaction between different size vessels in each market (spot, 1-year and 3-year time-charter). Also, this type of analysis can reveal differences in interactions between segments of the market as the contract duration varies.

The structure of this chapter is as follows. The next section presents the discussion on interrelationships between freight rates for different size vessels. Section 6.3 presents VECM and Granger-causality test used to investigate interrelationships between freight rates in each market. Section 6.3.2 presents the model used to examine the interaction between freight rate volatilities. Empirical results are presented in Section 6.4. The discussion on results is the subject of Section 6.5, followed by the last section, which concludes.

6.2. Interrelationships between different dry bulk sectors

It has been argued in chapter 1 and in the literature¹ that the dry bulk market is disaggregated by size and each size is mainly involved in the transportation of certain commodities in certain routes. This implies an idiosyncratic behaviour in demand, supply, freight rate levels and volatility of freight rates for different size vessels.

Despite the argument of market segmentation in the dry bulk sector, there are overlaps between cargo transportation and operational capabilities of standard size vessels, which in turn suggests that markets for these vessels might be linked together. For example, there are occasions when vessels of adjacent size class are used as substitutes, for instance, panamax instead of handysize, and capesize instead of panamax, and vice versa. However, there are certain factors such as commodity parcel size distribution, and port and route characteristics, affecting the degree of substitutions between vessels. Substitutions between different size vessels are especially higher when the demand and consequently freight rates for one size class is high enough to attract vessels from other size categories.

The above argument suggests that one should expect that news and shocks to one sub-market might be transmitted across to other sub-markets as switching of vessels between sub-markets, in order to maximise profits, changes the supply demand balance in these sub-markets. For instance, if there is an increase in demand and subsequently freight rates for handysize vessels, other size categories (for example panamax vessels) will react by participating in the handysize market, perhaps by accepting part cargoes, if it is profitable. The shift of panamax vessels to the market for handysize vessels will cause an oversupply in the handysize market and a shortage of supply in the panamax market. As a result, handysize rates will drop while panamax rates will rise. This process might be reversed to overcome the shortage of supply in the panamax market due to the shift of these vessels to the handysize market. Therefore, a series of such movements between sectors may take place until both markets return to equilibrium.

¹ Kavussanos (1996a and 1997) establishes market segmentation through differences in dry bulk freight and second-hand price volatilities. Glen (1990) establishes market segmentation in the tanker industry.

Despite the importance of discovering the true nature of such interrelationships among freight rates and freight rate volatilities for understanding the behaviour of freight rate series, operational and chartering activities (e.g. hedging), and for forecasting purposes, no systematic analysis has been performed in the literature. The only exceptions are Berg-Andreassen (1997b) and Veenstra and Franses (1997) on the interrelationship of Baltic routes, and Kavussanos (1996a) on modelling dynamics of freight rate volatilities for three size dry bulk carriers.

Berg-Andreassen (1997b) examines the interconnectivity of dry bulk freight rates for 13 Baltic Exchange routes using Johansen's (1988) cointegration technique and shows that eight of the thirteen routes are pair-wise cointegrated, while the other five routes are not in general cointegrated with other series. He attributes the divergence in those five routes to the underlying nature of the commodities transported in these routes as well as their geographical distinctions and concludes that interconnectivity between freight rates in most of Baltic routes is an indication of the market efficiency. Veenstra and Franses (1997) study the interrelationships among six Baltic Exchange routes for panamax and capesize dry bulk carriers in a multivariate framework and find five cointegrating relationships between them. The existence of five cointegrating relationships between six freight series is argued to be due to the existence of a single common stochastic trend, which relates freight rates in all routes. The authors conclude that despite the existence of long run relationships between freight rate series, freight rate forecasts cannot be improved through a VECM specification and therefore the efficient market hypothesis seems to hold in dry bulk freight market.

Both Veenstra and Franses (1997) and Berg-Andreassen (1997b), despite recognising the existence of long run relationships between freight rate series, do not provide any insight into the short run dynamics of these rates and as to how freight rates for different size vessels may interact as duration of contract varies. Furthermore, studies such as Franses (1997) and Berg-Andreassen (1997b) do not investigate the interrelationship between volatilities of freight rates.

Kavussanos (1996a) documents differences in the dynamics of freight rate volatilities for different size dry bulk carriers in a univariate setting for the first time. It has been shown that freight rates for larger vessels show higher time-varying volatilities compared to those for smaller size vessels. However, no attempt has been made to investigate interrelationships or

spillover effects between freight rate volatilities. It should also be noted that modelling time-varying volatilities in a multivariate form, even if spillover effects are not considered, is more appropriate than the univariate approach since contemporaneous correlation between freight rates are allowed.

Thus, this chapter aims to extend Veenstra and Franses (1996) and Berg-Andreassen (1997b) analysis by investigating and comparing the interrelationships between freight rates and freight rate volatilities for different size dry bulk carriers in spot and period markets (1-year and 3-year time-charter). This study can also be considered as an extension of Kavussanos (1996a) in modelling time-varying freight rate volatilities in a multivariate framework and at the same time investigating the existence of spillover effects between freight rate volatilities across spot and period markets.

6.3. Cointegration and Granger-causality in mean and variance

It was shown in chapter 4 that spot, 1-year and 3-year time charter rate series for different size dry bulk carriers are nonstationary and integrated of order one, $I(1)$. Therefore, in order to examine the dynamic interrelationships among freight rates for different size class, in each market (spot, 1 year and 3 years time charter), a conventional VAR approach is not appropriate. A more appropriate modelling strategy, as mentioned in chapter 3, would be a VECM model, which uses cointegrating relationships between nonstationary variables in the following form

$$\Delta \mathbf{z}_t = \boldsymbol{\mu}_0 + \boldsymbol{\mu}_1 t + \sum_{i=1}^k \boldsymbol{\Gamma}_i \Delta \mathbf{z}_{t-i} + \boldsymbol{\alpha} \boldsymbol{\beta}' \mathbf{z}_{t-k} + \boldsymbol{\Psi} \mathbf{D}_t + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{IN}(\mathbf{0}, \boldsymbol{\Sigma}) \quad (6.1)$$

where $\mathbf{z}'_t = [y_{1t} \ y_{2t} \ \dots \ y_{nt}]$ is a vector of freight rate series, n is the number of variables, $\boldsymbol{\mu}_0$ and $\boldsymbol{\mu}_1$ are $(n \times 1)$ vector of parameters for deterministic components in the VECM, $\boldsymbol{\Gamma}_i$ are $(n \times n)$ matrices of short run parameters and $\boldsymbol{\Pi}$ is a $(n \times n)$ matrix of long run relationships. \mathbf{D}_t is a vector of centralised seasonal dummy variables and $\boldsymbol{\Psi}$ is a matrix containing coefficients of seasonal dummies. $\boldsymbol{\alpha}$ is a $(n \times r)$ matrix whose elements represent coefficients of the speed of adjustment of each LHS variable to long run cointegration relationships, and $\boldsymbol{\beta}'$ is a $(r \times n)$ matrix whose elements are parameters that form r stationary long run relationships between n nonstationary freight rate series.

Deterministic components, $\boldsymbol{\mu}_0$, and $\boldsymbol{\mu}_1$, can be included in both the short and long run models. However, their significance is tested using likelihood ratio tests or multivariate Schwarz information criterion since the asymptotic distribution of the cointegration tests statistics are dependent upon these elements (see, Johansen 1988 and 1991, and Johansen and Juselius 1990).

6.3.1. Granger-causality (spillover effects) in the mean

Once a correct VECM model for freight rate series in each market (i.e. spot, 1-year and 3-year) is specified and estimated, Granger-causality tests can be performed to examine the interrelationships between freight rates for different size vessels in each market. To test for

causality formally between variables in the VECM of equation (6.1), assuming $n=3$ and $r=2$ (i.e. there are three variables, n , and two cointegrating vectors, r), the VECM of (6.1) can be written as

$$\begin{aligned}\Delta y_{1,t} &= \mu_{0,1} + \sum_{i=1}^{p-1} a_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} a_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} a_{3,i} \Delta y_{3,t-i} + \alpha_{11} \beta_1 z_{t-1} + \alpha_{12} \beta_2 z_{t-1} + \varepsilon_{1,t} \\ \Delta y_{2,t} &= \mu_{0,2} + \sum_{i=1}^{p-1} b_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} b_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} b_{3,i} \Delta y_{3,t-i} + \alpha_{21} \beta_1 z_{t-1} + \alpha_{22} \beta_2 z_{t-1} + \varepsilon_{2,t} \\ \Delta y_{3,t} &= \mu_{0,3} + \sum_{i=1}^{p-1} c_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p-1} c_{2,i} \Delta y_{2,t-i} + \sum_{i=1}^{p-1} c_{3,i} \Delta y_{3,t-i} + \alpha_{31} \beta_1 z_{t-1} + \alpha_{32} \beta_2 z_{t-1} + \varepsilon_{3,t}\end{aligned}\quad (6.2)$$

where $a_{j,i}$, $b_{j,i}$ and $c_{j,i}$ ($j=1,2,3$, $i=1,\dots,p$) are the coefficients of the short run model, $\alpha_{j,1}$ and $\alpha_{j,2}$ ($j=1,2,3$) are speed of adjustments to the long run equilibrium and β_1 and β_2 represent the two cointegrating vectors. The VECM model of (6.2) can be estimated using OLS, once cointegrating vectors are identified using Johansen's (1988) cointegration technique. According to Granger (1969), a time series, $y_{1,t}$, is said to Granger-cause another series, $y_{2,t}$, if predictions of $y_{1,t}$ can be improved by using past values of $y_{2,t}$, when all other relevant information including the history of $y_{1,t}$ have been incorporated. Therefore, with respect to the above VECM, for $y_{2,t}$ to Granger-cause, $y_{1,t}$, coefficients of the former variable in the first equation in the system should be statistically different from zero; that is, $a_{2,i} \neq 0$. Similarly, for $y_{1,t}$ to Granger-cause $y_{2,t}$, coefficients of $y_{1,t}$ in the second equation in the system should be statistically different from zero; that is, $b_{1,i} \neq 0$. These hypotheses can be tested using F-tests on the joint significance of the lagged estimated coefficients. Alternatively, a Wald test can be used to test the joint significance of coefficients of lagged variables.

More insight on the relationship between freight rates for different size vessels in each market can be obtained using Generalised Impulse Response (GIR) analysis. Details of GIR functions (Pesaran and Shin 1997) are given in chapter 3. GIR analysis on each VECM model allows one to trace the impact of a shock to freight rates in one size vessel on freight rates for other size categories. Furthermore, GIR of cointegrating vectors in the VECM can be performed to measure the response of each cointegrating vector to shocks to each freight rate series in the system (Pesaran and Shin 1996). Plots of GIR of cointegrating vectors over time indicate the speed at which, each long run stationary equilibrium relationship between variables ($\beta_1' z_t$ and $\beta_2' z_t$) in the system is restored when a variable in the system is perturbed.

Braun and Mitnik (1993) argue that the performance of the impulse response analysis and forecast error variance decomposition depends on the correct lag specification of the VAR model. They compare the impulse responses of trivariate VAR models of the US post-war series (investment expenditures, price of investment and discount rate) with different lag orders and find significant differences in the impulse response analysis results. Therefore, in order to draw valid conclusions and inferences on the relationships between freight rates for different size bulk carriers, it is important to estimate a VECM with correct lag order as well as deterministic components.

6.3.2. Granger-causality (spillover effects) in the variance

The second objective of this chapter is to examine the spillover effects between freight rate volatilities in different markets. For this purpose, the VECM model of equation (6.1) is extended to VECM-GARCH to model both means and volatilities of freight rates in each market in a simultaneous framework. Details of multivariate GARCH models are given in chapter 3. Once a VECM with correct deterministic components and lag structure is defined for each market, the following multivariate BEKK model (equation 3.98) is used to specify the second moments of freight rate series (see Engle and Kroner, 1995).

$$\Delta \mathbf{z}_t = \boldsymbol{\mu}_0 + \sum_{i=1}^k \boldsymbol{\Gamma}_i \Delta \mathbf{z}_{t-i} + \boldsymbol{\alpha} \boldsymbol{\beta}' \mathbf{z}_{t-k} + \boldsymbol{\Psi} \mathbf{D}_t + \boldsymbol{\varepsilon}_t \quad ; \quad \boldsymbol{\varepsilon}_t \sim \text{student-t}(0, \boldsymbol{\Sigma}_t, \nu) \quad (6.3)$$

$$\boldsymbol{\Sigma}_t = \mathbf{A} \mathbf{A}' + \mathbf{B} \boldsymbol{\Sigma}_{t-1} \mathbf{B}' + \mathbf{C} \boldsymbol{\varepsilon}_{t-1} \boldsymbol{\varepsilon}_{t-1}' \mathbf{C}' + \mathbf{S1} \mathbf{u}_{1,t-1} \mathbf{u}_{1,t-1}' \mathbf{S1}' + \mathbf{S2} \mathbf{u}_{2,t-1} \mathbf{u}_{2,t-1}' \mathbf{S2}' + \mathbf{S3} \mathbf{u}_{3,t-1} \mathbf{u}_{3,t-1}' \mathbf{S3}'$$

where $\boldsymbol{\Sigma}_t$ is a $(n \times n)$ symmetric matrix containing time-varying variances and covariance of residuals, \mathbf{A} is an $(n \times n)$ lower triangular matrix of coefficients, \mathbf{B} and \mathbf{C} are $(n \times n)$ diagonal matrices of coefficients. $\mathbf{S1}$, $\mathbf{S2}$ and $\mathbf{S3}$ are matrices, which contain parameters of spillover effects and $\mathbf{u}_{1,t-1}$, $\mathbf{u}_{2,t-1}$ and $\mathbf{u}_{3,t-1}$ are matrices whose elements are lagged square error terms (see chapter 3, section 3.1.1.5 for more details). In this setting, spillover effects between volatilities can be tested through the coefficients of $\mathbf{S1}$, $\mathbf{S2}$ and $\mathbf{S3}$ matrices. For example, the two elements of $\mathbf{S1}$, s_{122} and s_{133} measure the spillovers of the volatility of the first equation to volatilities of second and third equations, respectively.

6.4. Empirical results

Empirical results of different models suggested in previous sections to investigate the interrelationships between freight rate levels and volatilities in each market (spot, 1-year and 3-year) are discussed below. The data set used is the same as the one used in chapter 4; that is, spot, 1-year and 3-year time-charter rates for handysize, panamax and capesize dry bulk vessels for the period January 1980 to August 1997.

6.4.1. Interrelationships between freight rates

The appropriate lag length for unrestricted VAR models based on the SBIC are 3 for spot and 2 for 1-year and 3-year time-charter rates. Johansen's (1988) reduced rank estimation method (through λ_{\max} and λ_{trace} statistics²) is used next to identify the number of cointegrating vectors in each model. Cointegration analysis results in Panels A, B and C of Table 6.1 reveal that there are two cointegrating vectors among the three series for each system in the spot, 1-year and 3-year time-charter rates³.

Panel D of Table 6.1 reports the estimates of normalised cointegrating vectors, which represent long run relationships between freight rates, for three size categories in the spot, 1-year and 3-year time-charter markets, respectively. Coefficients of both cointegrating vectors, β_1 and β_2 in each market are normalised with respect to capesize and panamax rates, respectively. The likelihood ratio tests on restricting the cointegrating vectors to represent exactly the spread between freight rates for different size vessels are also presented in panel D of Table 6.1. These test statistics could not be rejected at the 5% significant level, indicating that the first cointegrating vector is in fact the spread between capesize and handysize spot rates, while the second vector is the spread between panamax and handysize spot rates. This in turn implies that spread series contain information on future movements of freight rates. We discuss more about the role of the spread series when estimates of the VECM models for each market are presented. Also, since restrictions on cointegrating

² See chapter 3 for more details on calculation of λ_{trace} and λ_{\max} statistics.

³ The corresponding critical values for λ_{\max} and λ_{trace} test statistics are from Osterwald-Lenum (1992). The λ_{\max} statistics test the null of $r=q$, (r is number of the cointegrating vectors, $q=0,1, \dots, n-1$) against the alternative of $r=q+1$. While the λ_{trace} statistics test the null of $r=q$ against the unrestricted alternative that $r>q$.

vectors in are valid, both VECM models and impulse response analysis are based on restricted cointegrating vectors.

Table 6.1: Johansen (1988) cointegration analysis of size disaggregated freight rates

Sample period 1980:1-1997:8

Equation (6.1)

$$\Delta \mathbf{z}_t = \boldsymbol{\mu}_0 + \boldsymbol{\mu}_1 t + \sum_{i=1}^k \boldsymbol{\Gamma}_i \Delta \mathbf{z}_{t-i} + \boldsymbol{\alpha} \boldsymbol{\beta}' \mathbf{z}_{t-k} + \boldsymbol{\Psi} \mathbf{D}_t + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{IN}(0, \boldsymbol{\Sigma})$$

Hypothesis		Test Statistic	Hypothesis		Test Statistic	Critical Values			
H ₀	H ₁	λ _{max}	H ₀	H ₁	λ _{trace}	λ _{max}		λ _{trace}	
						95%	90%	95%	90%
PANEL A: Spot Rates, (k=2)									
r=0	r=1	32.16	r=0	r>0	50.99	21.12	19.02	31.54	28.78
r=1	r=2	14.64	r=1	r>1	18.83	14.88	12.98	17.86	12.98
r=2	r=3	4.19	r=2	r>2	4.19	8.07	6.50	8.07	6.50
PANEL B: 1-Year Time-Charter Rates, (k=1)									
r=0	r=1	34.36	r=0	r>0	56.58	21.12	19.02	31.54	28.78
r=1	r=2	18.92	r=1	r>1	22.22	14.88	12.98	17.86	12.98
r=2	r=3	3.30	r=2	r>2	3.30	8.07	6.50	8.07	6.50
PANEL C: 3-Year Time-Charter Rates, (k=1)									
r=0	r=1	25.84	r=0	r>0	42.13	21.12	19.02	31.54	28.78
r=1	r=2	13.61	r=1	r>1	16.29	14.88	12.98	17.86	12.98
r=2	r=3	2.69	r=2	r>2	2.69	8.07	6.50	8.07	6.50

PANEL D: Likelihood ratio test on cointegrating vectors

Market	Unrestricted Cointegrating vector	H ₀ : Restricted Cointegrating vector	LR test $\chi^2_{(4)}$ [p-value]
Spot	$\beta_1 = [1 \quad 0 \quad -1.0652]$ $\beta_2 = [0 \quad 1 \quad -1.1594]$	$\beta_1^r = [1 \quad 0 \quad -1]$ $\beta_2^r = [0 \quad 1 \quad -1]$	6.001 [0.050]
1-year TC	$\beta_1 = [1 \quad 0 \quad -1.1498]$ $\beta_2 = [0 \quad 1 \quad -1.0740]$	$\beta_1^r = [1 \quad 0 \quad -1]$ $\beta_2^r = [0 \quad 1 \quad -1]$	1.488 [0.475]
3-year TC	$\beta_1 = [1 \quad 0 \quad -0.8735]$ $\beta_2 = [0 \quad 1 \quad -0.9227]$	$\beta_1^r = [1 \quad 0 \quad -1]$ $\beta_2^r = [0 \quad 1 \quad -1]$	0.641 [0.726]

- 90% Critical values for different specifications of the cointegration models are obtained from Osterwald-Lenum(1992) table 1* .
- Unrestricted (normalised) cointegrating vectors, β_1 and β_2 represent the linear relationships between capesize and handysize freight rates, and panamax and handysize freight rates, respectively.
- Restricted cointegrating vectors, β_1^r and β_2^r represent the spread between capesize and handysize freight rates, and the spread between panamax and handysize freight rates, respectively.
- Restrictions on cointegrating vectors are tested using the Johansen (1991) test statistics,

$$Q_H = (T - nk) \sum_{i=1}^r \ln[(1 - \hat{\lambda}_i^*) / (1 - \hat{\lambda}_i)]$$

where, T is the number of observations, n and k are the number of variables and lags in the system. $\hat{\lambda}_i^*$ and $\hat{\lambda}_i$ are the eigenvalues associated with the restricted and unrestricted cointegrating vectors.

The results from estimating the short-run parameters of the final VECM for the spot, 1-year and 3-year time-charter markets using Seemingly Unrelated Regressions Estimation (SURE) are reported in Tables 6.2, 6.3 and 6.4, respectively. The SURE method is used because the system is reduced to a partial VECM as insignificant variables are dropped to arrive at the most parsimonious model. This ensures efficient and consistent parameter estimates.

Diagnostic tests for residual autocorrelation, heteroscedasticity, ARCH and normality for each short-run equation are reported at the bottom of each table. Ljung-Box test statistics for 12th order residual autocorrelation do not reject the null of no autocorrelation at the 5% significant level in all cases. White (1980) tests for heteroscedasticity indicate there is no heteroscedasticity in any of the short run models across the contracts. The only exception is the short run model for capesize spot rates, therefore, the White (1980) correction is used to correct the standard errors of this model. In equations with significant ARCH effects it is found that these are stationary, and as a result the unconditional variance of the residuals is constant and OLS and SURE yield the BLUE (see Greene 1997, p. 570). Overall, diagnostic test results do not indicate any misspecification, except that residuals are not normally distributed.

6.4.1.1. The estimated VECM of the spot market

Results of the VECM model for spot rates for different size dry bulk carriers are presented in Table 6.2. Coefficients of the ECT, $\alpha_{1,i}$, in the short run model measure the speed at which the dependent variables respond to a disequilibrium shock, and also indicate the direction to which the dependent variable will move in the next period to restore the long run equilibrium relationship. For example, in the short run model for capesize spot rates, the negative and significant coefficient of the first ECT, $\alpha_{1,1}=-0.127$, indicates that when the long run relationship between capesize and handysize freight rates, i.e. the spread between the two rates increases, capesize rates decrease in the next period. Positive and significant coefficient of the first ECTs in the short run model for handysize rates ($\alpha_{1,3}=0.047$) suggests that freight rates for these vessels respond to the disequilibrium between freight rates for capesize and handysize vessels and increase in the next period to restore the equilibrium. Meanwhile, panamax rates increase (by $\alpha_{1,2}=0.136$) in response to disequilibrium between capesize and handysize spot rates in order to restore the long run relationship.

Table 6.2: SURE estimates of the restricted VECM of spot rates

Sample period 1980:1-1997:8

$$\Delta z_t = \mu_0 + \mu_1 t + \sum_{i=1}^k \Gamma_i \Delta z_{t-i} + \alpha \beta' z_{t-k} + \Psi D_t + \varepsilon_t, \quad \varepsilon_t \sim IN(0, \Sigma) \quad \text{Equation (6.1)}$$

Panel (A) Parameter estimates of the VECM

Coeff.	Regressor	$\Delta LCSZ_t$		$\Delta LPMX_t$		$\Delta LHSZ_t$	
$\mu_{0,i}$	intercept	-0.020	(-1.231)	0.075	(5.564)	0.005	(0.800)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.127**	(-2.351)	0.136**	(4.359)	0.047**	(2.261)
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.431**	(-7.484)		
$\gamma_{1,1i}$	($\Delta LCSZ_{t-1}$)	-0.266**	(-3.892)			0.044*	(1.696)
$\gamma_{1,2i}$	($\Delta LPMX_{t-1}$)	0.387**	(4.100)			0.195**	(5.022)
$\gamma_{1,3i}$	($\Delta LHSZ_{t-1}$)					-0.298**	(-4.952)
$\gamma_{2,1i}$	($\Delta LCSZ_{t-2}$)	-0.286**	(-4.593)				
$\gamma_{2,2i}$	($\Delta LPMX_{t-2}$)			-0.176**	(-3.100)		
$\gamma_{2,3i}$	($\Delta LHSZ_{t-2}$)			0.356**	(4.032)		
$\psi_{3,i}$	(D3 _t)			0.060**	(2.014)		
$\psi_{6,i}$	(D6 _t)			-0.115**	(-3.743)	-0.038*	(-1.858)
$\psi_{7,i}$	(D7 _t)	-0.156**	(-2.941)	-0.147**	(-4.603)	-0.090**	(-4.166)
R-bar-squared		0.219		0.304		0.211	
Q(12)		20.42	[0.059]	17.92	[0.118]	7.354	[0.833]
WHITE		28.33	[0.000]	0.259	[0.611]	0.167	[0.682]
ARCH(12)		6.755	[0.000]	4.552	[0.000]	1.007	[0.854]
Normality		245.3	[0.000]	128.8	[0.000]	4.420	[0.108]
System Log-Likelihood		412.74					
Multivariate AIC		-12.262					
Multivariate SBIC		-11.927					

Panel (B) Granger-causality tests

	Capesize		Panamax		Handysize	
Capesize Granger-causes	---		1.230	[0.541]	4.809*	[0.090]
Panamax Granger-causes	8.248**	[0.016]	---		9.628**	[0.008]
Handysize Granger-causes	2.785	[0.248]	11.33**	[0.003]	---	

- LCSZ, LPMX and LHSZ represent log of capesize, panamax and handysize spot rates, respectively.
- ECT_{1,t-1}= $\beta'_1 z_{t-1}$ and ECT_{2,t-1}= $\beta'_2 z_{t-1}$ denote the first and second error correction terms, respectively.
- Figures in () and [] are t-statistics and p-values, respectively.
- t statistics are corrected for heteroscedasticity and serial correlation using White and Newey-West consistent variance-covariance matrices where appropriate.
- * and ** indicate significance at the 10% and the 5% levels, respectively.
- Q(12) is the Ljung-Box test for 12th order residual autocorrelation with probability values in brackets.
- WHITE is the White tests for heteroscedasticity.
- ARCH(12) is the F test for Autoregressive Conditional Heteroscedasticity with probability values in brackets.
- Normality is the Jarque-Bera normality test with probability values in brackets.
- Granger-causality tests are performed on unrestricted VECM model. These are Wald tests of excluding the respective lagged variables (in the row) from the each equation (in column), and follow a $\chi^2(r)$ distribution, where r is the number of restrictions (r=2 in this case).

Similarly, the negative and significant coefficient of the second ECT, $\alpha_{2,2}$ =-0.431, in the panamax equation suggests that when the spread between panamax and handysize freight rates exceeds its long run value (a positive disequilibrium), panamax rates decrease in the next period. However, insignificant coefficient of the second ECT in the handysize equation indicates that handysize freight rates may not respond to the disequilibrium and the response

of panamax rates is enough to restore the long run equilibrium between freight rates for these two vessel sizes.

Significant coefficient of July seasonal dummy in the capesize equation in the spot market indicates a 15.6% decrease in July. In the case of panamax spot rates, significant coefficients of seasonal dummies indicate a 6.0% increase in freight rates during March followed by 11.5% and 14.7% decrease in June and July, respectively. Handysize spot rates also show 3.8% and 9.0% fall in June and July, respectively. Details of underlying factors for such seasonal fluctuations are discussed in chapter 4. These results seem to be in line with those findings.

Panel B of Table 6.2 presents Granger-causality (Wald) tests on the interrelationships between freight rates for different size vessels. These amount to testing the significance of one series in improving the predictability of freight rates for other categories. For example, to test whether handysize rates Granger-cause capesize rates, the joint significance of lagged changes in handysize rates in the capesize equation is tested⁴. The Wald test statistic value of 2.785 is not significant at the 5% level, indicating that handysize rates do not Granger-cause capesize rates.

Granger-causality tests indicate that there is causality from handysize rates to panamax rates. Also, panamax rates Granger-cause both capesize and handysize rates, and there is no causality between handysize and capesize rates. The fact that there is no causal relationship between spot rates for capesize and handysize vessels is because these markets are quite distinct in terms of the cargo and routes they serve. This implies that spot rates for these vessels are only related in the long run through cointegrating relationships and short term changes in any of these markets do not affect the freight movements in the other. Overall, the Granger-causality results suggest that there is information flow on short term dynamics of freight rates from the market for smaller vessels to the market for larger vessels.

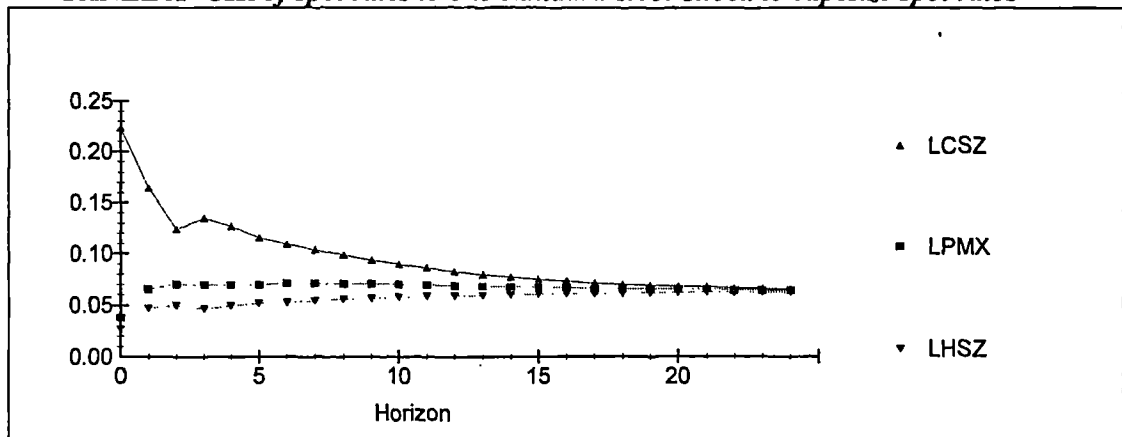
⁴ Note that the test for the joint significance of lagged values of a variable, and error correction terms in an equation of the VECM, is a test for exogeneity of the variable explained by that equation. That is, the rejection of the joint significance of lagged values and error correction terms, indicates that the variable is strongly exogenous to the system. Whereas the test for the joint significance of error correction terms in an equation indicates that the variable is weakly exogenous to the system (see Harris 1996 for more details on tests for exogeneity in the VECM).

Results of the GIR analysis based on the estimated VECM for the spot market are illustrated in Figures 6.1 and 6.2. Panels A, B and C of Figure 6.1 plot the GIRs of spot rates for capesize, panamax and handysize vessels to a one standard error shock in each freight rate. It can be seen that spot rates for all size categories increase first and settle to their new levels after nearly 8 to 10 months. However, the path to the new equilibrium level seems to be different in each case. The rise of freight rates to new levels can be explained first, by the fact that spot freight series are nonstationary and retain the shock for a long period. Second, the existence of long run relationships between freight series suggest that in the case of a shock to any series in the system (disequilibrium), other freight series respond by adjusting to new levels to restore long run equilibrium relationships. For example, a sudden (shock) rise in freight rates for handysize vessels can attract panamax vessels to operate in the handy market causing a short supply in the panamax market, which in turn leads to an increase in panamax rates. At the same time, capesize vessels may find the panamax market profitable and operate in this market. The shift of capesize vessels to the panamax market can cause a short supply in the capesize market leading to an increase in capesize freight rates.

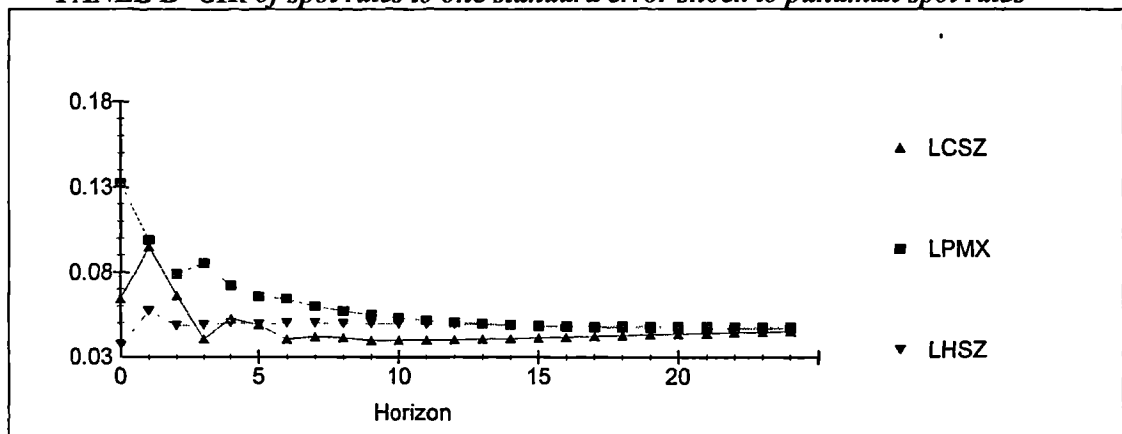
Panels A, B and C of Figure 6.2 plot the GIRs of the two cointegrating vectors (representing the spread between capesize and handysize rates, CV1, and the spread between panamax and handysize rates, CV2) in the VECM for the spot market to a shock, with a magnitude of one standard error, to capesize, panamax and handysize spot rates, respectively. The graph in panel A suggests that the response of CV1 to a shock to capesize freight rates is more pronounced than the response of CV2 vector to the same shock. This can be explained by the fact that the first cointegrating relationship is the spread between capesize and handysize rates, while the second cointegrating relationship represents the difference between panamax and handysize rates. Therefore, one would expect a larger impact on the first cointegrating relationship by a shock to capesize rates, as the effect is direct in comparison to the effect of a shock to capesize rates on CV2 vector which is indirect and through the other equations in the system.

Figure 6.1: GIR analysis of spot rates for three size dry bulk carriers

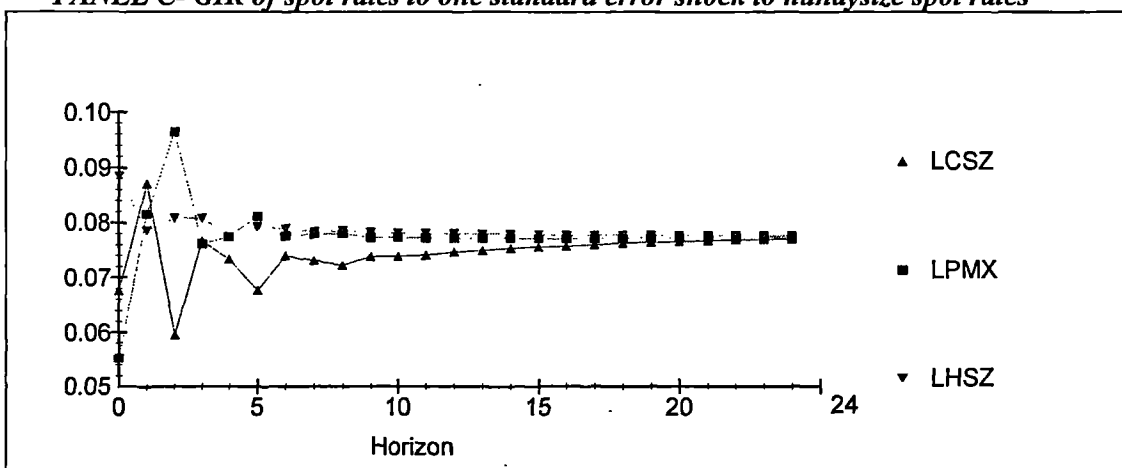
PANEL A- GIR of spot rates to one standard error shock to capesize spot rates



PANEL B- GIR of spot rates to one standard error shock to panamax spot rates

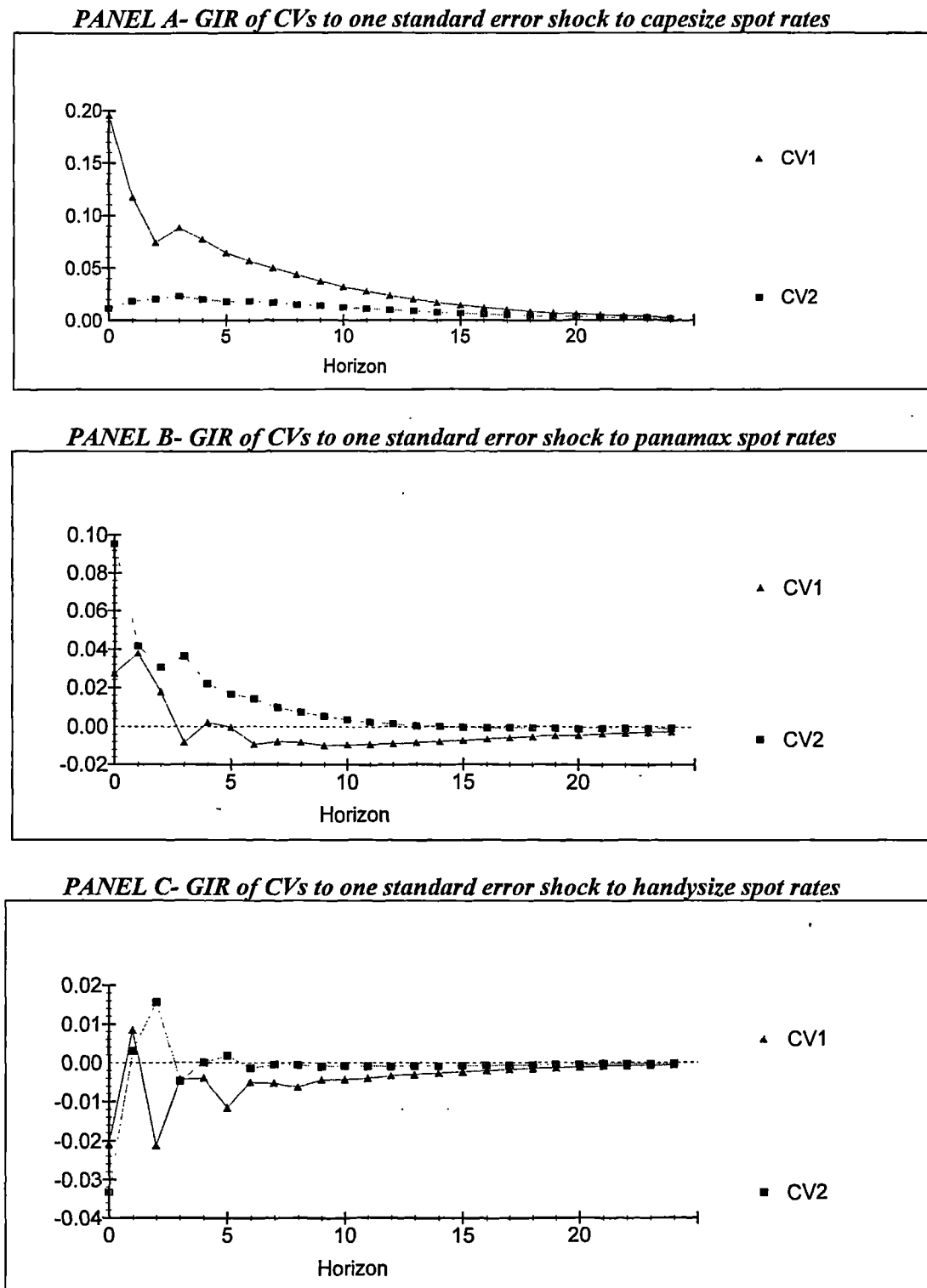


PANEL C- GIR of spot rates to one standard error shock to handysize spot rates



- LCSZ, LPMX and LHSZ represent logs of spot rate indices for capesize, panamax and handysize vessels, respectively.

Figure 6.2: GIR analysis of cointegrating vectors in the VECM of the spot market



- CV1 and CV2 represent the 1st and 2nd cointegrating vectors in the VECM model for spot rates.

In the case of a shock to panamax freight rates (panel B of Figure 6.2), it can be seen that the instantaneous impact of the shock on CV2 is greater than the impact on CV1. This is also expected, since CV2 is a linear combination of panamax and handysize rates as opposed to CV1, which is a linear combination of capesize and handysize rates. The instantaneous effect of the shock on CV1 is due to the transmission of the response of handysize rates to the shock through CV2.

The response of CVs to a shock with a magnitude of one standard error to handysize rates is shown in panel C of Figure 6.2. It can be seen that the instantaneous response of both CVs is negative and die out after 4 to 5 months. This is expected since CVs, by construction, are the difference between capesize and handysize, and panamax and handysize rates, respectively. Therefore, a (positive) shock to handysize rates should cause a negative disequilibrium; that is, negative response by the CVs.

Another interesting result of the GIR analysis of CVs is the time required for the CVs to return to their original states; that is, the time taken by the system to restore itself to its long run equilibrium. In the case of a shock to capesize rates, Figure 6.2 panel A, responses of CV1 seem to be greater than those of CV2, while both CVs converge to their initial levels after about 10 to 15 months. Responses of both CVs to a shock to panamax rates, Figure 6.2 panel B, seem to be positive initially with a relatively faster convergence rate compared to the responses of CVs to shocks to capesize rates. However, the CV1 seems to become negative after 3 periods during the adjustment process and slowly returns to the initial equilibrium. Effects of a shock to panamax rates on both CVs seem to diminish in about 10 to 15 months. Responses of CVs to shocks to handysize spot rates, Figure 6.2 panel C, are initially negative, but they overshoot in the first two months to positive values during the adjustment process and then return to their long run equilibrium after 4 to 6 months.

Plots of responses of CVs to shocks to handysize freight rates indicate that the effect of such shocks die out relatively faster than responses of CVs to shocks to capesize rates and panamax rates. This might be due to the difference in the size of the shock to the system as a one standard error shock to capesize (0.22) or panamax rates (0.13) are almost 2.5 and 1.5 times larger than one standard error shock to handysize rates (0.09), respectively (see Figure 6.1). The fact that shocks to freight rates for larger vessels are greater than shocks to freight

rates for smaller vessels can be explained by higher volatility freight rates for larger vessels compared to smaller ones, as investigated by Kavussanos (1996a).

6.4.1.2. The VECM of 1-year time-charter market

Results of the VECM model for 1-year time-charter rates for different size dry bulk carriers are presented in Table 6.3. The first cointegrating relationship ($\beta_1 z_t$) represents the spread between 1-year time-charter rates for capesize and handysize vessels while the second relationship ($\beta_2 z_t$) is the spread between rates for panamax and handysize vessels.

The estimated coefficient of the first ECT, $\alpha_{1,1}=-0.071$, in the short run model for capesize rates suggests that when the difference between 1-year charter rate for capesize and handysize increases, capesize rates respond and decrease in the next period. Coefficient of the first ECT in the handysize equation, $\alpha_{1,3}$, is found to be insignificant, indicating that handysize rates do not respond to changes in long run spread between capesize and handysize rates. However, panamax rates seem to respond to disequilibrium between capesize and handysize rates, since the coefficient of the first ECT in the panamax model, $\alpha_{1,2}=0.110$, is significant. Negative and significant coefficient of the second ECT in the panamax model, $\alpha_{2,2}=-0.231$, and positive and significant coefficient of the same ECT in the handysize model, $\alpha_{2,3}=0.060$, suggest that 1-year time-charter rates for both vessels respond to disequilibrium and adjust in the next period to restore the long run equilibrium relationship between these two charter rates.

Significant and negative coefficients of the June seasonal dummy in the short run models for all vessel sizes indicate a drop of 3.9%, 4.9% and 4.2% in 1-year time-charter rates for capesize, panamax and handysize, respectively. Panamax and handysize rates show a further drop of 3.3% and 2.9% in July, respectively. Significant and positive coefficient of the March seasonal dummy in the handysize equation indicate 3.0% increase in 1-year time charter rates for handysize vessels in March.

Granger-causality tests, reported in panel B of Table 6.3, reject the existence of causal relationship between time-charter rates for different size vessels in all directions with the exception of causality from handysize to panamax rates and from panamax to capesize rates.

This indicates that short term relationships between 1-year time-charter rates for different size vessels are lower compared to the spot market. The Granger-causality tests also indicate a unidirectional information flow from time-charter rates for smaller size vessels to rates larger ones.

Table 6.3: SURE estimates of the restricted VECM of 1-year time-charter rates

Sample period 1980:1-1997:8

$$\Delta z_t = \mu_0 + \mu_1 t + \sum_{i=1}^k \Gamma_i \Delta z_{t-i} + \alpha \beta' z_{t-k} + \Psi D_t + \varepsilon_t, \quad \varepsilon_t \sim \text{IN}(0, \Sigma) \quad \text{Equation (6.1)}$$

Panel(A) Parameter estimates of the VECM							
Coeff.	Regressor	ΔLCSZ1_t		ΔLPMX1_t		ΔLHSZ1_t	
$\mu_{0,i}$	intercept	0.034**	(2.543)	0.026**	(2.170)	-0.021**	(-2.257)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.071**	(-2.803)	0.110**	(4.409)		
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.231**	(-5.042)	0.060**	(2.345)
$\gamma_{1,1i}$	($\Delta \text{LCSZ1}_{t-1}$)	0.305**	(4.710)			0.067*	(1.941)
$\gamma_{1,2i}$	($\Delta \text{LPMX1}_{t-1}$)	0.248**	(2.803)	0.236**	(3.614)		
$\gamma_{1,3i}$	($\Delta \text{LHSZ1}_{t-2}$)			0.211**	(2.597)	0.292**	(4.754)
$\psi_{3,i}$	(D3 _t)					0.030**	(2.756)
$\psi_{6,i}$	(D6 _t)	-0.039**	(-2.183)	-0.046**	(-3.307)	-0.040**	(-3.766)
$\psi_{7,i}$	(D7 _t)			-0.033**	(-2.762)	-0.031**	(-3.105)
R-bar-squared		0.208		0.244		0.280	
Q(12)		16.31	[0.177]	11.32	[0.502]	15.20	[0.231]
WHITE		0.554	[0.460]	0.096	[0.756]	0.240	[0.624]
ARCH(12)		1.556	[0.108]	3.591	[0.000]	0.991	[0.459]
Normality		16.88	[0.000]	84.93	[0.000]	88.94	[0.000]
System Log-Likelihood				997.35			
Multivariate AIC				-17.831			
Multivariate SBIC				-17.528			
Panel (B) Granger-causality test							
		Capesize		Panamax		Handysize	
Capesize Granger-causes		---		2.178	[0.140]	1.741	[0.187]
Panamax Granger-causes		5.286**	[0.012]	---		0.280	[0.596]
Handysize Granger-causes		0.001	[0.974]	5.313**	[0.021]	---	

- See notes in Table 6.2.
- LCSZ1, LPMX1 and LHSZ1 represent log of capesize, panamax and handysize 1-year time-charter rates respectively.

Figures 6.3 and 6.4 plot the results of GIR analysis of the VECM for 1-year charter rates. Panels A, B and C of Figure 6.3 plot the GIRs of 1-year time-charter rates for each size category to a shock, with a magnitude of one standard error, to capesize, panamax and handysize rates, respectively. It can be seen that 1-year time-charter rates for all sizes increase initially and then settle permanently to new levels after 15 to 18 months following a shock to capesize rates, 12 to 14 months following a shock to panamax rates and handysize rates. This can be explained first, by the fact that 1-year time-charter rates are nonstationary

and retain the shock for a long period (see chapter four). Second, the existence of long run relationships between time-charter series suggests that the effects of shocks to one freight rate can be transmitted through the system to other rates. That is, once the system is in disequilibrium due to a shock to one of freight rates, other freight series respond by adjusting to new levels to restore long run equilibrium relationships.

Panels A, B and C of Figure 6.4 plot the GIRs of the two identified CVs in the VECM to a shock, with a magnitude of one standard error, to 1-year rates for capesize, panamax and handysize vessels, respectively. The graph in panel A indicates that the initial response of CV1 to a shock to capesize freight rates is stronger than the initial response of CV2 to the same shock. This is because CV1 is the spread between 1-year rates for capesize and handysize vessels, whereas CV2 is the spread between 1-year rates for panamax and handysize vessels. Therefore, one would expect a greater initial response by CV1 compared to CV2 to shocks to capesize rates. This is because shocks to capesize rates have a direct effect on CV1 and an indirect effect through the system on CV2.

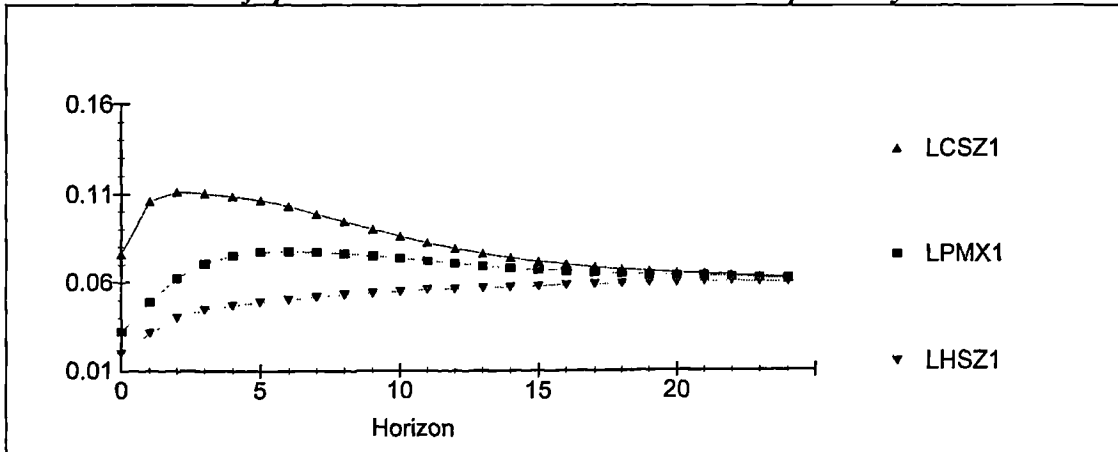
Also the GIR of CVs to a shock to capesize rates reveals that CV1 responds instantaneously to a shock to capesize rates and rises by 5%, with a further increase of 1% between 1 to 2 months after the shock. On the other hand, CV2 initially rises by 1% but the full impact of the shock on CV2 is observed after 4 to 5 periods. The reason for the delay in observing the full impact on CV2 is again the indirect effect of shocks to capesize rates on CV2 compared to CV1. This means that the effect of the shock to capesize rates is transmitted through the system to CV2.

Responses of CVs to shocks to 1-year time-charter rates for handysize vessels, Panel C of Figure 6.4, suggest that both CVs decrease by 1% to 1.5% initially and then rise by 1.5% to 2% after about 3 to 4 months to positive values. They both settle to the initial equilibrium after 15 to 20 periods. In the case of a shock to capesize rates, Figure 6.4 panel A, it can be seen that the initial response of CV1 is higher than the response of CV2, while both CV1 and CV2 converge to their initial level after about 15 to 20 months. Responses of both CVs to a shock to panamax rates, Figure 6.4 panel B, are also positive with a relatively long convergence period of approximately 15 to 20 months, compared to the similar case in the spot market model with a convergence period of 10 to 15 months.

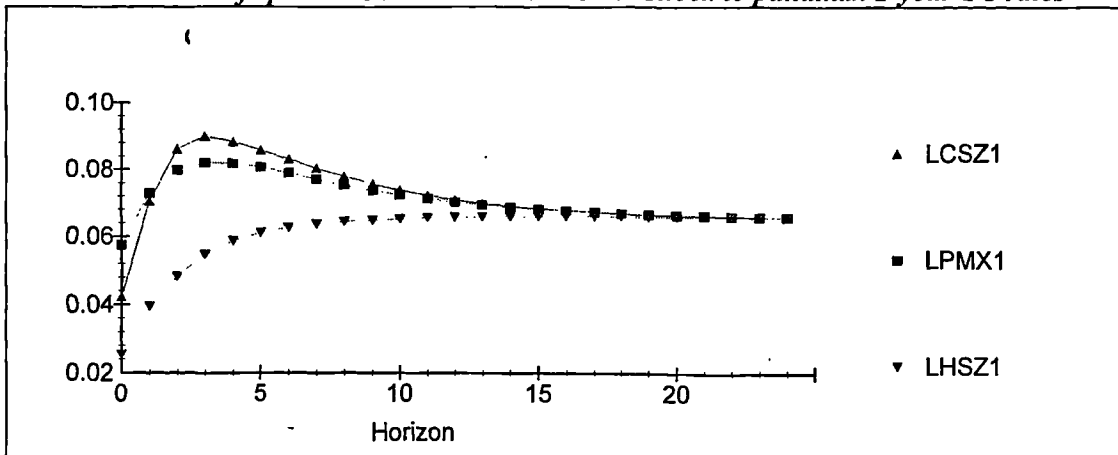
Responses of cointegrating vectors to shocks to 1-year time-charter rates for handysize vessels, Figure 6.4 panel C, are negative, but less than the responses of the cointegrating vectors to shocks to charter rates for larger vessels. Figure 6.4, panel C, also, indicates that both cointegrating vectors converge to their long run levels in 15 to 20 months, which is relatively longer compared to the convergence period of cointegrating vectors (6 to 8 months) in the spot market model when the shock is applied to handysize rates.

Figure 6.3: GIR analysis of 1-year TC rates for three size dry bulk carriers

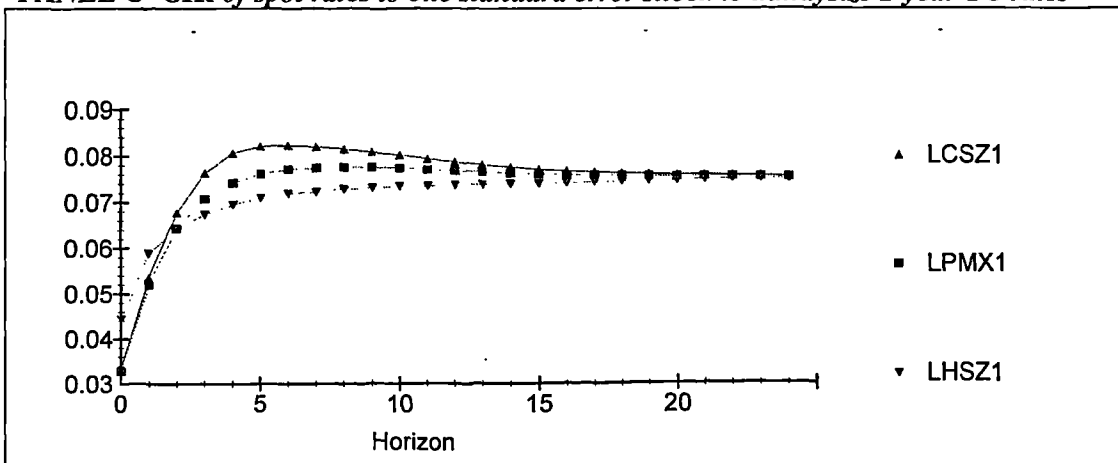
PANEL A- GIR of spot rates to one standard error shock to capesize 1-year TC rates



PANEL B- GIR of spot rates to one standard error shock to panamax 1-year TC rates



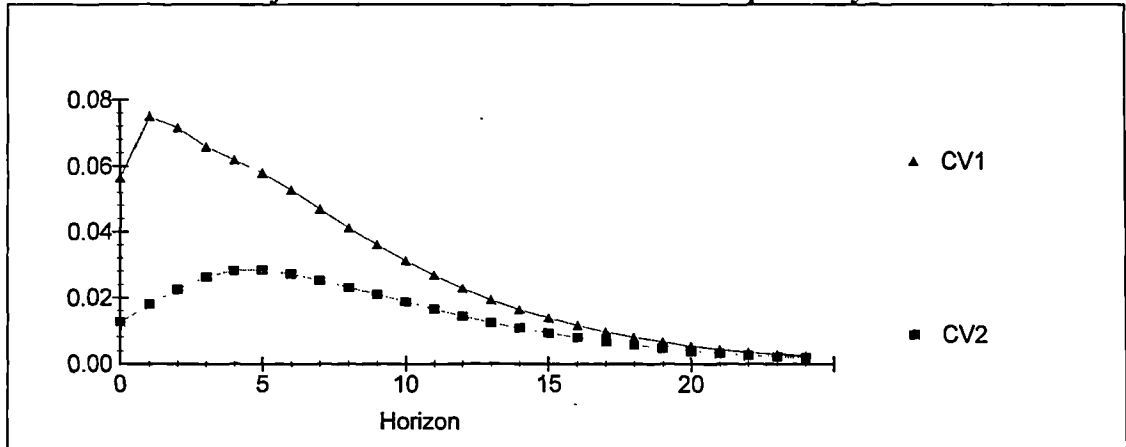
PANEL C- GIR of spot rates to one standard error shock to handysize 1-year TC rates



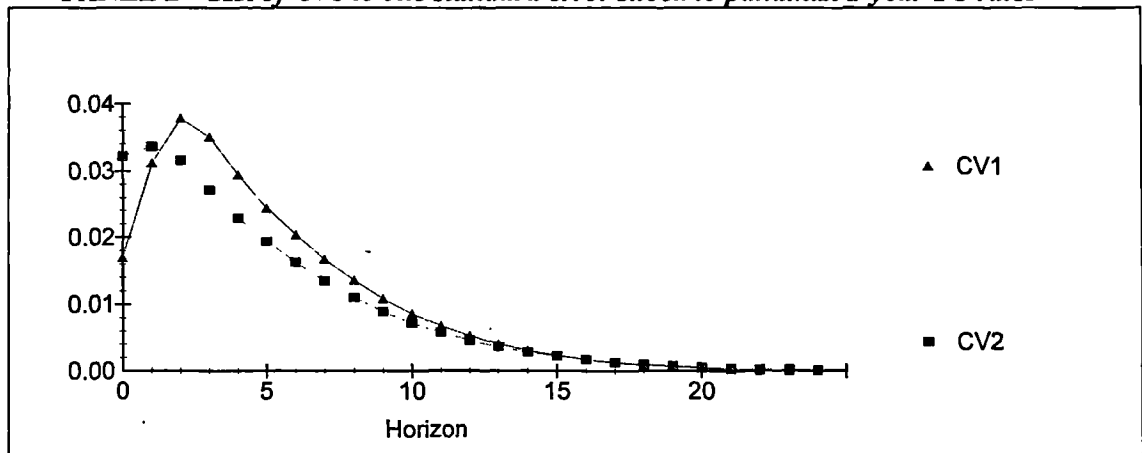
- LCSZ1, LPMX1 and LHSZ1 represent log of 1-year time-charter rates for capesize, panamax and handysize vessels, respectively.

Figure 6.4: GIR analysis of cointegrating vectors in the VECM for 1-year TC rate

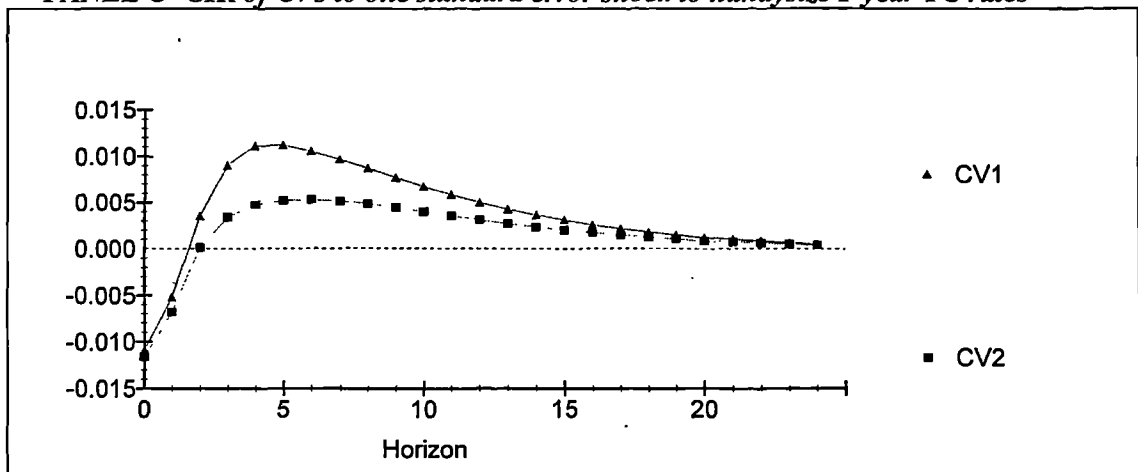
PANEL A- GIR of CVs to one standard error shock to capesize 1-year TC rates



PANEL B- GIR of CVs to one standard error shock to panamax 1-year TC rates



PANEL C- GIR of CVs to one standard error shock to handysize 1-year TC rates



- CV1 and CV2 represent the 1st and 2nd cointegrating vectors in the VECM model for 1-year time-charter rates.

6.4.1.3. The VECM of 3-year time-charter market

Results of the SURE VECM model for 3-year time-charter rates for different size dry bulk carriers are presented in Table 6.4. Panel A of the table reports coefficients the VECM model and Panel B present results of Granger-causality tests.

The coefficient of the first cointegrating vector in the short run model for capesize rates, $\alpha_{1,1}=-0.090$, suggests that when the difference between 3-year charter rates for capesize and handysize increases, capesize rates respond and decrease in the next period. The coefficient of the first ECT in the short run model for handysize rates, $\alpha_{1,3}=-0.054$, shows a reduction in handysize rates in response to a disequilibrium. Although, one expects that these two coefficients to have different signs, capesize and handysize rates still converge to restore the long run equilibrium as the coefficient of the ECT in the handysize equation is greater than the coefficient of ECT in the capesize equation. However, it may take longer for the system to settle. The coefficient of the first ECT in the short run model for panamax rates, $\alpha_{2,1}$, is not significant. The positive and significant coefficient of the second ECT, $\alpha_{2,3}=0.137$, in the short run model for handysize rates suggests that these rates respond to disequilibrium between panamax and handysize rates in the next period in order to restore the long run equilibrium between the two charter rates. The coefficient of the second ECT, $\alpha_{2,2}=-0.048$, in the short run model for panamax rates also indicate that freight rates for these vessels respond to disequilibrium between handysize and panamax rates.

Significant and positive coefficients of the August seasonal dummy in the short run models indicate 4.5%, 2.1% and 2.2% increase in 3-year time-charter rates for capesize, panamax and handysize rates, respectively, while handysize and panamax rates show a significant decrease of 1.3% and 1.5% in June, respectively. Positive and significance coefficients of the March dummy in capesize and panamax equations indicate that 3-year time-charter rates for these vessels increase by 3.7% and 2.2%, respectively.

Results of Granger-causality tests, reported in Panel B of Table 6.4, indicate that handysize rates significantly Granger-cause both capesize and panamax rates, while there is a feedback effect from panamax rates to handysize rates. The results also reject existence of any causality from capesize rates to freight rates for panamax and handysize vessels, which

indicates that short run dynamics of capesize rates do not have any predicting power for freight rates for smaller vessels. This suggests that, in line with what is observed in both spot and 1-year time-charter markets, the direction of information flow in the long term (3-year) charter market is from the market for small vessels to the market for large vessels.

Table 6.4: SURE estimates of the VECM of 3-year time-charter rates

Sample period 1980:1-1997:8

$$\Delta z_t = \mu_0 + \mu_1 t + \sum_{i=1}^k \Gamma_i \Delta z_{t-i} + \alpha \beta' z_{t-k} + \Psi D_t + \varepsilon_t, \quad \varepsilon_t \sim \text{IN}(0, \Sigma) \quad \text{Equation (6.1)}$$

Panel (A) Parameter estimates of the VECM

Coeff.	Regressor	ΔLCSZ_t		ΔLPMX_t		ΔLHSZ_t	
$\mu_{0,i}$	intercept	0.048**	(3.762)	0.017*	(1.854)	-0.019*	(-1.837)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.090**	(-4.015)			-0.054**	(-2.226)
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.048**	(-1.984)	0.137**	(3.435)
$\gamma_{1,1i}$	(ΔLCSZ_{t-1})	0.344**	(6.053)				
$\gamma_{1,2i}$	(ΔLPMX_{t-1})			0.333**	(5.302)	0.246**	(3.352)
$\gamma_{1,3i}$	(ΔLHSZ_{t-1})	0.344**	(3.764)	0.163**	(2.517)	0.174**	(2.508)
$\psi_{3,i}$	(D ₃)	0.037**	(2.737)	0.022**	(2.570)		
$\psi_{6,i}$	(D ₆)			-0.013*	(-1.702)	-0.015*	(-1.656)
$\psi_{8,i}$	(D ₈)	0.045**	(3.276)	0.021**	(2.287)	0.022**	(2.266)
R-bar-squared		0.244		0.213		0.193	
Q(12)		16.64 [0.163]		12.26 [0.425]		17.74 [0.123]	
WHITE		0.090 [0.768]		0.054 [0.816]		1.847 [0.174]	
ARCH(12)		1.033 [0.420]		1.982 [0.028]		2.795 [0.002]	
Normality		74.04 [0.000]		30.17 [0.000]		689.6 [0.000]	
System Log-Likelihood				1134.87			
Multivariate AIC				-19.13			
Multivariate SBIC				-18.81			

Panel (B) Granger-causality test

	Capesize	Panamax	Handysize
Capesize Granger-causes	--	0.744 [0.388]	0.007 [0.935]
Panamax Granger-causes	2.4813 [0.130]	--	8.319** [0.006]
Handysize Granger-causes	6.094** [0.009]	4.049** [0.044]	--

- See notes in Table 6.2.
- LCSZ3, LPMX3 and LHSZ3 represent log of capesize, panamax and handysize 3-year time-charter rates respectively.

Figures 6.5 and 6.6 plot the results of GIR analysis of the VECM for the 3-year time-charter market. Panels A, B and C of Figure 6.5 plot the GIRs of 3-year time-charter rates for each size category to a one standard error shock to 3-year time-charter rates for capesize, panamax and handysize dry bulk carriers, respectively. It can be seen that 3-year time-charter rates for all dry bulk carriers increase and settle permanently to new levels after 15 to 20 months following a shock to capesize or panamax rates. In the case of a shock to handysize rates, 3-year time-charter rates for all dry bulk carriers increase and settle permanently to new levels

after 8 to 10 months. The permanent increase in 3-year time-charter rates following a shock can be explained by the fact that these rates are nonstationary and there are long run relationships between them. As a result, in the case of a shock to one of freight rate series; i.e. a market disequilibrium, other freight series respond and adjust to their new levels in order to restore the long run equilibrium relationships.

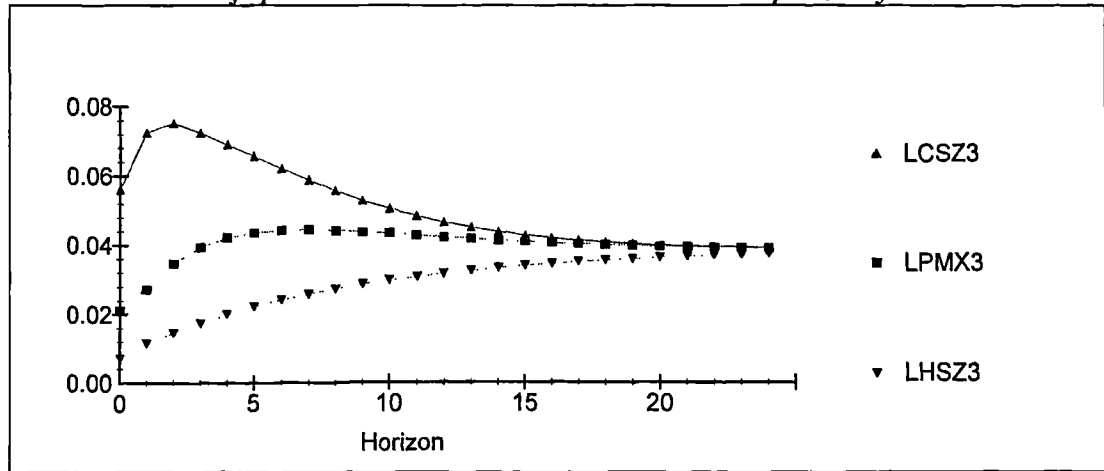
Panels A, B and C of Figure 6.6, plot the GIRs of the two first cointegrating vectors (CVs) in the VECM of the 3-year to a shock, with a magnitude of one standard error, to 1-year rates for capesize, panamax and handysize vessels, respectively. The graph in panel A indicates that the response of the first cointegrating vector (CV1) in the system to a shock to capesize freight rates is greater than the response of the second cointegrating vector (CV2) to the same shock. This is because CV1 represents the spread between capesize and handysize rates, while CV2 represents the spread between panamax and handysize rates. Therefore, one would expect a stronger response by CV1 to a shock to capesize rates compared to the response of CV2, since the effect of such shock on CV1 is direct and on CV2 is indirect and through the lagged variables and ECTs in the system.

Also, the plot of the GIR of CVs to shocks to freight rates for each size class can be used as an indication of the time taken by the system to restore itself to the long run equilibrium after the shock. It can be seen that in the case of a shock to capesize rates, Panel A of Figure 6.6, maximum impacts on CV1 and CV2 are observed after 1 and 3 periods, respectively. Both CV1 and CV2 converge to their initial level after about 15 to 20 months. Responses of CV1 and CV2 to a shock to panamax rates, Figure 6.4 panel B, also indicate that maximum impact for CV1 is observed 3 periods after the shock due to lagged transmission effects through the system, which is explained earlier. Effects of panamax shocks on CVs die after 20 to 24 periods.

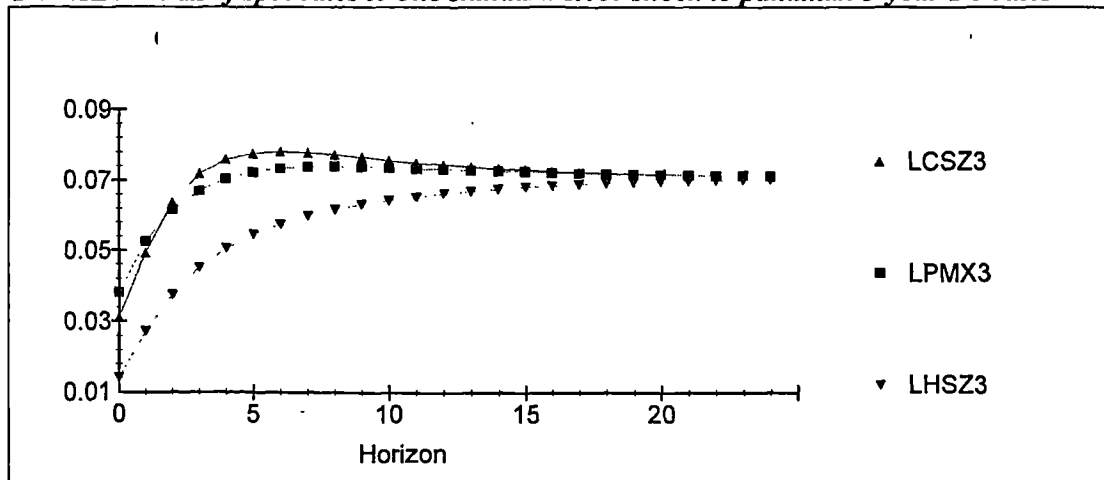
Responses of CV1 and CV2 to one standard error shock to 3-year time-charter rates for handysize vessels, Figure 6.4 panel C, are negative, but less than the responses of the CV1 and CV2 to shocks to time-charter rates for larger vessels. Figure 6.6 panel C also indicates that both cointegrating vectors converge to their long run levels in 10 to 12 months.

Figure 6.5: GIR analysis of 3-year TC rates for three size dry bulk carriers

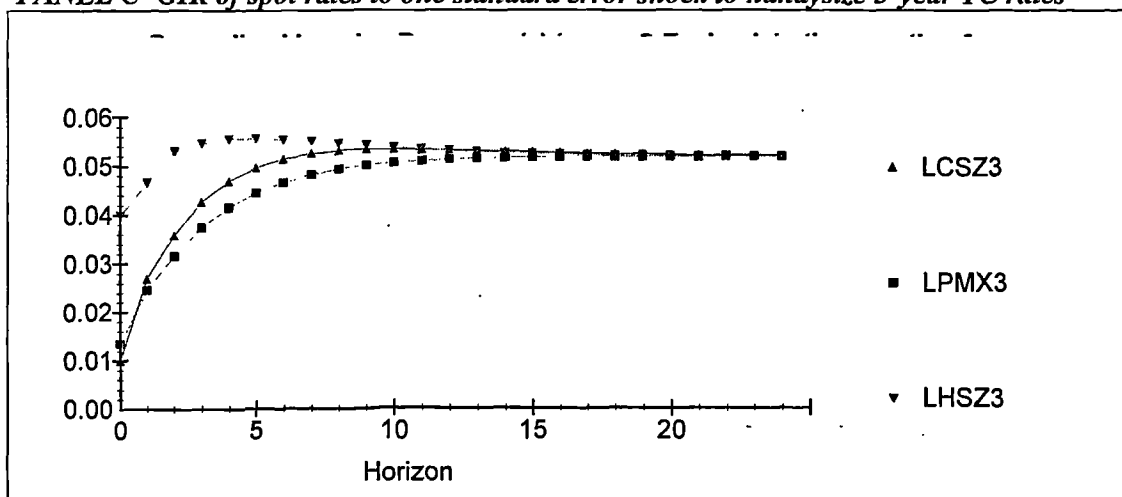
PANEL A- GIR of spot rates to one standard error shock to capesize 3-year TC rates



PANEL B- GIR of spot rates to one standard error shock to panamax 3-year TC rates

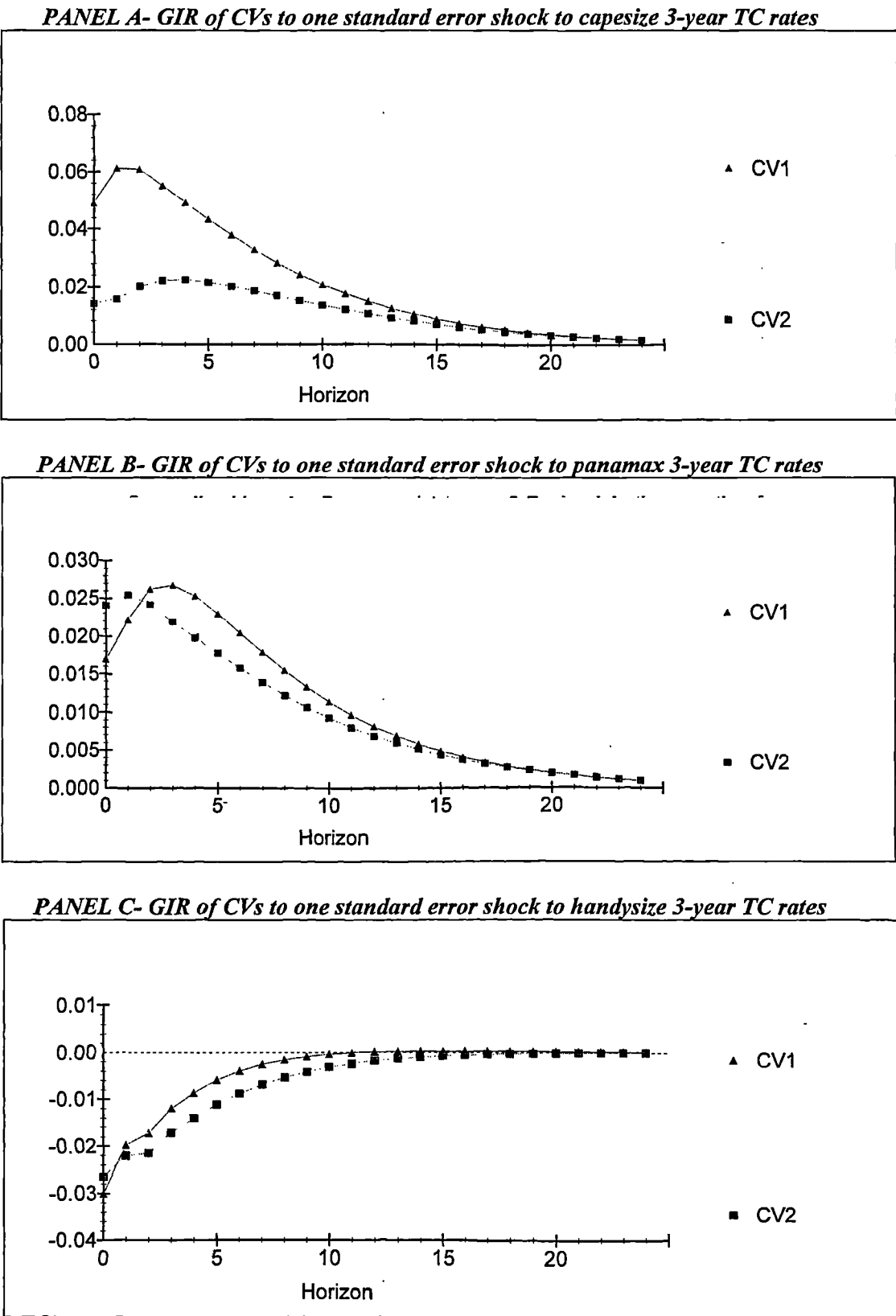


PANEL C- GIR of spot rates to one standard error shock to handysize 3-year TC rates



- LCSZ3, LPMX3 and LHSZ3 represent logs of 3-year time-charter rates for capesize, panamax and handysize vessels, respectively.

Figure 6.6: GIR analysis of cointegrating vectors in the VECM of the 3-year TC market



• CV1 and CV2 represent the 1st and 2nd cointegrating vectors in the VECM for 3-year time-charter rates.

6.4.2. Convergence to the Long-Run Equilibrium and persistence profiles

Persistence profiles are in fact the time profiles of the impact of a system-wide shock⁵ on the cointegrating relationships. The value of the profile is equal to unity on impact and it dies out with time depending on how fast the system returns to its initial equilibrium. The speed of convergence to the long run equilibrium depends on the relationships between variables in the system as well as their sensitivity to shocks. The persistence profile, therefore, provides important information on the speed at which the effects of system-wide shocks on the cointegrating relationships disappear, even though shocks generally have lasting impacts on nonstationary variables. A comparison of persistence profiles of cointegrating vectors in VECM models for spot, 1-year and 3-year time-charter markets provides information on how fast these markets adjust to their long run equilibrium.

Persistence profiles of cointegrating vectors of the VECM models for the spot, 1-year and 3-year time-charter markets in response to system-wide shocks are plotted in Figure 6.7 panels A, B and C, respectively. Panel A shows that persistence profiles of both cointegrating vectors in the spot market model die out 4 to 6 months after the system has been shocked. In contrast, persistence profiles of cointegrating relationships in both 1-year and 3-year time-charter models, panels B and C, die out quite slowly. In fact, both persistence profiles in period markets return to their long run equilibrium after 10 to 12 months.

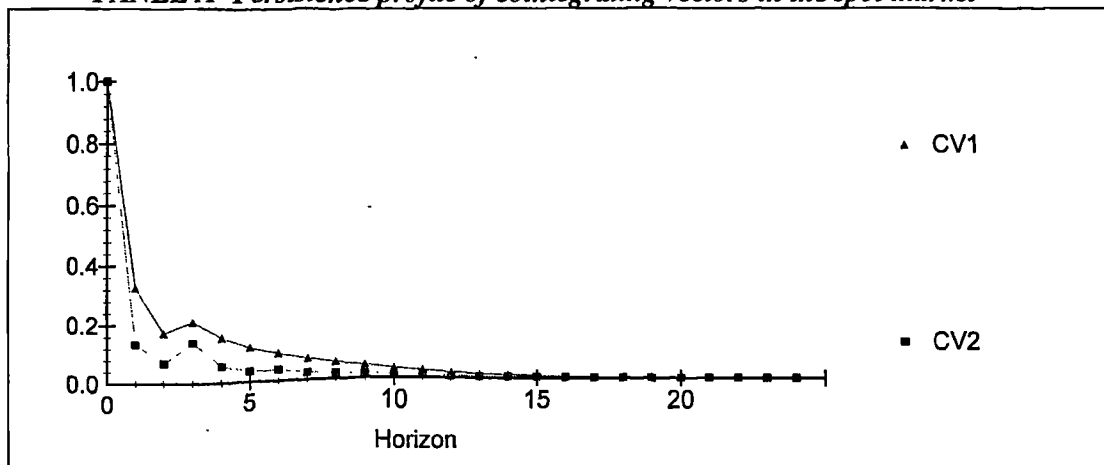
The difference between persistence profile patterns in VECM models of the spot and time-charter markets may be explained by the fact that spot rates respond at a relatively faster rate to shocks compared to time-charter rates. This is because there are greater degrees of substitution and competition between adjacent size vessels in the spot market compared to period markets. The degree of substitution between different size categories in different charter markets explains the degree of interrelationships between freight rate series. The reason for restricted degree of competition and substitution between different size categories in period markets is in fact the operational strategy of charterers and the cost allocation differences between spot and time-charter contracts. In general, charterers hiring vessels

⁵ System-wide shocks, as argued by Pesaran and Shin (1996), could be viewed as shocks with a magnitude of 1 standard deviation drawn from the multivariate distribution of error terms, ε_t . Using this type of shocks is preferred to univariate shocks in measuring convergence of cointegrating relations to equilibrium since there is no need to orthogonalise the shocks (see, Pesaran and Shin 1996 for more details).

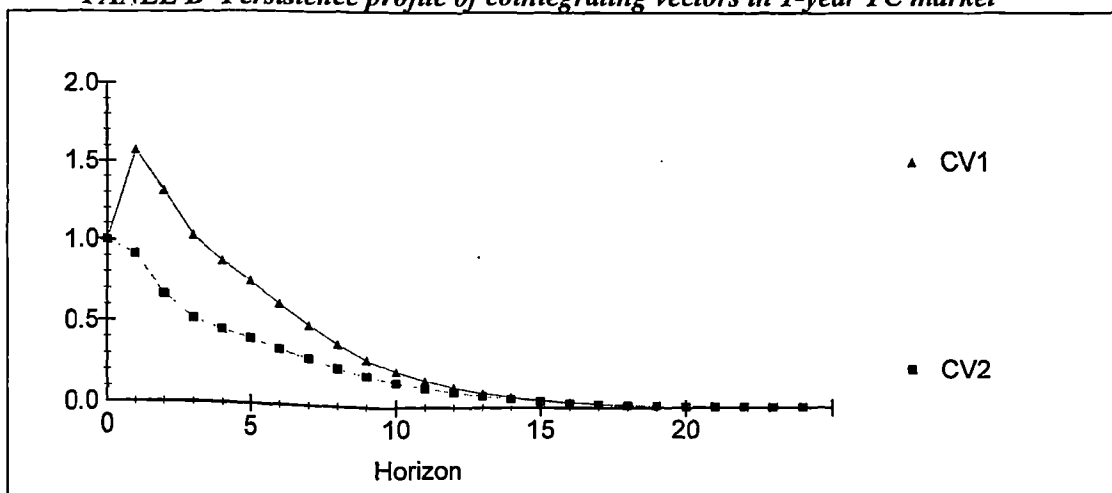
under period charter contracts are interested in a particular size vessel, which can satisfy their requirements with minimum costs. Thus, they are more concerned about the size of the vessel when operating in the period market. Charterers hiring vessels in the spot market are not so concerned about the size of the vessel since spot contracts are on \$/ton basis and shipowners are responsible for operating costs.

Figure 6.7: Comparison of persistence profiles of cointegrating vectors in VECM's of spot, 1-year and 3-year time charter markets

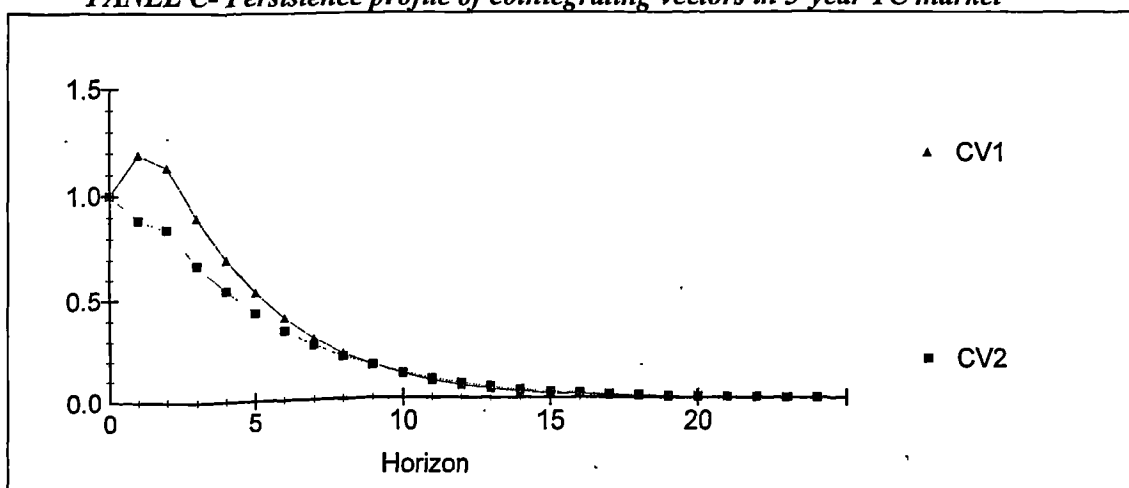
PANEL A- Persistence profile of cointegrating vectors in the spot market



PANEL B- Persistence profile of cointegrating vectors in 1-year TC market



PANEL C- Persistence profile of cointegrating vectors in 3-year TC market



- CV1 and CV2 represent the 1st and the 2nd cointegrating vectors in each VECM model.

6.4.3. Volatility spillover effects

The following sections present estimation results of the VECM-GARCH models of freight rates for three size vessels in the spot, 1-year and 3-year time-charter markets. The aim of the analysis is twofold. First, to model the mean and time-varying volatilities of freight rates for different size dry bulk carriers in a simultaneous framework and compare time-varying volatilities across sizes. The second objective is to identify and measure spillover effects between freight rate volatilities in each market.

A diagonal BEKK variance specification as in equation (3.98) is used, with the BFGS maximisation algorithm employed for estimation, assuming a multivariate t-distribution (see Bollerslev 1987) of error terms. The most parsimonious specification for each model is estimated by excluding insignificant variables. Along with conventional diagnostic tests, sign and size bias tests (Engle and Ng 1993) are performed to ensure that shocks with different sign or magnitude do not have asymmetric effects on time-varying volatilities.

6.4.3.1. Volatility spillovers in the spot market

The maximum likelihood estimates of the VECM-GARCH model of spot freight rates are in Table 6.5. Diagnostics show that the models are well specified. Sign and size bias tests are not significant in any case, except in the case of the capesize model where negative sign bias shows significance at the 5% level. However, the joint test for sign and size bias rejects any asymmetric effects at the 5% level. The estimated coefficient of degrees of freedom, ν , which is found to be 10.09, justifies use of t-distribution. The estimated implied kurtosis is 3.99 indicating excess kurtosis in residuals⁶. Coefficients of mean models correspond with those of SURE VECM presented earlier.

Focusing on the parameters describing the conditional variance in each market, it can be seen that handysize spot rates do not show any time-varying volatility, since both coefficients of lagged variance, b_{11} , and lagged squared error terms, c_{11} , are insignificant. Significant coefficients of lagged variance and lagged error terms in the variance equations for panamax and capesize vessels indicate that volatility of spot rates for these vessels are in fact time-

⁶ According to Bollerslev (1987), the theoretical kurtosis of a t-distribution is $3(\nu-2)/(\nu-4)$.

varying. Persistence factors⁷ of time-varying volatilities ($b_{ii}^2 + c_{ii}^2$) for capesize and panamax spot rates are found to be 0.904 and 0.823, respectively. The fact that both persistence factors are less than unity implies that the unconditional variances of capesize and panamax spot rates are stationary.

Coefficients of volatility spillover effects, $s1_{i,i}$ ($i=2,3$), $s2_{j,j}$ ($j=1,3$) and $s3_{k,k}$ ($k=1,2$), which pick up the effect of lagged squared forecast errors (residuals) of one equation in explaining the volatility of freight rates for other size vessels, are insignificant at the 5% level in every case, except, $s1_{2,2}=0.198$, which measures the volatility spillover from capesize rates to panamax rates. Significance of this coefficient implies that there is a unidirectional volatility transmission from capesize to panamax spot rates.

Figure 6.8 plots time-varying volatilities of spot rates for different size dry bulk carriers. It can be seen that, in general, capesize spot rates show higher time-varying volatilities than panamax spot rates, and panamax spot rates show higher volatility than handysize rates. The pattern of volatilities across sizes seems to be very similar. Higher time-varying volatilities for larger vessels compared to smaller ones can be explained by the fact that larger vessels are less flexible than smaller vessels in terms of their operation and employment in different routes and trades. Therefore, one would expect that shocks to freight rates for larger vessels have greater impact on volatility than shocks to freight rates for smaller vessels. The results are consistent with those of Kavussanos (1996a).

⁷ Persistence factor of volatility is defined as the degree of convergence of the conditional volatility to the unconditional volatility after a shock. For example, if the conditional volatility is defined as a GARCH (1,1) process, $\sigma_t^2 = a_0 + b_1 \sigma_{t-1}^2 + c_1 \varepsilon_{t-1}^2$, then the unconditional volatility would be $a_0 / (1 - b_1 - c_1)$. Therefore, the degree of persistence of the conditional volatility can be defined as $(b_1 + c_1)$. The conditional volatility converges to its unconditional value, if and only if $(b_1 + c_1) < 1$. Also, note that in the BEKK specification persistence is calculated as $(b_1^2 + c_1^2)$.

Table 6.5: Estimates of VECM-GARCH model for spot rates

Sample period 1980:1-1997:8

Equation (6.3)

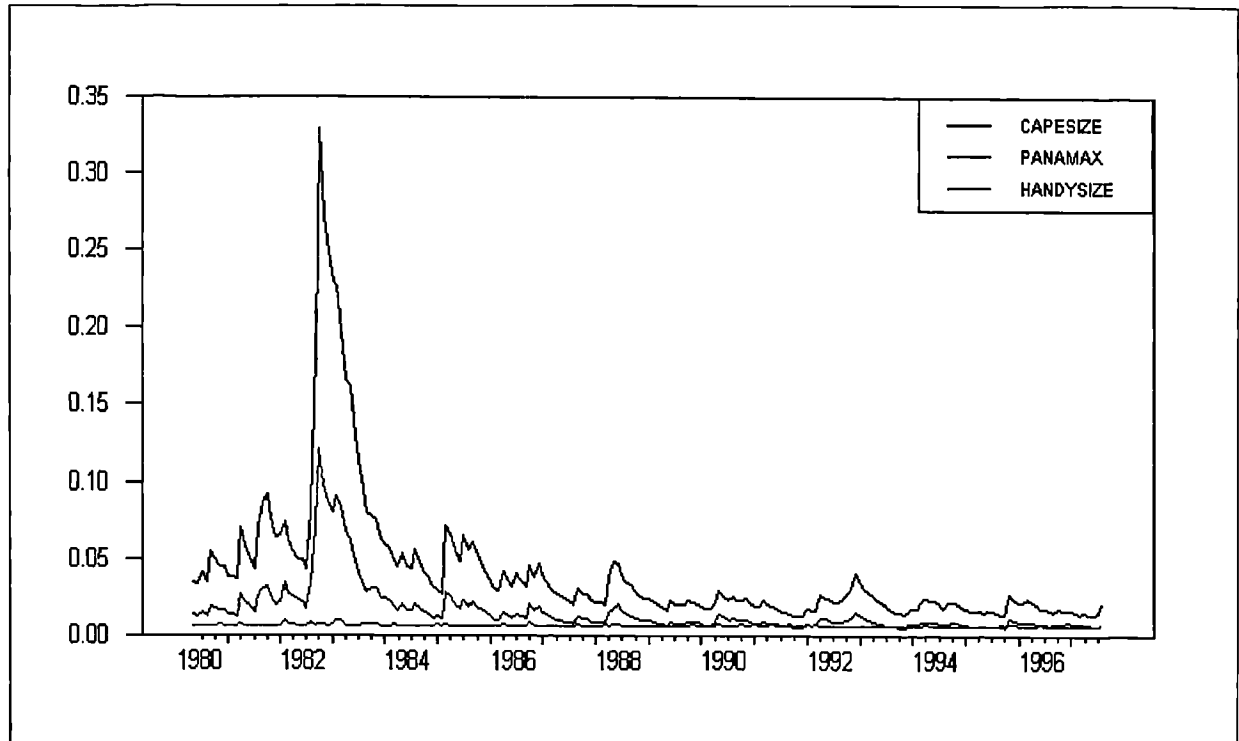
$$\Delta z_t = \mu_0 + \sum_{i=1}^k \Gamma_i \Delta z_{t-i} + \alpha \beta' z_{t-k} + \Psi D_t + \varepsilon_t, \quad \varepsilon_t \sim \text{student-t}(0, \Sigma_t, \nu)$$

$$\Sigma_t = A A' + B \Sigma_{t-1} B' + C \varepsilon_{t-1} \varepsilon_{t-1}' C' + S1 u_{1,t-1} u_{1,t-1}' S1' + S2 u_{2,t-1} u_{2,t-1}' S2' + S3 u_{3,t-1} u_{3,t-1}' S3'$$

Coeff.	Regressor	$\Delta LCSZ_t$		$\Delta LPMX_t$		$\Delta LHSZ_t$	
$\mu_{0,i}$	intercept	-0.006	(-0.628)	0.059**	(5.024)	-0.007	(-0.976)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.159**	(-3.980)	0.109**	(3.501)		
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.286**	(-5.303)	0.066*	(1.732)
$\gamma_{1,1i}$	($\Delta LCSZ_{t-1}$)	-0.229**	(-3.528)	0.093**	(2.449)	0.088**	(3.598)
$\gamma_{1,2i}$	($\Delta LPMX_{t-1}$)	0.387**	(4.528)			0.170**	(4.090)
$\gamma_{1,3i}$	($\Delta LHSZ_{t-1}$)					-0.320**	(-6.163)
$\gamma_{2,1i}$	($\Delta LCSZ_{t-2}$)	-0.199**	(-3.193)			0.058*	(2.453)
$\gamma_{2,2i}$	($\Delta LPMX_{t-2}$)	0.208**	(2.644)	-0.123**	(-2.384)		
$\gamma_{2,3i}$	($\Delta LHSZ_{t-2}$)			0.190**	(2.834)	-0.098*	(-1.893)
$\psi_{3,i}$	(D3 _t)			0.045*	(1.877)		
$\psi_{6,i}$	(D6 _t)			-0.105**	(-4.720)	-0.036*	(-1.910)
$\psi_{7,i}$	(D7 _t)	-0.087**	(-2.364)	-0.111**	(-4.823)	-0.077**	(-3.930)
$\psi_{8,i}$	(D8 _t)	0.084**	(2.376)				
Conditional variance parameters							
	$a_{ii}, i=1,2,3$	0.0002	(0.016)	0.009	(0.359)	0.050	(1.568)
	a_{21}			0.012	(0.972)		
	a_{31}			0.051**	(3.070)		
	a_{32}			0.025**	(9.912)		
	$b_{ii}, i=1,2,3$	0.847**	(12.23)	0.889**	(22.36)	0.449	(1.086)
	$c_{ii}, i=1,2,3$	0.432**	(4.250)	-0.182**	(-2.197)	0.055	(0.437)
	ν			10.09**	(3.000)		
Volatility spillovers							
		Capesize		Panamax		Handysize	
$s1_{i,i}, i=2,3$	Capesize	---		0.198**	(4.532)	-0.000	(-0.000)
$s2_{j,j}, j=1,3$	Panamax	0.236	(1.125)	---		0.076	(0.808)
$s3_{k,k}, k=1,2$	Handysize	0.000	(0.000)	-0.000	(-0.000)	---	
R-bar-squared		0.219		0.302		0.236	
Skewness		-0.592	[0.001]	-0.293	[0.087]	-0.134	[0.430]
Kurtosis		0.962	[0.005]	0.712	[0.039]	0.899	[0.009]
J-B test for normality		19.70	[0.000]	22.55	[0.000]	7.646	[0.022]
Q(12)		14.29	[0.285]	12.13	[0.435]	5.707	[0.930]
ARCH(12)		1.203	[0.284]	1.218	[0.274]	0.399	[0.963]
Persistence ($b_{ii}^2+c_{ii}^2$)		0.904		0.823		0.205	
System Log-likelihood				479.51			
AIC				-12.692			
SBIC				-11.970			
Sign and size bias test							
Sign bias		1.585	[0.115]	0.451	[0.652]	-0.022	[0.982]
Negative Size bias		-2.490	[0.014]	-0.734	[0.461]	0.346	[0.730]
Positive Size bias		-1.860	[0.064]	-1.122	[0.263]	-0.714	[0.476]
Joint test for 3 effects		2.348	[0.074]	0.594	[0.619]	0.362	[0.780]

- See notes in Table 6.2.
- ν is the estimated parameter for the degrees of freedom of student-t distribution and is common to all models.
- Volatility spillovers are measure by coefficients of S1, S2 and S3 matrices. Coefficients in the table, rounded up to 3 decimals, indicate volatility spillovers from the market shown in the row to the market shown in the column.
- Persistence coefficient is calculated as $a_{ii}^2 + b_{ii}^2$ (see footnote 7).
- The test statistics for the Engle and Ng (1993a) tests are the t-ratio of b in the regressions; $e\sigma_t^2 = a + bS_{t-1}^- + e_t$ (sign bias test); $e\sigma_t^2 = a + bS_{t-1}^- e_{t-1} + e_t$ (negative size bias test); $e\sigma_t^2 = a + bS_{t-1}^+ e_{t-1} + e_t$ (positive size bias test), where $e\sigma_t^2$ are the squared standardised residuals, e_t^2/σ_t , S_{t-1}^- is a dummy variable taking the value of one when e_{t-1} is negative and zero otherwise, and $S_{t-1}^+ = 1 - S_{t-1}^-$. The joint test is based on the regression $e\sigma_t^2 = a + b_1 S_{t-1}^- + b_2 S_{t-1}^- e_{t-1} + b_3 S_{t-1}^+ e_{t-1} + e_t$. The joint test $H_0: b_1 = b_2 = b_3 = 0$, is an F test with 95% critical value of 2.60. (see chapter 3, section 3.6.3 for more details)

Figure 6.8: Time-varying volatilities of spot rates for three size dry bulk carriers



6.4.3.2. Volatility spillovers in the 1-year time-charter market

The maximum likelihood estimates of the VECM-GARCH(1,1-5) model for 1-year time-charter rates are in Table 6.6. Ljung-Box tests show that there is no serial correlation present in the standardised residuals. The F-test for ARCH effects indicates that there is no conditional heteroscedasticity in capesize and handysize equations. However, estimation results for panamax equation indicates that standardised residuals show ARCH effects⁸. Sign and size bias tests reject the existence of any asymmetric effect on volatilities across all equations. The estimated coefficient of degrees of freedom, ν , found to be 6.529, justifies the use of the student-t distribution for the conditional density function. The implied kurtosis is calculated as 5.37, which indicates excess kurtosis in residuals.

⁸ Different specifications of VECM-GARCH (p,q) are used to capture excess ARCH effects in the residuals for the panamax equation, however, the ARCH effects could not be removed completely for this model. Therefore, estimation results of the VECM-GARCH model with the least ARCH effects in the standardised residuals for panamax model; that is, a VECM-GARCH(1,1-5) are presented.

Table 6.6: Estimates of VECM-GARCH model for 1-year time-charter rates

Sample period 1980:1-1997:8

Equation (6.3)

$$\Delta \mathbf{z}_t = \boldsymbol{\mu}_0 + \sum_{i=1}^k \Gamma_i \Delta \mathbf{z}_{t-i} + \boldsymbol{\alpha} \boldsymbol{\beta}' \mathbf{z}_{t-k} + \boldsymbol{\Psi} \mathbf{D}_t + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{student-t}(0, \boldsymbol{\Sigma}_t, \nu)$$

$$\boldsymbol{\Sigma}_t = \mathbf{A} \mathbf{A}' + \mathbf{B} \boldsymbol{\Sigma}_{t-1} \mathbf{B}' + \mathbf{C} \boldsymbol{\varepsilon}_{t-1} \boldsymbol{\varepsilon}_{t-1}' \mathbf{C}' + \mathbf{S}1 \mathbf{u}_{1,t-1} \mathbf{u}_{1,t-1}' \mathbf{S}1' + \mathbf{S}2 \mathbf{u}_{2,t-1} \mathbf{u}_{2,t-1}' \mathbf{S}2' + \mathbf{S}3 \mathbf{u}_{3,t-1} \mathbf{u}_{3,t-1}' \mathbf{S}3'$$

Coeff.	Regressor	ΔLCSZ1_t		ΔLPMX1_t		ΔLHSZ1_t	
$\mu_{0,i}$	intercept	0.029**	(2.499)	0.019*	(1.906)	-0.017**	(-2.411)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.060**	(-2.991)	0.104**	(4.390)		
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.203**	(-4.606)	0.046**	(2.425)
$\gamma_{1,1i}$	(ΔLCSZ_{t-1})	0.280**	(4.780)				
$\gamma_{1,2i}$	(ΔLPMX_{t-1})	0.234**	(2.563)	0.255**	(3.586)		
$\gamma_{1,3i}$	(ΔLHSZ_{t-1})					0.311**	(5.709)
$\psi_{3,i}$	(D3 _t)					0.018**	(2.608)
$\psi_{6,i}$	(D6 _t)	-0.046**	(-2.680)	-0.045**	(-3.721)	-0.047**	(-3.348)
$\psi_{7,i}$	(D7 _t)			-0.030**	(-3.222)	-0.026**	(-4.393)
Conditional variance parameters							
	$a_{ii}, i=1,2,3$	0.034**	(3.785)	0.004	(0.801)	0.001	(0.356)
	a_{21}			0.019**	(2.550)		
	a_{31}			0.007**	(3.249)		
	a_{32}			0.006**	(2.200)		
	$b_{1,ii}, i=1,2,3$	0.714**	(6.678)	0.907**	(13.52)	0.954**	(37.97)
	$c_{1,ii}, i=1,2,3$	0.321**	(2.600)	-0.010	(-0.145)	0.149*	(1.724)
	$c_{5,ii}, i=1,2,3$			0.141**	(2.131)		
	ν			6.529**	(4.044)		
Volatility spillovers							
		Capesize		Panamax		Handysize	
$s1_{i,i}, i=2,3$	Capesize	---		-0.070 (-0.429)		0.079* (1.864)	
$s2_{j,j}, j=1,3$	Panamax	0.370	(1.072)	---		0.000 (0.000)	
$s3_{k,k}, k=1,2$	Handysize	-0.402	(-1.185)	0.094 (0.380)		---	
R-bar-squared		0.221		0.245		0.280	
Skewness		0.033	[0.844]	0.664	[0.000]	0.518	[0.003]
Kurtosis		1.404	[0.000]	2.049	[0.000]	2.004	[0.000]
J-B test for normality		22.30	[0.000]	50.71	[0.000]	43.29	[0.000]
Q(12)		17.68	[0.136]	18.80	[0.094]	16.14	[0.184]
ARCH(12)		0.922	[0.552]	2.473	[0.005]	0.704	[0.742]
Persistence		0.613		0.822		0.932	
Log-likelihood				993.48			
AIC				-17.89			
SBIC				-17.29			
Sign and size bias test							
Sign bias		0.578	[0.563]	0.976	[0.330]	1.573	[0.117]
Negative Size bias		-0.430	[0.687]	-0.287	[0.774]	-0.447	[0.654]
Positive Size bias		-0.844	[0.399]	-0.767	[0.444]	-1.212	[0.226]
Joint test for 3 effects		0.241	[0.867]	0.429	[0.732]	1.036	[0.377]

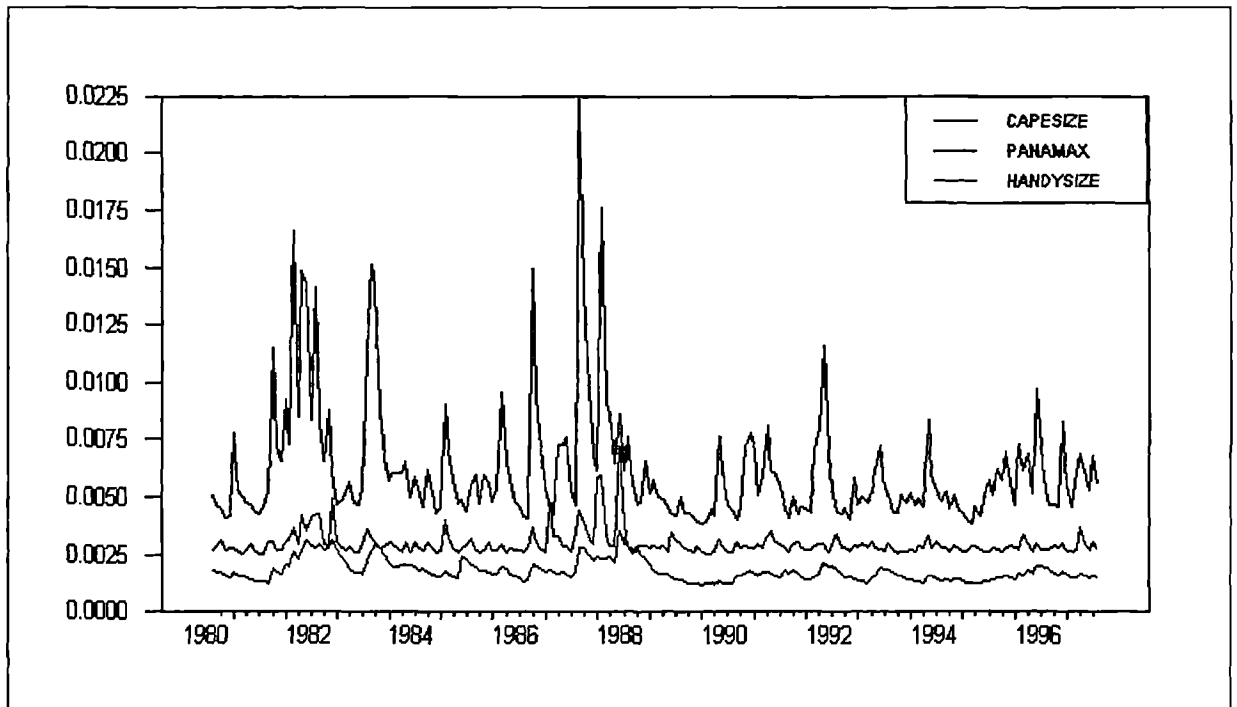
- LCSZ1, LPMX1 and LHSZ1 represent logs of capesize, panamax and handysize 1-year time-charter rates respectively.
- See also notes in Tables 6.2 and 6.5.

Turning to the parameters of the conditional variance in each market, significant coefficients of lagged variance and error terms indicate that time-charter volatilities are time-varying.

Based on the coefficients of variance equations, persistence factors ($b_{ii}^2 + c_{ii}^2$) are calculated as 0.613, 0.822 and 0.932 for capesize, panamax and handysize equations, respectively. There seem to be no spillover effects between volatilities as coefficients of s_{12j} , s_{2jj} , ($j=1, 3$) and s_{3kk} , ($k=1, 2$), are insignificant. The only exception is the unidirectional volatility transmission from the capesize to the handysize market, $s_{133} = 0.07$, which is significant at the 10% level. This is in contrast with what is observed in the spot market where volatility of capesize rates spillover to panamax rates. However, it can be argued that directions of spillover effects are once again from the market for larger vessels to the market for smaller vessels.

Time-varying volatility estimates of time-charter rates for three size vessels are plotted in Figure 6.9. A comparison between levels of time-varying volatilities in the time-charter market reveals that there is also a positive relationship between size and the level of volatilities; that is, capesize rates show higher time-varying volatility than panamax rates, and panamax spot rates show higher volatility than handysize rates. This is consistent with findings in Kavussanos (1996a). Also, it can be seen that 1-year time-charter volatilities do not follow similar patterns.

Figure 6.9: Time-varying volatilities of 1-year TC rates for three size dry bulk carriers



6.4.3.3. Volatility spillovers in the 3-year time-charter market

Table 6.7 reports the maximum likelihood estimation results of the VECM-GARCH for the 3-year time-charter market. The model seems to be well specified with no evidence of serial correlation or ARCH left in the standardised residuals. Sign and size bias tests also do not indicate any asymmetric effects on volatilities. The estimated coefficient of the degrees of freedom for the t-distribution, ν , is found to be 4.0002, justifying use of the student-t distribution for the conditional density function⁹.

Significant coefficients of lagged variance and error terms in the conditional variance model for all vessels indicate that volatilities of 3-year time-charter rates for these vessels are time-varying. Based on the coefficients of variance equations, persistence factors are calculated as 0.089, 0.475 and 0.756 for capesize, panamax and handysize equations, respectively. Turning to the parameters of volatility spillovers, significant coefficient of $s_{122}=0.244$ suggest that there is a uni-directional volatility spillover from capesize to panamax rates. This is in line with what is observed in the spot market, but not the 1-year time-charter market where unidirectional volatility spillovers effect from capesize to handysize rate is observed.

Time-varying volatility estimates of 3-year time-charter rates for three size vessels are plotted in Figure 6.10. A comparison between levels of time-varying volatilities of 3-year rates for different size vessels reveals a similar difference in levels as in the case of spot and 1-year time-charter market models; that is, volatility levels increase with vessel size. However, volatility patterns are not the same across sizes. A comparison between volatilities of 3-year time-charter rates (Figure 6.10) and those of spot and 1-year rates (Figure 6.8 and Figure 6.9, respectively) suggests that levels of estimated time-varying volatilities in the latter market are lower than spot and 1-year time-charter rates for each class. In other words, for each vessel, levels of conditional volatilities decrease as the duration of the contract increases.

⁹ Since the coefficient of the degrees of freedom should be greater than 4 for the kurtosis to be defined and it was not the case in this particular model, we restricted the coefficient of ν to vary between ($4 < \nu < 34$). This is done by using a logistic function, $\nu = [4 + 30 / (1 + e^{-(\nu^*)})]$, which allows ν^* to take any value, but ν is bound between 4 and 34. It should be noted that $\nu > 30$ indicates that the distribution is approximately normal.

Figure 6.10: Time-varying volatilities of 3-year TC rates for three size dry bulk carriers

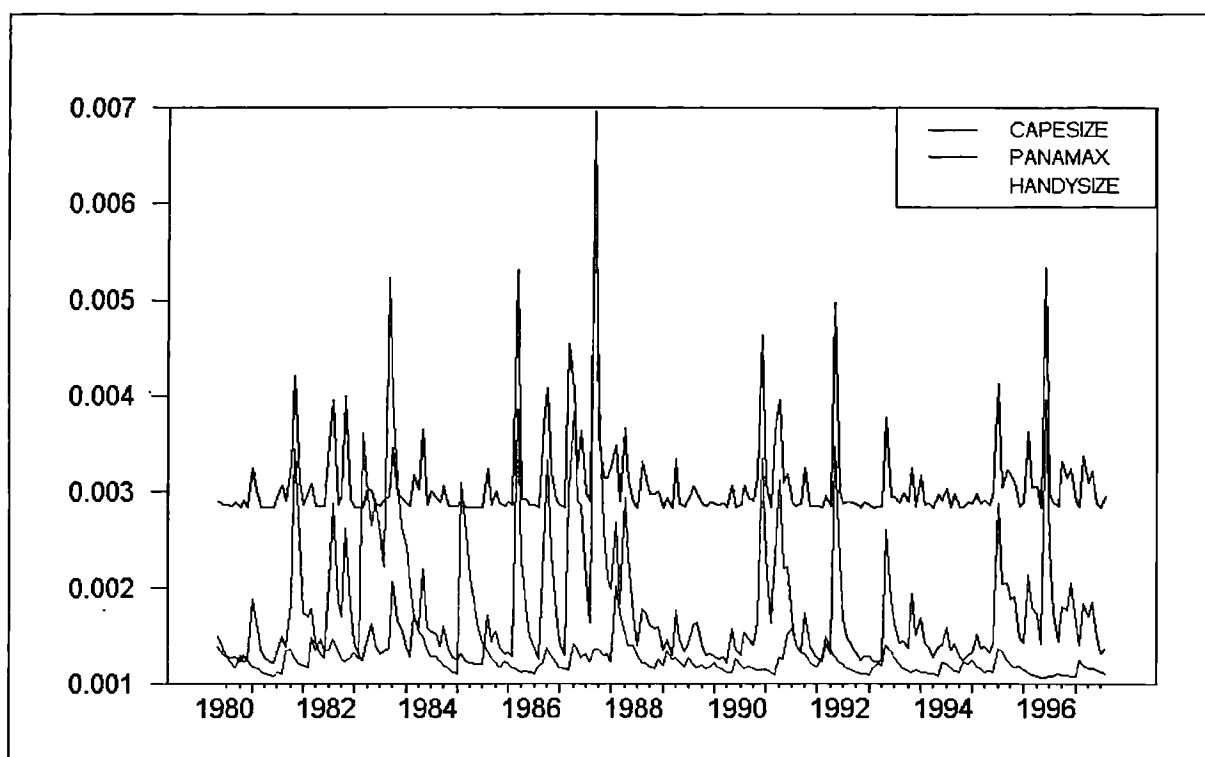


Table 6.7: Estimates of VECM-GARCH model for 3-year time-charter rates

Sample period 1980:1-1997:8

Equation (6.3)

$$\Delta z_t = \mu_0 + \sum_{i=1}^k \Gamma_i \Delta z_{t-i} + \alpha \beta' z_{t-k} + \Psi D_t + \varepsilon_t, \quad \varepsilon_t \sim \text{student-t}(0, \Sigma_t, \nu)$$

$$\Sigma_t = AA' + B\Sigma_{t-1}B' + C\varepsilon_{t-1}\varepsilon'_{t-1}C' + S1u_{1,t-1}u'_{1,t-1}S1' + S2u_{2,t-1}u'_{2,t-1}S2' + S3u_{3,t-1}u'_{3,t-1}S3'$$

Coeff.	Regressor	$\Delta LCSZ3_t$		$\Delta LPMX3_t$		$\Delta LHSZ3_t$	
$\mu_{0,i}$	intercept	0.033**	(4.492)	0.003	(0.773)	-0.010**	(-2.661)
$\alpha_{1,i}$	(ECT _{1,t-1})	-0.061**	(-4.760)	0.040**	(2.320)	-0.032**	(-2.307)
$\alpha_{2,i}$	(ECT _{2,t-1})			-0.075**	(-3.529)	0.072**	(2.816)
$\gamma_{1,1i}$	($\Delta LCSZ_{t-1}$)	0.243**	(5.276)				
$\gamma_{1,2i}$	($\Delta LPMX_{t-1}$)	0.238**	(3.410)	0.343**	(6.109)	0.274**	(5.163)
$\gamma_{1,3i}$	($\Delta LHSZ_{t-1}$)	0.132**	(2.384)			0.193**	(3.144)
$\psi_{8,i}$	(D8 _t)	0.032**	(3.826)	0.016*	(2.154)	0.012*	(1.715)

Conditional variance parameters

$a_{ii}, i=1,2,3$	0.050**	(13.209)	0.015**	(5.564)	0.006	(0.181)
a_{21}			0.013**	(5.264)		
a_{31}			0.003	(1.214)		
a_{32}			0.018**	(3.754)		
$b_{ii}, i=1,2,3$	0.176**	(4.106)	0.624**	(7.378)	0.835**	(8.668)
$c_{ii}, i=1,2,3$	0.240*	(1.686)	0.292**	(2.825)	-0.242**	(-2.870)
ν'			11.91**	(8.330)		
ν			4.00020			

Volatility spillovers

		Capesize		Panamax		Handysize	
$s1_{i,1}, i=2,3$	Capesize	---		0.244**	(3.421)	-0.0003	(-0.004)
$s2_{j,1}, j=1,3$	Panamax	0.212	(0.918)	---		-0.004	(-0.020)
$s3_{k,1}, k=1,2$	Handysize	-0.0001	(-0.000)	0.0006	(0.006)	---	

R-bar-squared	0.241		0.193		0.193	
Skewness	-0.477	[0.005]	0.424	[0.013]	0.527	[0.002]
Kurtosis	3.602	[0.000]	1.910	[0.000]	9.120	[0.000]
J-B test for normality	120.5	[0.000]	37.87	[0.000]	730.4	[0.000]
Q(12)	12.72	[0.389]	11.87	[0.455]	12.88	[0.377]
ARCH(12)	0.846	[0.603]	1.330	[0.205]	1.145	[0.327]
Persistence	0.089		0.475		0.756	
Log-likelihood			1191.32			
AIC			-19.62			
SBIC			-19.04			

Sign and size bias test

Sign bias	1.503	[0.134]	-1.941	[0.053]	-0.517	[0.605]
Negative Size bias	-0.092	[0.927]	0.298	[0.766]	0.181	[0.857]
Positive Size bias	-0.817	[0.414]	-0.042	[0.988]	-0.522	[0.602]
Joint test for 3 effects	1.183	[0.317]	2.407	[0.070]	0.374	[0.769]

- See also notes in Tables 6.2 and 6.5.
- LCSZ3, LPMX3 and LHSZ3 represent log of capesize, panamax and handysize 3-year time-charter rates respectively.
- ν' is a parameter in the logistic function $\nu = [4 + 30/(1 + e^{\nu'})]$ used to restrict ν , the parameter of degrees of freedom for the student-t distribution, between 4 and 34. Note that $\nu > 30$ implies a normal distribution.

6.5. Discussion

Three different systems (for spot, 1-year and 3-year time-charter rates) of VECM and VECM-GARCH models for freight rates for three size vessels have been estimated over the period January 1980 to August 1997 and the best models in terms of specification and diagnostics have been selected for analysis. Results show that there are two cointegrating vectors present in each VECM model. This implies that, in each model, there are two unique long run relationships between three freight series, which means that there is only one common stochastic trend that drives the three series in each model (Stock and Watson, 1988). The common stochastic trend that drives the three series in each market is most likely demand for international seaborne trade, which itself depends on world economic activity.

The short run dynamics of freight rates for different size vessels in each market can be attributed to changes in those idiosyncratic factors that influence the supply and demand factors for each individual size category in the dry bulk market. Among these factors are: production, consumption and seasonal factors in trade in commodities that are carried by these vessels, changes in port infrastructure and routes between sources of supply and demand for commodities. Technological advances on the supply side of the market for freight services are important factors driving freight rates too. Also, the fact that ships of adjacent size class may be used as substitutes when the market for one size class is relatively more profitable may increase the short term dynamics between freight rates.

Impulse response analyses performed reveal that the interaction between freight rates for different size vessels are higher in the spot market than 1-year and 3-year time-charter markets. This might be due to the difference between the charterers' decision making process on hiring vessels in the spot market and time-charter markets. Decisions on hiring vessels in the spot market are thought to be more instantaneous, based on short terms and sometimes urgent transportation requirements. In contrast to the spot market, decisions made by charterers to hire vessels in the period market are in general based on detailed analysis of costs and transportation needs. For example, consider a charterer operating in the spot market. Since spot rates are paid in \$/ton for certain amount of cargo, the charterer does not need to worry about voyage costs (bunkers, etc.) and consequently specifications of the vessel in terms of consumption, size, age, etc. Therefore, the charterer may accept any offer

(perhaps the cheapest one) as long as specifications of loading and discharging ports' facilities and approach permit the safe passage and berthing of the vessel. On the other hand, since freight rates in the time charter market are in \$/day, duration of contracts are long, and charters are responsible for voyage costs, they carefully study costs and requirements and hire the appropriate size vessel. In other words, the fact that charterers are more concerned about hiring the right size vessel in long period shipping contracts in order to optimise their transportation costs may reduce the degree of substitution between different size vessels in period markets compared to the spot market.

Furthermore, there might be situations where owners operating in the spot market find that even a part cargo is better than waiting for a full load. They may even accept a part cargo on a back haul voyage rather than returning to the loading area in ballast. Such decisions by owners in the spot market increase the competition between vessels of different sizes for cargo and consequently increase the interaction between their freight rates. As a result, shocks to freight rates for any size vessel in the spot market are transmitted across to freight rates for other size categories faster than shocks in the period charter markets.

Results of Granger-causality tests indicate that the direction of information flow on short run dynamics of mean of freight rates in all markets (spot, 1-year and 3-year time-charter) is from small to larger vessels. This suggests that freight rates for small size vessels lead the market and pick up the information faster than larger ones.

Analysis of spillover effects between volatilities of freight rates for different size vessels in the spot and period markets reveal that volatilities of freight rates for capesize vessels affect volatilities of freight rates for smaller vessels across the contract maturity spectrum. Specifically, shocks to the capesize market are transmitted to the market for smaller vessels without any feedback effects. The unidirectional volatility spillovers from capesize market to the market for smaller vessels can be explained by the fact that the market for larger vessels is more sensitive to news than the market for smaller size vessels. This is because small vessels are more flexible than capesize vessels in terms of trading (see Kavussanos 1996a), which allows them to operate in transportation of a large number of commodities over different routes as opposed to larger vessels which operate in few routes and carry limited number of commodities. As a result, shocks to freight rates for smaller vessels, due to changes in demand for transportation of certain types of commodities over a particular route

may be absorbed by employment of these vessels in other trading routes. On the other hand, the number of routes and trades are limited for large vessels. As a result, unexpected changes in the market for these vessels may have a greater impact on the whole dry bulk market compared to the effect of unexpected events the market for smaller vessels.

In addition, the carrying capacity of larger vessels compared to smaller ones and the agents' expectations about movements of vessels between markets might be important factor in causing volatility spillovers. Given that the carrying capacity of a capesize vessel is twice as a panamax vessel (three times as a handysize vessel), shift of one capesize vessel to the panamax market, during the capesize market downturn or a relatively good panamax market, may satisfy the demand for two panamax vessels. In an opposite situation, two panamax vessels are required to satisfy the demand for one capesize vessel. This suggests that shift of larger vessels to markets for smaller vessels may have greater impacts on the supply and demand balance in markets for smaller vessels compared to impacts on supply and demand balance in the market for larger vessels caused by shift of smaller vessels to the market for large vessels.

Furthermore, estimated multivariate volatility models revealed that levels of time-varying volatilities of freight rates in each of the spot and period (1-year and 3-year) markets are directly related to vessel size; that is, the level of time-varying volatility is higher for larger vessels compared to smaller ones. These results are consistent with those of Kavussanos (1996a). Results also indicate that the level of time-varying volatilities for each size vessel are also related to the duration of contract; that is, the longer the duration of contract, the lower the level of time-varying volatility. This is because time-charter (period) rates reflect weighted average of expected future spot rates (see chapter 5) and therefore sharp changes in spot rates are smoothened when time-charter rates are formed. Also, spot rates are more influenced from current market conditions and news, whereas period rates depend on agents' expectations about the future market conditions over a period of time.

6.6. Conclusions

In this chapter, interrelationships between freight rates for three different size dry bulk carriers have been examined for spot, 1 year and 3 years time-charter rates. Since freight rates are nonstationary, the cointegrating relationships between variables are utilised for analysis through VECM estimation. The models are extended to consider spillover effects between variances in each system. Statistical tests (Johansen 1988 and 1991) indicate the existence of two cointegrating vectors in each system, suggesting one common stochastic trend driving the series in the long run. This trend is thought to be international trade.

Results of Granger-causality tests reveal that, in general, the direction of information flow on short run dynamics of mean of freight rates is from small to larger vessels, which suggests that the market for smaller vessels might be the leading market. This may be due to their share of the market in terms of the number of commodities they transport as opposed to the market for larger vessels which is limited. Thus, events and changes in international seaborne trade may first affect the freight for smaller vessels and then transmitted to freight rate for larger ones as only the changes in demand for transportation of a few commodities drive freight rates for large vessels.

Generalised Impulse Response analysis on VECM models reveal that shocks to freight rates have permanent effects on levels of freight rates. It also suggests that the interaction between freight rates for different size vessels is higher in the spot market compared to time charter markets. This is attributed to the fact that the degree of substitution between different size vessels is higher in the spot market compared to period markets. This is mainly because of the difference between spot and time charter contracts in terms of long term commitments of charterers as charterers operating in period markets are more concerned about the size of the vessel and costs, and try to hire a vessel with optimum capacity and costs.

Multivariate volatility models reveal that there are unidirectional volatility spillover effects from larger to smaller size vessels in the spot and period markets. This is attributed to the operational inflexibility and sensitivity of freight rate for larger vessels to unexpected news compared to small ones. This sensitivity of the market for larger vessels cause higher

fluctuations in freight rates for larger vessel, which may force them to switch to the market for smaller vessels and disturb the supply and demand balance in those markets.

7 CHAPTER SEVEN

EFFICIENT PRICING OF SHIPS IN THE DRY BULK SECTOR

7.1. Introduction

The efficiency of dry bulk freight markets for capesize, panamax and handysize has been investigated in chapter 5. It was found that the EHTS fails to explain the relationship between long and short term shipping contracts. Failure of the EHTS is explained by the existence of time-varying risk premia, which have been attributed to a number of uncertainties surrounding the spot market in comparison to the time-charter market. Such uncertainties include; spot freight rate volatility, fluctuations in voyage costs, unemployment risk, and relocation costs.

Dynamic interrelationships between freight rates for three size bulk carriers and freight rate volatility spillovers between the markets have also been examined in chapter 6. It was found that freight rate levels for different size dry bulk carriers are closely interrelated and there are spillovers between their time-varying volatilities. Interactions between freight rates are found to be higher between sub-sectors in the spot compared to period charter markets. This is attributed to the fact that charterers are more concerned on selecting appropriate size vessels in the period charter markets compared to the spot market due to operational costs and their transportation requirements.

Having investigated the properties of freight sub-markets and the interaction between them, this chapter considers two other important markets of the dry bulk shipping industry; that is, the markets for second-hand and newbuilding vessels. The aim of this chapter is then to investigate the EMH in the markets for second-hand and newbuilding dry bulk vessels. Different statistical tests are performed to examine the validity of the EMH in price formation. These tests include; 1) informational efficiency tests on unpredictability of excess returns, 2) restrictions implied by the present value relationship on the VAR model, 3) and variance ratio tests (Campbell and Shiller 1987 and 1988). Having failed to find support for the present value model and price efficiency in this sector, an attempt is made to relate risk and return using GARCH-M models, where the excess returns on shipping investments are related to the variance of the excess returns' forecast errors.

It is important to investigate whether the markets for second-hand and newbuilding dry bulk vessels are efficient and agents price assets rationally, since failure of the EMH, if it is not due to the existence of time-varying risk premia, may signal arbitrage opportunities. For example, if the market for vessels is found to be consistently inefficient and prices deviate from their rational values, then trading strategies can be adapted to exploit excess profit making opportunities. Thus, when prices are lower than their fundamental values¹, then buying and operating these vessels (or selling when prices rise) might be profitable since they are under-priced in comparison to their future profitability (i.e. the earnings from freight operations). On the other hand, when prices are higher than their corresponding rational values it might be profitable to charter vessels rather than buying them since they are overpriced in comparison to their expected future profitability. Therefore, from the point of view of both asset players and long term ship operators, it is important to understand the pricing mechanism as well as the efficiency of the market for ships.

Despite numerous studies in the literature on testing the EMH in various capital and financial markets², there are only a few studies in the literature on real estate market, which directly deal with this issue in markets for real assets³. Considering ships as real assets with limited economic life, some researchers found it interesting to look at the market for ships and investigate the ship price formation. In fact, it was not until the work of Beenstock (1985) and Stranden (1984) on ship price formation, which triggered a series of studies such as Wright (1993), Hale and Vanags (1992) and Glen (1997) on testing efficient pricing in the market for ships. It has to be mentioned that both Stranden (1984) and Beenstock (1985) assume that ships are capital assets and use a present value model for ship price determination. However, they differ in their assumptions regarding the formation of investors' expectations.

¹ Here by fundamental or rational value of assets we mean the discounted present value of the expected stream of income that they generate over their lifetime.

² For example, Fama and French (1988) and Poterba and Summers (1988) examine long horizon predictability of the US stock returns, Campbell and Shiller (1987 and 1988) examine the efficiency of US stock prices using the present value relationship, Pesaran and Timmermann (1994) investigate the predictability of excess returns in the UK (over one year, one quarter and one month) for the period 1954 to 1971, Cuthbertson et al (1999) examines the EMH in different sectors of the UK stock market for the period 1965 to 1992.

³ For example, Case and Shiller (1989) investigate the efficiency of the market for family homes in the U.S., Meese and Wallace (1994) test the efficiency of house prices in San Francisco, and Clayton (1998) examines the predictability of excess returns on properties in Vancouver (B.C.). Using different methodologies and data sets, they all conclude that the real estate market is inefficient.

Stranden (1984) investigates the price formation in the dry bulk and tanker sectors, over the period 1968 to 1981 using annual data. She finds that prices are more influenced by changes in the long term equilibrium profits than changes in current operating profits and argues that such a relationship can be viewed as support for the validity of the semi-rational expectations assumption in ship price formation. Beenstock (1985) proposes a dynamic general equilibrium model for the determination of ship prices, in which prices are related to current and expected freight rates and world economic activity under the assumption of RE and the EMH regardless of the validity of these hypotheses. Wright (1993) investigates the validity of three different forms of the expectations hypothesis, namely rational, static and adaptive expectations, in the formation of second-hand prices for small dry bulk carriers for the period 1980 to 1990 using quarterly data. Wright finds support for all hypotheses and concludes that because of the nature of the shipping industry in terms of its exposure to many factors such as the world economy, political developments and changes in climate, agents may use different forms of expectations depending on their feelings about the market.

Vergottis (1988) investigates the efficiency of the market for newbuilding vessels, using regression tests on quarterly newbuilding and second-hand price series from 1960 to 1985 and reports inconclusive results. Hale and Vanags (1992) test weak form efficiency in the second-hand market for three sizes of dry bulk carriers for the period October 1979 to July 1988 using the Engle-Granger (1987) cointegration technique. Their results are also inconclusive and they suggest that the validity of the EMH in the market for ships should be considered cautiously. Glen (1997) re-examines the informational efficiency in size disaggregated dry bulk and tanker sectors for the period 1980 to 1995 using Johansen's (1988) multivariate cointegration technique. Despite employing a more powerful test, in terms of identifying cointegrating relationships between variables compared to Hale and Vanags (1992) approach, he fails to find conclusive evidence on the efficiency of the market for ships as he finds that lagged price changes in one size vessel improve predictability of price changes in other size vessels in the dry bulk sector.

In sum, despite several attempts made in the literature to test the efficiency of the market for ships, it is still not clear whether markets for merchant ships are efficient. This might be due to the following reasons. First, studies such as , Beenstock (1985), Stranden (1984), Vergottis (1988) and Wright (1993) fail to recognise the stochastic properties of variables, which is argued to be important in regressions analysis of time series and the validity of

inferences (see chapter 3 for more details). Second, as it is shown in chapter 2, studies such as Wright (1993), Hale and Vanags (1992) and Glen (1997) do not employ the appropriate formulation for testing the EMH. For example, Wright (1993) employs a present value model in the determination of ship prices, which seems to be inappropriate because not only the discount rate is assumed to be constant, but also the discounted resale value of the vessel is missing from the model. On the other hand, Hale and Vanags (1992) and Glen (1997), despite recognising the stochastic properties of ship prices, fail to recognise that the existence of cointegrating relationships between prices is only a necessary condition for the validity of the EMH and not a sufficient condition. This is because the existence of cointegrating relationships between price series implies that prices move together in the long run but it does not rule out the existence of excess profit making opportunities. Finally, most of these studies investigate the validity of the EMH over a relatively short period of time, which may cause period specific biases as shipping is characterised as a cyclical and volatile industry (see Stopford 1997 and 1998); thus, considering only part of the shipping cycle may affect the results.

Therefore, the aim of this chapter is to investigate the validity of the EMH and RE, in ship price formation over a relatively long period (1976 to 1998), which is thought to cover several cycles. In addition, apart from standard tests for market efficiency, such as orthogonality and unpredictability of excess returns on investment which are used extensively in the financial economics literature, we employ recently developed testing techniques proposed by Campbell and Shiller (1987 and 1988) to examine the hypothesis. We extend their methodology further by applying it to real assets with limited economic life. Moreover, we explain failure of the EMH by relating excess returns to investors' perceptions of risk and model such relationships through recently developed GARCH-M models.

The structure of this chapter is as follows. Section 7.2. presents the theoretical background and the methodologies proposed in the asset pricing literature for testing the EMH. Section 7.3 presents the methodology, which is used to model and measure time-varying risk premia in the formation of ship prices. The data and their properties are discussed in section 7.4. Section 7.5 presents the empirical results. The discussion and implications of the results are in section 7.6 and conclusions are the subject of the last section.

7.2. The Efficient Market Hypothesis

A market is said to be efficient if asset prices in that market, with rational investors, are determined competitively through the interaction between supply and demand, and fully and instantaneously incorporate all available information. In an efficient market, rational investors are believed to utilise information that is relevant in the determination of asset prices or returns immediately to exercise any excess profit making opportunities. Therefore, according to the EMH, there should be no opportunities for making profits in excess of what the rational investors expect to make⁴.

There are three different but related approaches in the financial economics literature for testing different implications of the EMH. The first approach is based on the presumption that in an efficient market excess returns are independent of historical information available at time t or earlier, which implies that excess returns should be unpredictable. The second approach, which is also based on the assumption of unpredictability, investigates whether risk-less trading strategies, based on the available information set, can generate excess profits and outperform the market. The third approach uses the assumption that investors in an efficient market are rational, therefore prices in such a market should reflect the rational value of the underlying asset, which is in fact the expected profitability of the asset.

In this chapter we do not pursue the EMH tests based on profitable trading strategies. Instead we focus on tests based on the unpredictability of excess returns as well as rational valuation formula, RVF, and present value models. This is because testing the EMH based on profitable trading strategies employs ad-hoc models and arbitrary investment strategies, and given the difficulties in identifying the behaviour of investors in the market for ships, it might not be the most appropriate approach.

7.2.1. Unpredictability of Excess Returns and EMH

Investors in the shipping industry, like investors in any other sector of the economy, are not only interested in earnings from the day to day operation of ships, they are also interested in

⁴ See chapter 1, section 1.7 for more detail on the EMH and its implications on different markets.

capital gains from such investments. Therefore, from the investors' point of view expected one period returns, $E_t R_{t+1}$, on shipping investments is equal to the expected one period capital gain between time t and $t+1$, $(E_t P_{t+1} - P_t)/P_t$, plus the expected return from operation, $E_t \Pi_{t+1}/P_t$, where $E_t P_{t+1}$ is the expected price at time $t+1$ and $E_t \Pi_{t+1}$ is operating profit⁵ over the period t and $t+1$. Mathematically,

$$E_t R_{t+1} = \left(\frac{E_t P_{t+1} - P_t + E_t \Pi_{t+1}}{P_t} \right) \quad (7.1)$$

or in logarithmic form

$$E_t r_{t+1} \equiv \ln(1 + E_t R_{t+1}) = \ln(E_t P_{t+1} + E_t \Pi_{t+1}) - \ln(P_t) \quad (7.2)$$

Similarly, the log expected return over n periods, i.e. from period t to $t+n$ can be written as

$$E_t r_{t,t+n} = E_t r_{t,t+1} + E_t r_{t+1,t+2} + \dots + E_t r_{t+n-1,t+n} = \sum_{i=1}^n E_t r_{t+i-1,t+i} \quad (7.3)$$

One implication of the EMH, assuming investors are risk neutral, is that excess returns on shipping investments over returns on other types of investment available to investors should be unpredictable (Fama and French, 1988). In other words, the excess return, exr_{t+i} , on a shipping investment over alternative investment opportunities (the market return) should not be correlated with information available at time t . Otherwise, if excess returns can be predicted, then there will be riskless profitable opportunities, which invite investors to adjust their portfolios to maximise their end of period profit. In an efficient market such adjustments eliminate any excess profit making opportunities.

It is then possible to define the expected one period excess return, $E_t exr_{t+1}$, as the expected return on one period shipping investment, r_{t+1} , over the market return, r_t^m , as follows

$$E_t exr_{t+1} = E_t r_{t+1} - r_t^m \quad (7.4)$$

⁵ $E_t \Pi_{t+1}$ is assumed to be equal to the time-charter equivalent less the operating cost. Also it is assumed that expected operating profits between time t and $t+1$, $E_t \Pi_{t+1}$, are collected at time $t+1$, i.e. the end of the investment period.

Here, the return on alternative investments (the market return) is assumed to be the LIBOR plus a margin (e.g. 1%), r_t^m , as this is usually the case with shipping loans. Therefore, if investors expect that the return on shipping, $E r_{t+1}$, is higher than the market return, r_t^m , then they will be willing to invest on ships. It can be seen from equation (7.4) that in order to foresee the excess return, one needs to know the expected return on shipping, which is given by equation (7.1). Assuming investors form RE about expected ship prices and operating profits next period,

$$E_t P_{t+1} = P_{t+1} + \omega_{t+1} \quad (7.5)$$

$$E_t \Pi_{t+1} = \Pi_{t+1} + \nu_{t+1}$$

where ω_t and ν_t are orthogonal RE forecast errors with the following properties;

$$E(\omega_{t+1})=0, E(\omega_{t+1}, \Lambda_t)=0 \quad \text{and} \quad E(\omega_{t+1}, \omega_{t-j})=0 \quad ; \quad j=0,1,2,\dots$$

$$E(\nu_{t+1})=0, E(\nu_{t+1}, \Lambda_t)=0 \quad \text{and} \quad E(\nu_{t+1}, \nu_{t-j})=0 \quad ; \quad j=0,1,2,\dots$$

where Λ_t is the information set available at time t (past prices, profits, returns, etc), $E(\omega_{t+1})=0$ and $E(\nu_{t+1})=0$ indicate that forecast errors should have zero mean, and $E(\omega_t, \omega_{t-j})=0$ and $E(\nu_t, \nu_{t-j})=0$, imply that forecast errors are not correlated. Expected returns can be obtained by substituting actual price and operating profit values at $t+1$ in (7.1) and solving for expected returns. Hence, one period excess returns, based on RE, can be written as

$$exr_{t+1} = r_{t+1} - r_t^m = \varepsilon_{t+1} \quad (7.6)$$

where $\varepsilon_{t+1} = \nu_{t+1} + \omega_{t+1}$ and the RE assumptions in equation (7.5) should still hold. Therefore, it is possible to investigate the validity of the joint hypotheses of RE and the EMH by testing the excess return series for serial correlation and predictability using the following regression

$$exr_{t+1} = \alpha_0 + \alpha_1 exr_t + \alpha_2 exr_{t-1} + \dots + \alpha_p exr_{t-p} + \gamma \Lambda_t + \eta_{t+1}, \quad \eta_{t+1} \sim iid(0, \sigma_\eta^2) \quad (7.7)$$

and testing whether $\gamma=0$ and $\alpha_i=0$, for $i=1,\dots,p$, where Λ_t is the information set available at time t other than lagged excess returns, which may be used to predict excess returns⁶.

Sale and purchase of ships normally involves the lengthy process of negotiations through brokers, inspections by surveyors and preparation of necessary paper work by banks until the actual delivery. This process may take any time between a few of weeks to several months. On the other hand, the time span between ordering a newbuilding vessel and the actual delivery may take much longer, i.e. any time between 6 months to one year.

In order to test the joint hypothesis of EMH and RE, which implies unpredictability of excess returns on shipping investments, we consider two cases of 1 and 3-month excess holding period returns. It is also assumed that second-hand vessels purchased and sold within a short period (1 to 3 months) retain their vintage and are considered as the same age (for example, 5-years old). Furthermore, we only consider the return on 5 years old second-hand dry bulk carriers at this stage, since newbuilding vessels are not normally available for immediate trade.

7.2.2. Profitable trading strategies and the EMH

Since the EMH implies that abnormal returns on riskless trading strategies based on available information are zero, any significant and persistent profitable trading opportunities, above what is required to compensate the risk, can refute the EMH. The existence of such excess profit making opportunities is known as stock market anomalies. A large number of studies in the literature are devoted to detecting and explaining stock market anomalies using calendar effects, financial announcements and other important events. For example, Keane (1983) and Brockman (1997) find significant calendar effects in stock returns. De Bondt and Thaler (1989) and Jegadeesh and Titman (1993) find that trading strategies based on accounting ratios and using winners' and losers' portfolios earns abnormal profits. Levis (1989) also reports profitable investment strategies based on dividend yield, price-earnings ratios, and share prices. Reinganum (1983) finds that risk adjusted returns are higher for small-caps

⁶ The information set may include variables such as lagged freight rates, voyage costs, operating costs, interest rates, etc. which may be used by investors in predicting future returns on shipping investments.

compared to large-caps. Lee et al (1990) and Byrley (1991) find excess profit making and arbitrage opportunities when trading in close end mutual funds.

A notable example of this type of test of the EMH is Pesaran and Timmermann (1994). They first investigate the predictability of excess returns on two stock indices, i.e. S&P 500 and Dow Jones for the period 1960 to 1990 on monthly, quarterly and annual basis. They find that predictability of excess returns increases with the duration of the holding period. They also test whether active trading strategies (switching between the index and bonds) based on some predetermined criteria outperforms the passive (buy and hold) trading strategy, when transaction costs are considered. They report that an annual switching strategy yields higher returns than the buy and hold approach, even when transaction costs are high. However, they find that a monthly and a quarterly switching strategy outperform the passive strategy only when transaction levels are low.

There are two main problems with this type of test for the EMH. First, actual trading strategies based on predetermined criteria (e.g. prediction of excess returns) may indicate market imperfections and result in excess profits, even when adjusted for transaction cost. However, they do not incorporate the higher levels of risk associated with active trading as such strategies involve predicting price movements and switching between investments. Therefore, one has to test whether risk adjusted measures, such as Sharpe and Treynor indices⁷ of mean variance efficiency, to investigate whether trading strategies actually outperform alternative strategies. Second, profitable trading strategies are, in general, based on relatively ad-hoc switching models and arbitrary investment approaches. As a result, it is difficult to examine variety of trading strategies and rule (e.g. Markov Regime Switching, Trend and Moving Average strategies, etc) and identify amongst them the most profitable trading method for shipping investments, even if such a method exists.

⁷ These are indices, which measure the expected excess returns per unit risk. For example, for any asset or portfolio a , the Sharpe Ratio is defined as the mean excess return divided by the standard deviation of return, $sr_a = (\mu_a - R_f) / \sigma_a$. Where, sr_a is the Sharpe Ratio, μ_a is the mean returns, R_f is the risk free rate and σ_a is the standard deviation of expected excess returns (see Campbell, Lo and MacKinlay, 1997 for more details).

7.2.3. Present value models and tests for market efficiency

Present value models have been used to test whether rational agents price assets efficiently. This refers to the third approach of testing the EMH (see Section 7.1), given the form of expectations on which future cash flows are based. Tests for the EMH based on present value models compare the actual price of the asset to its fundamental value, the latter being the discounted present value (DPV) of the expected future cash flows from holding the asset. The EMH implies that these two values should be equal, at least in the long run. However, there might be divergences in the short term due to a variety of reasons, such as time-varying risk premia and speculative trades, which may result in the EMH to fail.

According to the present value relationship, the price of a vessel at time t , P_t , should be equal to the expected future price of the vessel, $E_t P_{t+1}$, plus the expected operating profits in that period, $E_t \Pi_{t+1}$, discounted by the expected return, $E_t R_{t+1}$. Rearranging equation (7.1) and solving for P_t in terms of the expected price of the vessel, expected operational profits and expected rate of return, results in the following expression.

$$P_t = \left(\frac{E_t P_{t+1} + E_t \Pi_{t+1}}{1 + E_t R_{t+1}} \right) \quad (7.8)$$

Equation (7.8) can be solved by forward recursive substitutions to yield the following present value model

$$P_t = \frac{E_t \Pi_{t+1}}{(1 + E_t R_{t+1})} + \frac{E_t \Pi_{t+2}}{(1 + E_t R_{t+1})(1 + E_t R_{t+2})} + \dots \quad (7.9)$$

$$+ \frac{E_t \Pi_{t+n}}{(1 + E_t R_{t+1}) \dots (1 + E_t R_{t+n})} + \frac{E_t P_{t+n}^{sc}}{(1 + E_t R_{t+1}) \dots (1 + E_t R_{t+n})}$$

or

$$P_t = \sum_{i=1}^n \left(\prod_{j=1}^i (1 + E_t R_{t+j})^{-1} \right) E_t \Pi_{t+i} + \left(\prod_{j=1}^n (1 + E_t R_{t+j})^{-1} \right) E_t P_{t+n}^{sc} \quad (7.10)$$

where, $E_t P_{t+n}^{sc}$ is the expected resale or residual value of the vessel after n periods.

Present value models with a constant discount factor

Assuming that shipowners expect a constant required rate of return on their investment, $E_t R_{t+1} = R$, equation (7.8) can be written as

$$P_t = \delta E_t P_{t+1} + \delta E_t \Pi_{t+1} = \delta (E_t P_{t+1} + E_t \Pi_{t+1}) \quad (7.11)$$

where, $\delta = (1/(1+R))$. Also (7.9) or (7.10), can be written as,

$$P_t = \sum_{i=1}^n \delta^i E_t \Pi_{t+i} + \delta^n E_t P_{t+n}^{SC} \quad (7.12)$$

Assuming the transversality condition holds (i.e. $\lim_{n \rightarrow \infty} \delta^n E_t P_{t+n}^{SC} = 0$), equation (7.12) can be written as

$$P_t = \sum_{i=1}^{\infty} \delta^i E_t \Pi_{t+i} \quad (7.13)$$

Equation (7.13) implies that if the market is efficient and no bubbles are present, the price of the vessel at each point in time should be equal to the sum of discounted present values of expected operating profits over the economic life of the vessel. Equations (7.12) and (7.13) are known as the rational valuation formula, RVF, where the RHS represents the fundamental value or theoretical price of the vessel.

Present value models with a time varying discount factor

Using a first order Taylor series expansion Campbell and Shiller (1988) show that equation (7.2) can be linearised around the geometric mean of P and Π to give

$$\ln(1 + E_t R_{t+1}) = \rho \ln(E_t P_{t+1}) + (1 - \rho) \ln(E_t \Pi_{t+1}) - \ln P_t + k \quad (7.14)$$

Where $\rho = \bar{P}/(\bar{P} + \bar{\Pi})$, $k = -\ln(\rho) - (1 - \rho)\ln(\bar{\Pi}/\bar{P} - 1)$, therefore, letting $p_t = \ln(P_t)$, $E_t p_{t+1} = \ln(E_t P_{t+1})$, $E_t r_{t+1} = \ln(1 + E_t R_{t+1})$ and $E_t \pi_{t+1} = \ln(E_t \Pi_{t+1})$ equation (7.14) can be written as

$$p_t = \rho E_t p_{t+1} + (1 - \rho) E_t \pi_{t+1} - r_{t+1} + k \quad (7.15)$$

which can be solved forward recursively to yield

$$p_t = \sum_{i=0}^{n-1} \rho^i (1 - \rho) E_t \pi_{t+1+i} - \sum_{i=0}^{n-1} \rho^i E_t r_{t+1+i} + \rho^n E_t p_{t+n}^{sc} + k(1 - \rho^n)/(1 - \rho) \quad (7.16)$$

where p_{t+n}^{sc} represents the residual value of the asset after n periods. The advantage of the above transformation (linearisation of (7.10)) is that (7.16) allows for time varying discount rates in the present value model in contrast to (7.12), where discount rates are assumed to be constant. This is important when investigating the EMH since present value models with constant discount rates may not be appropriate and would lead to bias results and wrong inferences.

7.2.3.1. Variance ratio test of present value models

Several studies in the literature are devoted to examining different implications of the EMH in various markets and over different time periods. In the pioneering work of Shiller (1981) on the predictability of stock prices through their fundamentals a set of variance bounds tests have been proposed to compare the behaviour of the actual price and the theoretical price implied by the RVF. This argument is derived and adapted for shipping investments in what follows.

In order to test the validity of the RVF in ship price formation, it is necessary to use data on expected profits from shipping operations during the life of the vessel as well as the expected scrap value of the vessel. Since such data are not available, a model should be used to forecast the future earnings and scrap prices. Shiller (1981) proposes a way to overcome this problem by assuming that investors' expectations are rational. That is, they use all available information in order to predict the future values of those variables under question. The RE assumption implies that agents do not make systematic errors in their forecasts. Shiller (1981)

suggests using the actual values of variables on the RHS of equations (7.12) and (7.13) and calls the sum of discounted present values the *perfect foresight price*, P'_t .

$$P'_t = \sum_{i=1}^n \delta^i \Pi_{t+i} + \delta^n P_{t+n}^{SC} \quad (7.17)$$

Where, according to the orthogonality condition of the RE assumption,

$$E_t \Pi_{t+i} = \Pi_{t+i} + \varepsilon_{t+i} \quad , \quad \varepsilon_{t+i} \sim \text{iid}(0, \sigma_\varepsilon^2) \quad , \quad i = 1, \dots, n \quad (7.18)$$

$$E_t P_{t+n}^{SC} = P_{t+n}^{SC} + v_{t+n} \quad , \quad v_{t+n} \sim \text{iid}(0, \sigma_v^2) \quad (7.19)$$

Therefore, for the RVF+RE hypothesis in the determination of ship prices to hold, the actual price at time t should be equal to the perfect foresight price at time t plus the sum of RE forecast errors, η_t ; that is,

$$P_t = P'_t + \eta_t \quad , \quad \eta_t = \varepsilon_t + \varepsilon_{t+1} + \dots + \varepsilon_{t+n} + v_{t+n} \quad (7.20)$$

The mean of RE forecast errors, η_t , is zero, since they are assumed to be random, i.e. investors do not make systematic errors. Shiller argues that such equality implies that the variance of actual prices should be equal to the sum of variances of perfect foresight prices and RE errors. Mathematically,

$$\text{Var}(P'_t) = \text{Var}(P_t - \eta_t) = \text{Var}(P_t) + \text{Var}(\eta_t) - 2\text{Cov}(P_t, \eta_t) \quad (7.21)$$

where $\text{Var}(P_t)$ and $\text{Var}(P'_t)$ are unconditional variances of actual and perfect foresight prices, respectively, and $\text{Var}(\eta_t)$ is the variance of the RE forecast errors. Since according to the RE assumption forecast errors are independent of prices, $\text{Cov}(P_t, \eta_t) = 0$, we can write

$$\text{Var}(P'_t) = \text{Var}(P_t) + \text{Var}(\eta_t) \quad (7.22)$$

The above equation implies that the variation in actual prices should be less than the variation in perfect foresight prices. This leads to a direct test for the validity of RVF+RE of the following form

$$Var(P'_t) > Var(P_t) \quad \text{or} \quad VR = \frac{Var(P'_t)}{Var(P_t)} > 1 \quad \text{or} \quad SDR = \frac{SD(P'_t)}{SD(P_t)} > 1 \quad (7.23)$$

where $SD(P_t)$ and $SD(P'_t)$ are standard deviations of actual and perfect foresight prices, respectively, and, VR and SDR denote variance and standard deviation ratios, respectively.

There are several issues raised in the literature in applying the variance ratio test. Perhaps the most important one concerns the condition of stationarity of prices and dividends (or profits from operation in shipping in this case). Flavin (1983) points out that results from variance ratio tests are biased in small samples due to the excess persistence in fundamental values and actual prices. Kleidon (1986) criticises Shiller's approach and argues that the power of the test depends on the stationarity of variables. This is because nonstationary price series are not covariance stationary and this invalidates the test. In fact, through a series of Monte Carlo simulations on nonstationary series, Kleidon (1986) shows that the variance ratio test rejects the null of $SD(P'_t) > SD(P_t)$ or $Var(P'_t) > Var(P_t)$ more often than it should be rejected and such rejections are found to be dependent on the discount factor used.

Different methods are proposed in the literature to overcome the problems associated with the nonstationarity of price and profit series in testing the EMH stock price formation, which implicitly or explicitly use the cointegrating relationship between stock prices and dividends. For instance, Mankiw et al (1991) suggest that it is possible to compare the variability of actual and perfect foresight prices to the one of a naïve forecast, \ddot{P}_t (forecast from a random walk model), deflated by the actual price, which might be stationary.

$$Var\left(\frac{P'_t - \ddot{P}_t}{P_t}\right) \geq Var\left(\frac{P_t - \ddot{P}_t}{P_t}\right) \quad (7.24)$$

Gilles and Leroy (1991) argue that if prices are nonstationary and form a cointegrating relationship with the dividend series, d_t , which follow a geometric random walk process, then the variance ratio tests may be performed on the price dividend ratio series. Thus, according to Gilles and Leroy (1991), for the EMH to hold, the variance of the actual price dividend ratio should be smaller than the variance of the fundamental price dividend ratio.

$$Var(P'_t / d_t) \geq Var(P_t / d_t) \quad (7.25)$$

Scott (1990) proposes a slightly different approach for testing the EMH when prices and dividends are nonstationary and form cointegrating relationships. Scott suggests deflating the actual and the perfect foresight prices by last period's dividends, d_{t-1} , to obtain stationary series. Then the following regression, corrected for serial correlation and heteroscedasticity, can be used to test the EMH.

$$(P'_t / d_{t-1}) = a + b(P_t / d_{t-1}) + \eta_t \quad (7.26)$$

Thus, the null of the EMH, i.e. prices being equal to their fundamentals, requires non-rejection of the set of restrictions $a=0$ and $b=1$.

Despite the efforts made to overcome the problem of stationarity of variables, all the above tests share a further shortcoming. This is because, they all use the perfect foresight price, P'_t , and therefore one needs to make assumptions on the unobservable terminal value of the stock price, $E_t P^{SC}_{t+n}$. This in turn may cause biases in sample variances and additional problems when the sample size is relatively small (see Gilles and Leroy, 1990). Also assuming RE and using the actual price at the end of the investment horizon instead of the terminal value in order to construct the *Perfect Foresight Price* reduces the number of remaining observations, and as a result the power of the test might be affected.

Campbell and Shiller (1987) also identify shortcomings in volatility tests and suggest a modified version of the present value model for testing the RVF and EMH in asset price formation, which takes into account the nonstationary properties of prices and dividends. They utilise the cointegrating relationship between stock prices and dividends and use the VAR methodology to form expectations on the behaviour of dividends in the present value model. One advantage of this approach is that the stochastic properties of the variables can be taken into account in testing. This enhances the reliability and power of the tests since direct use of nonstationary variables in regression analysis is shown to yield misleading results (Kleidon, 1986). Another advantage of using the VAR model is that it utilises all publicly available information, included in the historical movements of prices and dividends as well as their dynamic relationship, in forming expectations about the future behaviour of dividends. Finally, the VAR approach allows a number of restrictions and tests for the validity of the RVF to be constructed accordingly.

Campbell and Shiller (1988) extend the VAR model and its restrictions on testing the EMH one step further, by allowing for a time-varying discount rate in the present value model using a log-linear representation of the RVF. The log-linear transformation leads to specification of the log dividend price ratio in terms of future dividend growth rates and time-varying discount rates. The following section outlines the Campbell and Shiller (1987 and 1988) VAR methodology, which is adapted to test the validity of the EMH and the RVF in the formation of prices for different size dry bulk carriers.

7.2.3.2. Testing the EMH and the VAR methodology

It is widely known that variables such as ship prices and operating profits are nonstationary, $I(1)$ variables, (see for example chapter 4 of this thesis, Kavussanos, 1997). Therefore, as noted by Kleidon (1986) and Campbell and Shiller (1987), the direct tests of present value models suggested by Shiller (1981) may yield misleading results; that is, rejection of the null more often than it should be.

Following Campbell and Shiller (1987 and 1988), subtracting π_t from both sides of (7.16), and following some algebraic manipulation (see appendix 7.A), result in the following equation

$$S_t = \sum_{i=0}^{n-1} \rho^i E_t \pi r_{t+1+i} + \rho^n E_t S_{t+n}^{sc} + c \quad (7.27)$$

where $S_t = p_t - \pi_t$, $\pi r_t = \Delta \pi_t - r_t$ and $S_t^{sc} = p_t^{sc} - \pi_t$. S_t is in fact the spread between the log of price and the log of operating profits, and S_t^{sc} represents the spread between the log of the residual price of the vessel and the log of operating profit. It can be seen that although logs of prices and operating profit series, p_t and π_t , might be $I(1)$, their linear combinations, i.e. S_t and S_t^{sc} , may form cointegrating relationships and result in stationary variables. Also, since $\pi r_t = \Delta \pi_t - r_t$ is stationary, the above formulation ensures that all variables in the

model are stationary, therefore, a direct test for the EMH and present value models can now be performed under the stationarity condition.⁸

It has been mentioned that when data on expected values are not available, some form of forecasting scheme should be adapted in order to predict the expected values on the RHS of equation (7.27). Following Campbell and Shiller (1987 and 1988), we use a VAR model, which consists of a set of stationary endogenous variables. These variables are the spread between the log of price and the log of operating profits, S_t , changes in the log of operating profits minus the discount rate, π_t , and the spread between the log of the residual price and the log of operating profits, S_t^{SC} .⁹

$$\begin{aligned} S_t &= \mu_{1,0} + \sum_{i=1}^p \mu_{1,i} S_{t-i} + \sum_{i=1}^p \mu_{2,i} \pi_{t-i} + \sum_{i=1}^p \mu_{3,i} S_{t-i}^{SC} + \varepsilon_{1,t} \\ \pi_t &= \phi_{1,0} + \sum_{i=1}^p \phi_{1,i} S_{t-i} + \sum_{i=1}^p \phi_{2,i} \pi_{t-i} + \sum_{i=1}^p \phi_{3,i} S_{t-i}^{SC} + \varepsilon_{2,t} \\ S_t^{SC} &= \lambda_{1,0} + \sum_{i=1}^p \lambda_{1,i} S_{t-i} + \sum_{i=1}^p \lambda_{2,i} \pi_{t-i} + \sum_{i=1}^p \lambda_{3,i} S_{t-i}^{SC} + \varepsilon_{3,t} \end{aligned} \quad (7.28)$$

The advantage of the VAR model in this form is that it utilises all available information (historical price and earning series) in determining the expected values of variables on the RHS. The VAR model can be written in compact form, known as the companion matrix notation. The companion form of the VAR can facilitate presentation of dynamic multi-period forecasts of endogenous variables of the VAR model with several lags (see Appendix 7.A for more details). Considering \mathbf{Z}_t as a vector of endogenous and lagged endogenous variables stacked in such a way so as to form $\mathbf{Z}'_t = [S_t, \pi_t, S_t^{(SC,\Pi)}, \dots, S_{t-p}, \pi_{t-p}, S_{t-p}^{(SC,\Pi)}]$, then the companion form of the VAR model can be written as

$$\mathbf{Z}_{t+1} = \mathbf{A}\mathbf{Z}_t + \boldsymbol{\varepsilon}_{t+1} \quad (7.29)$$

⁸ Alternatively, assuming the transversality condition, the transformed version of equation (7.27) reduces to $S_t = \sum_{i=0}^{\infty} \rho^i E_t \pi_{t+i+1} + c$.

⁹ Again, assuming the transversality condition the VAR model will be reduced to a bivariate VAR with S_t and π_t as endogenous variables.

or

$$\begin{bmatrix} S_{t+1} \\ \pi_{t+1} \\ S_{t+1}^{(SC,\Pi)} \\ \vdots \\ S_{t-p+1} \\ \pi_{t-p+1} \\ S_{t-p+1}^{SC} \end{bmatrix} = \begin{bmatrix} a_{1,1} & b_{1,1} & c_{1,1} & \cdots & a_{1,p} & b_{1,p} & c_{1,p} \\ a_{2,1} & b_{2,1} & c_{2,1} & \cdots & a_{2,p} & b_{2,p} & c_{2,p} \\ a_{3,1} & b_{3,1} & c_{3,1} & \cdots & a_{3,p} & b_{3,p} & c_{3,p} \\ 1 & 0 & \cdots & & & & \\ 0 & 1 & & & & & \\ \vdots & & \ddots & & & & \\ & & & \ddots & & & \\ & & & & 1 & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} S_t \\ \pi_t \\ S_t^{SC} \\ \vdots \\ S_{t-p} \\ \pi_{t-p} \\ S_{t-p}^{SC} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \quad (7.30)$$

Where, A is a $(3px3p)$ matrix, known as the companion matrix of the VAR, and ε_t is a vector of error terms and zeros. Thus, using the chain rule of forecasting, the i period ahead forecast of Z_t can be written as

$$E_t(Z_{t+i}) = A^i Z_t \quad (7.31)$$

Selection vectors $e1=[1, 0, 0, 0 \dots]$, $e2=[0, 1, 0, 0 \dots]$ and $e3=[0, 0, 1, 0, \dots]$, can then be used to express each endogenous variable in the VAR as follows;

$$S_t = e1 E_t Z_t, \quad \pi_t = e2 Z_t, \quad S_t^{SC} = e3 Z_t$$

And the forecast values would be

$$\begin{aligned} E_t S_{t+i} &= e1 E_t (Z_{t+i}) = e1 A^i Z_t \\ E_t \pi_{t+i} &= e2 E_t (Z_{t+i}) = e2 A^i Z_t \\ E_t S_{t+i}^{SC} &= e3 E_t (Z_{t+i}) = e3 A^i Z_t \end{aligned} \quad (7.32)$$

Substituting the expected values obtained from the VAR model in equation (7.27) results in

$$e1 Z_t = \sum_{i=0}^n \rho^i e2 A^{i+1} Z_t + \rho^n e3 A^n Z_t \equiv S_t^* \quad (7.33)$$

The RHS of the above equation is the weighted average of the predicted values of discounted expected operating profits plus the discounted expected resale value, which is the *theoretical spread*, S_t^* . The EMH and the RVF implies that the *theoretical spread* and the actual spread should move close together over time. Thus for the theoretical spread to be equal to the actual spread the following restrictions should be satisfied

$$e1 = A \sum_{i=0}^{n-1} \rho^i e2A^i + \rho^n e3A^n \quad (7.34)$$

or

$$e1 = e2A(I - \rho A)^{-1}(I - \rho^n A^n) + \rho^n e3A^n \quad (7.35)$$

The above set of restrictions on parameters of the VAR implies that the spread between the log of price and the log of operation profits at time t should be equal to the sum of discounted present value (DPV) of expected changes in the log of operation profit plus the DPV of the log of the expected residual value of the vessel.

Restrictions in (7.34) are highly nonlinear, and can be tested using the following Wald test

$$W = f(\Theta) \{ \text{Var}[f(\Theta)] \}^{-1} f(\Theta)' \sim \chi^2(r) \quad (7.36)$$

where $f(\Theta)$ and $\text{Var}[f(\Theta)]$ represent the non-linear restrictions (7.34) on the VAR model and their variance, respectively, while r indicates the number of restrictions. The latter can be estimated using the first derivative of the non-linear restrictions with respect to the estimated parameters, $df(\Theta)$, and the variance covariance matrix of the estimated coefficients, $\text{Cov}(\Phi)$, as follows:

$$\text{Var}[f(\Theta)] = df(\Theta)' [\text{Cov}(\Phi)] df(\Theta) \quad (7.37)$$

Since the above Wald test is based on the covariance of estimated coefficients, one should make sure that the estimated variance/covariance matrix is corrected for heteroscedasticity and serial correlation using the White (1980) and Newey and West (1987) corrections to avoid any bias in the Wald test statistic.

Campbell and Shiller (1987) utilise another implication of the EMH by arguing that if the theoretical spread, S_t^* , is the best forecast of discounted future operating profits, then the variance of the theoretical spread, $\text{Var}(S_t^*)$, must be equal to the variance of the actual spread, $\text{Var}(S_t)$. As a consequence, the ratio of the variances of these two spread series should be close to unity, $\text{VR} = \text{Var}(S_t) / \text{Var}(S_t^*) = 1$. This test is different from that of Shiller's

(1981) volatility test presented earlier because it is performed on stationary series (S_t^* and S_t) as opposed to Shiller's (1981) test, which is performed on nonstationary series causing statistical problems. In addition, this test is based on prediction of spread series using the VAR model in contrast to Shiller's (1981) test, which uses the rational value of operating profits and the terminal value of the asset based on some assumptions.

7.2.3.3. Empirical evidence on present value models and the EMH

The number of studies in the literature testing the implications of the EMH in asset pricing using the Campbell and Shiller (1987 and 1988) technique is increasing as the VAR methodology has become a standard approach of evaluating the validity of the RVF in asset price formation. Different markets, sample periods and various discount rates (constant or time varying) are used to examine the validity of the theory. For example, Mills (1992) examines the UK stock market¹⁰ on a monthly basis for the period 1965 to 1990 using a constant discount rate and finds similar results to Campbell and Shiller (1987 and 1988); that is, failure of the RVF in explaining the price behaviour.

Cuthbertson et al (1997) examine the EMH in the UK stock market using the same approach as Campbell and Shiller (1988) for the period 1918 to 1993 and reject the EMH when discount rates are assumed to be constant or equal to the risk free rate. They also find that results may improve when equilibrium expected returns are assumed to be determined through the CAPM. However, they report that results are not robust to the lag length chosen for the VAR model.

In a recent study, Cuthbertson et al (1999) argue that failure of the EMH in the UK market might be due to sectoral aggregation or use of an inappropriate conditional equilibrium model for returns. They re-examine the UK market using industry disaggregated quarterly data for the period 1965 to 1992¹¹. To ensure that the results are robust with respect to the conditional model used, they estimate expected returns using two versions of the CAPM (i.e. Merton's

¹⁰ Mills (1992) uses the financial times all share index along with its associated dividends to test the EMH.

¹¹ Cuthbertson et al (1999) use disaggregated data, which are based on five sub-sectors; Industrials, Financial Services, Capital Goods, Consumer Goods and Other Sectors.

intertemporal CAPM and the consumption CAPM), as well as a constant rate of return and the return on T-bills. Their results fail to support the EMH for the aggregated and the disaggregated form of the UK market, especially, when the consumption CAPM is used to estimate equilibrium returns. However, they report that disaggregation may improve the results for some sub-sectors when expected returns in individual sectors are assumed to depend on the sectors' own variance rather than covariance of returns with the market return. Cuthbertson et al (1999) conclude that the failure of the EMH in previous studies might be due to aggregation of data or inadequacy of the model used to derive the expected returns. Therefore, they suggest that using sectoral data and appropriate models to estimate expected returns may improve the results of the VAR model and the EMH tests.

7.2.4. Rational Bubbles

So far it has been argued that in an efficient market the actual price of an asset should be equal to its fundamental value; that is, the DPV of the stream of income expected to be generated by the asset over its economic life. However, there might be cases, where the market price of the asset deviates from its fundamental value substantially even when the assumption of RE and EMH holds. This might be due to existence of “rational bubbles”. Since deviations from the fundamental value take place under the EMH and RE, the bubble is known as a “rational bubble”. Rational bubbles arise because of the possible indeterminate solutions to rational expectations models, which is reflected in equation (7.11) which is an Euler equation for price determination. The recursive forward solution for equation (7.11) yields

$$P_t = \sum_{i=1}^{\infty} \delta^i E_t \Pi_{t+i} \quad (7.38)$$

Where the transversality condition (i.e. $\lim_{n \rightarrow \infty} \delta^n E_t \Pi_{t+n} = 0$) should hold to obtain a unique solution for (7.38). In the presence of a rational bubble there is another mathematical solution that satisfies (7.38), which can be shown as follows

$$P_t = \sum_{i=1}^{\infty} \delta^i E_t \Pi_{t+i} + B_t \quad (7.39)$$

where B_t is the rational bubble with a growth rate which is more than one for expected profits. This is known as a bubble with explosive properties, and can cause a divergence between the actual and the fundamental price of the asset¹². In fact, when B_t is large relative to the fundamental value, then actual prices can deviate substantially from their fundamental values. Yet, the EMH might hold since agents also price the bubble and are willing to hold the asset, which includes the bubble, for a required rate of return and still no supernormal profits can be made.

Mathematically, rational bubbles imply that there might be an infinite number of solutions to equation (7.39), which relates the asset price to its fundamental value. However, if the asset has a limited life span, which means that the asset depreciates over time, then the present value model should include the residual or terminal value of the asset; that is equation (7.12).

$$P_t = \sum_{i=1}^n \delta^i E_t \Pi_{t+i} + \delta^n E_t P_{t+n}^{SC}$$

This implies that if the price of the asset contains a rational bubble, the bubble should be present in the terminal value of the asset too. Therefore, as pointed out by Campbell and Shiller (1987), in this case, the rational bubble will be included in the null hypothesis that the present value model is true.

On the other hand, Campbell et al (1997) point out that prices for assets with close substitutes, such as commodities, cannot include rational bubbles. This is because there are price limits for such assets, which is contrary to the explosive behaviour of rational bubbles. In the case of merchant ships, it can be argued that second-hand and newbuilding prices cannot rise indefinitely because when prices are rising, shipyards produce more vessels, which in turn reduces ship prices due to oversupply and restricted employment opportunities. Thus, preventing development of rational bubbles in ship prices.

There are a number of tests proposed in the literature for rational bubbles; see, Diba and Grossman (1988) and West (1987) among others. For example, West (1987) suggests testing

¹² Different examples for bubbles can be found in Blanchard and Watson (1982), Evans (1991), Froot and Ochs (1991) and Flood and Garber (1994), while West (1987 and 1988), Diba and Grossman (1988) offer different tests for rational bubbles. Mills (1993), Cuthbertson (1996b) and Campbell, Lo and Mackinlay (1997) discuss different tests for detecting rational bubbles in stock prices in more detail.

the existence of a rational bubble by estimating the relationship between price and dividend (profit) series using two different methods. He argues that in the presence of a rational bubble, two estimation methods should yield different estimates (see, Appendix 7.C). The problem with this test is that it depends on the correct specification of the data generating process for dividend series (operating profits). In addition, this test assumes a constant discount rate to relate price and dividend series, which might not be appropriate.

Diba and Grossman (1988) propose a test for detecting rational bubbles, which involves investigating the stationarity of price and operating profit series as well as the existence of a cointegrating relationship between the two series. The null hypothesis of no bubbles in this test requires the price and profit series to be $I(1)$ as well as to be cointegrated. The intuition behind this test is that since a rational bubble induces an explosive behavior in the actual price and not the fundamental value, then prices and operating profits should diverge over time. However, if price and operating profit series are nonstationary and cointegrated, they do not diverge and move together in the long run. Thus existence of a cointegration relationship between price and operating profits in the long run can be regarded as evidence against the existence of rational bubbles. The advantage of Diba and Grossman (1988) test over West's (1987) is that the nonstationary properties of the series are taken into account.

We investigate the existence of rational bubbles in newbuilding and second-hand prices for different size vessels, using both cointegration analysis between price and operating profits and West's (1987) test for rational bubbles.

7.3. Time-varying risk premia

The possible failure of the EMH plus RE in asset pricing in the literature is mainly attributed to the existence of (time-varying) risk premia; see for example, Engle et al (1987), French, Schwert and Stambaugh (1987), Chou (1988), Lamoureux and Lastrapes (1990), Bailie and DeGennaro (1990) and Nelson (1991). The intuition behind the theory of risk premia is that the excess returns on an investment over the return on the market rate (or risk free rate) should be related to investors' perceptions of risk for that investment. To investigate the issue empirically, consider adding a time varying risk premium, ϕ_{t+1} , to equation (7.6), and assume that the excess holding period return on the asset over the return on alternative investments is related to a time-varying risk premium. Mathematically

$$exr_{t+1} = r_{t+1} - r_t^m = \lambda_0 + \phi_{t+1} + \varepsilon_{t+1} \quad (7.40)$$

where, ϕ_{t+1} , the time-varying risk premium, is then modelled as the square root of the conditional variance of the forecast errors, which in turn are modelled as a GARCH¹³ process (see, for example, Chou 1988 and Bailie and DeGennaro 1990) of the following form

$$exr_{t+1} = \lambda_0 + \sum_{i=0}^m \lambda_i exr_{t-i} + \phi_1 \sigma_{t+1} + \varepsilon_{t+1}, \quad \varepsilon_{t+1} \sim iid(0, \sigma_{t+1}^2) \quad (7.41)$$

$$\sigma_{t+1}^2 = a_0^2 + \sum_{i=0}^q b_i^2 \varepsilon_{t-i}^2 + \sum_{i=0}^p c_i^2 \sigma_{t-i}^2$$

where σ_{t+1}^2 is the conditional variance. It should be noted that when the frequency of the data is finer than the number of periods, e.g. $n > 1$, over which excess returns are calculated, then error terms in (7.41) would be correlated and the model should be modified to incorporate such serial correlation in the forecast error. Such serial correlation arises from the fact that realised values of the prices at time $t+1$ to $t+n-1$ are not known when forecasts of P_{t+n} are set at time t (Hansen and Hodrick 1980). Hence, corresponding $n-1$ period ahead forecast errors ε_{t+i} , $i=1, \dots, n-1$ are not observable. Since ε_{t+i} , $i=1, \dots, n-1$ are not part of the available information set, we cannot rule out the possibility that $E(\varepsilon_{t+i}) \neq 0$ or $E(\varepsilon_{t+i} \varepsilon_{t+i-j}) \neq 0$, for $j=1, \dots, n-1$. Therefore, the forecast error is considered as being generated by an MA($n-1$) process and as a result model (7.41) is modified to incorporate such serial correlation as follows

¹³ Theoretical formulation and estimation techniques of GARCH-M models are discussed in chapter 3.

$$\begin{aligned}
exr_{t+n} &= \lambda_0 + \sum_{i=0}^m \lambda_i exr_{t+n-i} + \phi_1 \sigma_{t+n} + \eta_{t+n} \\
\eta_{t+n} &= \varepsilon_{t+n} + \sum_{i=0}^{n-1} \omega_i \varepsilon_{t+n-i} \quad \varepsilon_t \sim \text{iid}(0, \sigma_t^2) \\
\sigma_{t+n}^2 &= a_0^2 + \sum_{i=0}^p b_i^2 \sigma_{t+n-i}^2 + \sum_{i=0}^q c_i^2 \varepsilon_{t+n-i}^2
\end{aligned} \tag{7.42}$$

In the above GARCH-M framework, the coefficient of the time-varying volatility in the mean equation, ϕ_1 , represents the impact of the volatility of forecast errors on excess returns. Capital asset pricing theory implies a positive relationship between risk and excess return, therefore, one would expect ϕ_1 to be positive for investments such as shipping, which are thought to carry high risk.

7.4. Data on ship prices and operation profits

For the purpose of this study, monthly newbuilding, second-hand and scrap prices are collected for three different size dry bulk carriers (Capesize, Panamax and Handysize) from various issues of the Lloyd's Shipping Economist from January 1976 to December 1998. Capesize prices are only for the period January 1980 to December 1998. All prices are quoted in million dollars for each size and represent the average value of the vessel in any particular month.

Figure 7.1 plots the newbuilding prices for the three size dry bulk carriers over the sample period. It can be seen that newbuilding prices vary by vessel size but show similar stochastic behaviour over time. In fact, it can be argued that these series follow similar patterns and move together in the long run. However, their short run behaviour is not identical and indeed show different short term dynamics which might be related to differences in the demand and costs for their construction. Similar conclusions can be drawn for second-hand prices, which are shown in Figure 7.2, respectively. This is again because both second-hand prices are related to the current and expected future prospects and profitability of the freight market for each size category.

Historical demolition or scrap prices are shown in Figure 7.3. These are mainly related to world scrap metal price, but they seem to show a similar long run pattern as operating profits. This might be due to the fact that both scrap prices and operating profits are related to the world's industrial production and economic activity. Therefore, one would expect that the two series are linked and driven by the same stochastic trend; i.e. the world's industrial production. However, our empirical results show that these prices are also related to the profitability of the freight market (see the cointegration analysis between scrap prices and operating profits in section 7.5.2). This is because if the market was not profitable for a relatively long period, then owners of old (inefficient) vessels which might have been laid up for sometime, scrap these old vessels to cut further costs and losses. This results in an increase in the supply of vessels for scrap and a fall in scrap prices. Similarly, if the market was profitable for a relatively long period, then owners have enough reserves to avoid scrapping old vessels in a market downturn. In this case, the supply in the scrap market is reduced and scrap prices surge.

Figure 7.1: Newbuilding prices for three size bulk carriers

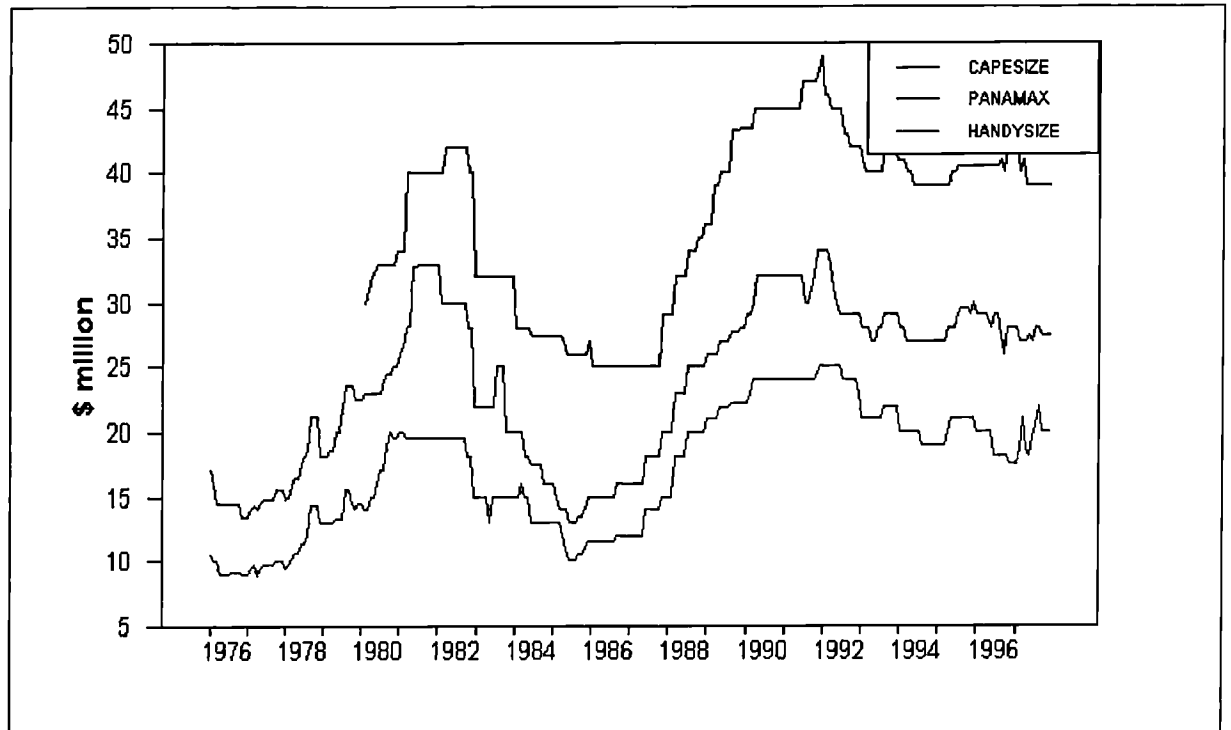


Figure 7.2: Second-hand prices for three size bulk carriers

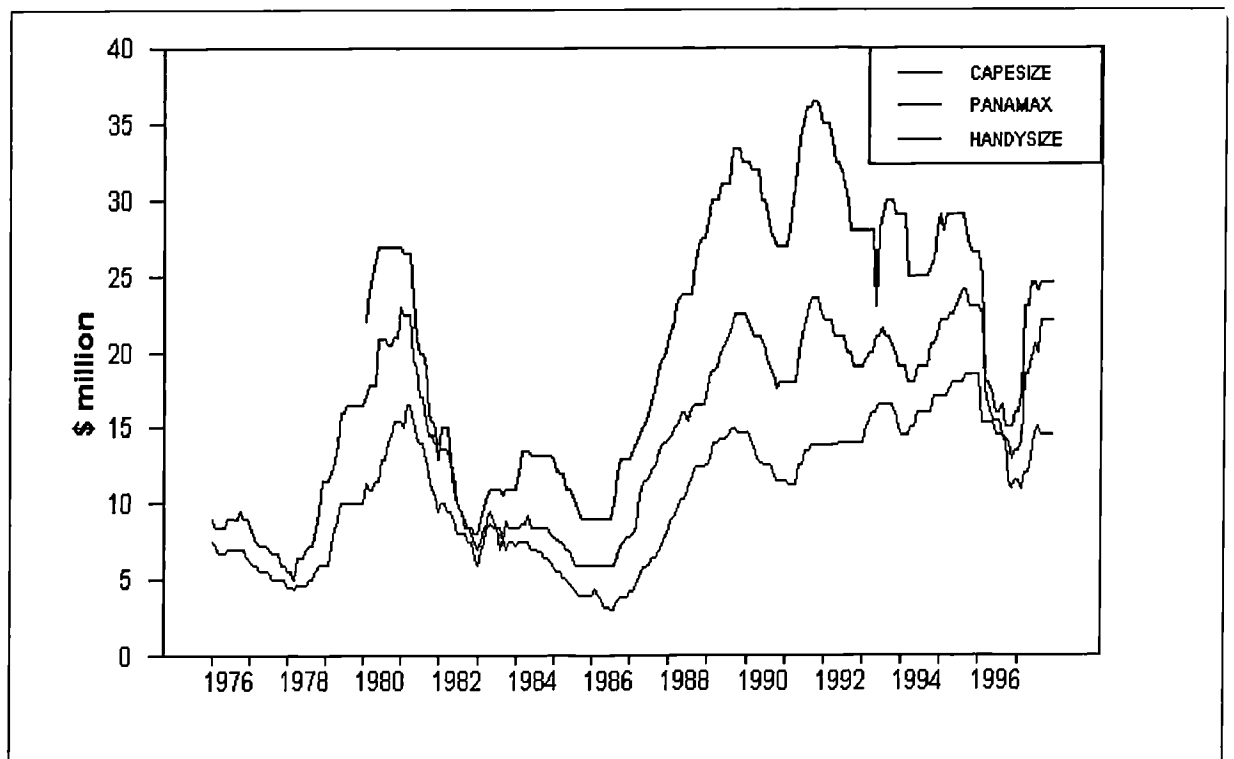
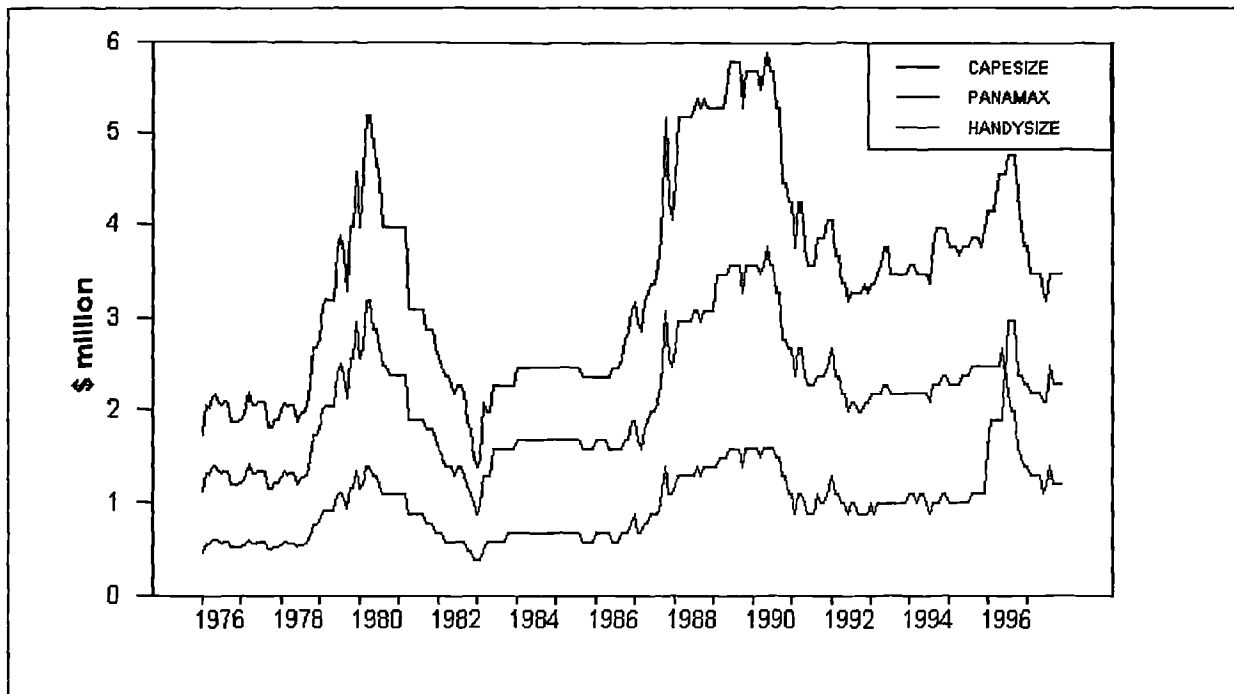


Figure 7.3: Scrap prices for three size bulk carriers



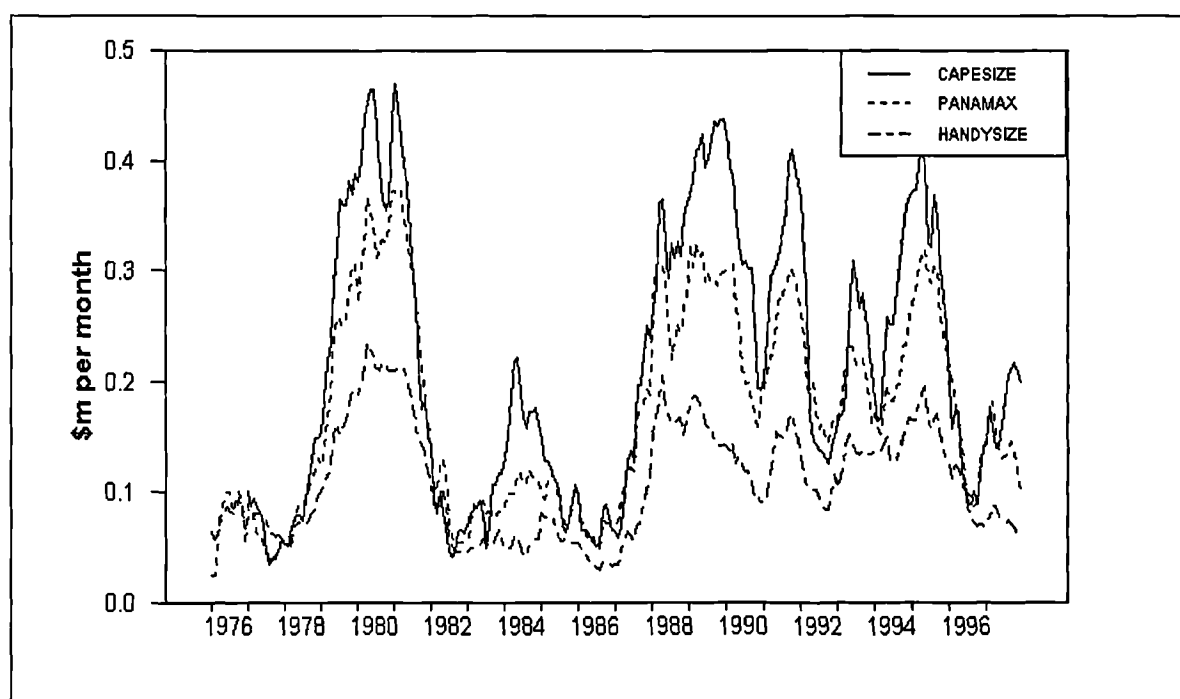
In shipping, earnings (operating profits) at time t , Π_t , can be defined as time-charter rates, TC_t , less operating costs, OC_t ; i.e., $\Pi_t = TC_t - OC_t$. We consider time-charter rates in estimating operating profits because these rates do not include voyage costs (see chapter 1), and therefore represent the net earnings from chartering activities, a part of which should be paid for operating costs. Details of estimating operating costs for different size vessels are presented in chapter 1.

Figure 7.4 plots the operating profit series for the three different type vessels under consideration over the sample period. High degree of fluctuations in operating profit series indicate the risky nature of shipping operations. Since operating profit is freight revenue less operating costs, which are more or less stable and adjust with inflation, it can be argued that the volatility observed in operating profits is mainly due to freight rate fluctuations.

Table 7.1, Panel A, reports descriptive statistics of levels of newbuilding, second-hand and scrap prices, as well as operating profits for capesize, panamax and handysize vessels. The results indicate that mean levels of prices for larger vessels are higher than smaller ones. Also, mean levels of newbuilding prices are higher than means of second-hand and scrap prices in all cases, as expected. Unconditional volatilities of prices (variances) indicate a

similar pattern as the mean levels across sizes and ages of vessels. That is, prices for larger vessels fluctuate more than prices for smaller vessels, and prices for newbuildings fluctuate more than second-hand ones and both of these prices fluctuate more than scrap prices. The results are consistent with those in Kavussanos (1997).

Figure 7.4: Operating profits for three size bulk carriers



Based on the coefficients of excess kurtosis, price series as well as operating profits appear to be platykurtic across vessel sizes and ages. Jarque-Bera (1980) tests indicate significant departures from normality. The Ljung-Box Q statistics (Ljung and Box, 1978) for first and 12th order autocorrelations in levels of price and operating profit series are all significant, indicating that serial correlation is present in the price and profit series. Engle's (1982) ARCH tests for 1st and 12th order ARCH effects indicate the existence of autoregressive conditional heteroscedasticity in all price and profit series.

Table 7.1: Summary statistic of price and profit series

Panel A- Descriptive statistics (\$m)										
Capesize	N	Mean	Var.	Skew.	Kurtosis	J-B	Q(1)	Q(12)	ARCH (1)	ARCH(12)
Newbuilding prices, P^{NB}	227	36.58	44.79	-0.42 [0.01]	-1.05 [0.00]	17.31 [0.00]	233 [0.00]	2224 [0.00]	222 [0.00]	2174 [0.00]
Second-hand prices, P^{SH}	227	21.79	65.59	-0.17 [0.28]	-1.27 [0.00]	16.42 [0.00]	234 [0.00]	2062 [0.00]	223 [0.00]	1953 [0.00]
Scrap prices, P^{SC}	227	3.61	1.120	0.39 [0.02]	-0.62 [0.06]	14.13 [0.00]	217 [0.00]	1913 [0.00]	215 [0.00]	1854 [0.00]
Operating Profits, Π	227	0.216	0.016	0.27 [0.10]	-1.14 [0.00]	19.88 [0.00]	215 [0.00]	1244 [0.00]	214 [0.00]	1159 [0.00]
Panamax										
Newbuilding prices, P^{NB}	276	23.72	37.52	-0.25 [0.09]	-1.26 [0.00]	21.26 [0.00]	270 [0.00]	2577 [0.00]	269 [0.00]	2490 [0.00]
Second-hand prices, P^{SH}	276	14.79	34.33	-0.14 [0.34]	-1.49 [0.00]	26.32 [0.00]	271.4 [0.00]	2406 [0.00]	269.7 [0.00]	2159 [0.00]
Scrap prices, P^{SC}	276	2.12	0.43	0.52 [0.00]	-0.34 [0.26]	13.89 [0.00]	260 [0.00]	2154 [0.00]	258 [0.00]	2239 [0.00]
Operating Profits, Π	276	0.169	0.009	0.36 [0.02]	-1.10 [0.00]	19.73 [0.00]	264.0 [0.00]	1855 [0.00]	263.6 [0.00]	1708 [0.00]
Handysize										
Newbuilding prices, P^{NB}	276	17.22	22.36	-0.16 [0.27]	-1.20 [0.00]	17.83 [0.00]	269 [0.00]	2643 [0.00]	269 [0.00]	2598 [0.00]
Second-hand prices, P^{SH}	276	10.53	18.01	-0.03 [0.82]	-1.24 [0.00]	17.80 [0.00]	273 [0.00]	2597 [0.00]	271 [0.00]	2432 [0.00]
Scrap prices, P^{SC}	276	0.974	0.134	0.871 [0.00]	0.788 [0.01]	42.12 [0.00]	254 [0.00]	1839 [0.00]	243 [0.00]	1467 [0.00]
Operating Profits, Π	276	0.106	0.003	0.436 [0.00]	-0.860 [0.00]	17.28 [0.00]	266 [0.00]	1972 [0.00]	266 [0.00]	1876 [0.00]
Panel B- Philips-Perron Unit root tests for log prices and log operating profits										
	Capesize			Panamax			Handysize			
	Levels	First diff.		Levels	First diff.		Levels	First diff.		
Newbuilding prices, P^{NB}	-1.44	-15.28		-1.56	-15.02		-1.72	-15.09		
Second-hand prices, P^{SH}	-1.40	-11.99		-1.73	-13.00		-1.46	-12.30		
Scrap prices, P^{SC}	-1.60	-14.98		-1.95	-18.41		-2.48	-17.60		
Operating Profits, Π	-2.18	-9.21		-2.11	-12.25		-1.69	-11.00		

- The sample for capesize price and profit series covers the period February 1980 to December 1998. The sample for Panamax and Handysize price and profit series cover the period January 1976 to December 1998.
- N is the number of observations and figures in Panel A are in million dollars. Figures in [] are p-values.
- Skew and Kurt are the estimated centralised third and fourth moments of the data, denoted $\hat{\alpha}_3$ and $(\hat{\alpha}_4 - 3)$ respectively; their asymptotic distributions under the null are $\sqrt{T}\hat{\alpha}_3 \sim N(0,6)$ and $\sqrt{T}(\hat{\alpha}_4 - 3) \sim N(0,24)$.
- J-B is the Jarque - Bera (1980) test for normality; the statistic is $\chi^2(2)$ distributed.
- Q(1) and Q²(12) are the Ljung-Box (1978) Q statistics on the first and 12th order sample autocorrelation of the raw series; these tests are distributed as $\chi^2(1)$ and $\chi^2(12)$, respectively.
- ARCH(1) and (12) is the Engle (1982) test for ARCH effects; the statistic is χ^2 distributed with 1 and 12 degrees of freedom, respectively.
- The lag length for Philips-Perron test is chosen as 12.
- All tests include a constant as indicated by SIBC and the t test. 1%, 5% and 10% critical values for unit root test are -3.99, -3.43 and -3.13, respectively.

Finally, the results of Phillips and Perron (1988) unit root tests in Table 7.1, Panel B, suggest that all variables are nonstationary in logs, while their first log-differences are found to be stationary. Therefore, it is concluded that operating profits, newbuilding, second-hand and scrap prices for dry bulk carriers are in fact integrated of first order, I(1). Unit roots test results of second-hand prices are consistent with seasonal unit root tests results of Kavussanos (1997) where he concludes that there are no seasonal patterns in the second-hand prices, and that prices are I(1).

7.5. Estimation Results

First, the implication of the EMH regarding the unpredictability of 1- and 3-month excess holding period returns on shipping investments is tested for. Second the implication of the EMH regarding the RVF using a present value model and testing restrictions implied by the EMH on the VAR model and variance ratio tests on spread series are examined. However, before that, the existence of cointegrating relationships between operating profit and price series is established. This is important since establishing cointegration relationships between price and operating profit series would rule out the existence of rational bubbles in ship prices (Diba and Grossman 1988), and provide the necessary condition to set up the VAR model. Finally, a GARCH-M framework is used to investigate the relationship between excess holding period returns and the level of risk (variance of forecast errors).

7.5.1. Unpredictability of holding period returns

Table 7.2 reports descriptive statistics of 1-month and 3-month excess holding period returns of shipping investments over the market returns (LIBOR+1%) as well as the Ljung and Box (1978) tests for 1st and 12th order autocorrelation, Engle (1982) test for 1st and 12th order ARCH effects and Phillips and Perron (1988) unit root tests. Results suggest that sample means of 1-month excess holding periods are statistically zero. Whereas means of 3-months excess holding period returns are higher than 1-month excess returns and they are significantly different from zero (with the exception of the 3-month excess return for handysize vessels). Also, unconditional volatilities of 3-month excess holding period returns seem to be significantly higher than those of 1-month excess returns for all sizes, which is in line with the literature on asset pricing and risk-return relationships.

Furthermore, it can be seen that both 1- and 3-month excess returns for all size categories are serially correlated which implies that the series are predictable. This is not in line with the EMH, which requires the excess return series to be independent and unpredictable. However, there are two explanations for the existence of autocorrelation in excess return series. First, monthly aggregation of data on ship prices and operating profits might induce autocorrelation in excess return series (see, Working 1960). Second, the autocorrelation in excess return series might be due to thin trading as the number of vessels traded in a month are limited.

This means that information from one trade might effect the next one, which implies that price changes might not be solely due to arrival of news between successive trades, as required by the EMH.

Results of Phillips and Perron unit root tests indicate that excess holding period returns are stationary, $I(0)$. Having found that excess holding period return series are stationary and autocorrelated, ARMA(p,q) models are fitted in each case using Box-Jenkins methods and SBIC, with standard errors corrected for heteroscedasticity and serial correlation where appropriate using Newey-West (1987) method. The AR(2) models, appropriate for 1-month excess returns, are shown in Table 7.3. The Hansen and Hodrick (1982) correction for overlapping data is applied in the regression for 3-month excess returns by incorporating MA(2) terms in addition to the AR(2). This is because the horizon over which excess returns (3-months) are calculated is greater than the frequency of the observations (monthly). The significance of ARMA(2,0) and ARMA(2,2) models can be regarded as evidence against the informational efficiency in the market for dry bulk carriers. The coefficients of determination, \bar{R}^2 's, are between 9% and 13% for 1-month excess returns and 77% and 80% for 3-month excess returns, which indicates a relatively higher degree of predictability due to the existence of MA terms.

Table 7.2: Summary statistics of excess returns

		N	Mean	Var.	Skew.	Kurtosis	J-B	Autocorrelation		ARCH		PP test
								Q(1)	Q(12)	Q(1)	Q(12)	
Capesize												
1-Month	exr1	226	-0.001 [0.72]	0.004	-0.38 [0.02]	7.13 [0.00]	484 [0.00]	24.91 [0.00]	64.27 [0.00]	2.54 [0.111]	28.71 [0.00]	-10.93
3-Month	exr3	226	0.013 [0.14]	0.017	-0.38 [0.02]	1.62 [0.00]	30.02 [0.00]	155 [0.00]	303 [0.00]	102.7 [0.00]	247.4 [0.00]	-4.63
Panamax												
1-Month	exr1	275	0.002 [0.51]	0.004	0.657 [0.06]	5.78 [0.00]	387 [0.00]	24.25 [0.00]	104.4 [0.00]	1.235 [0.00]	18.76 [0.00]	-12.67
3-Month	exr3	275	0.026 [0.00]	0.018	-0.257 [0.08]	2.02 [0.00]	49.54 [0.00]	193.0 [0.00]	481.9 [0.00]	118.1 [0.00]	159.7 [0.00]	-4.65
Handysize												
1-Month	exr1	275	0.001 [0.82]	0.004	-0.245 [0.10]	2.18 [0.00]	57.43 [0.00]	34.31 [0.00]	108.8 [0.00]	9.432 [0.00]	39.75 [0.00]	-11.70
3-Month	exr3	275	0.022 [0.01]	0.017	-0.015 [0.92]	0.954 [0.00]	10.37 [0.01]	184.1 [0.00]	453.0 [0.00]	115.2 [0.00]	161.2 [0.00]	-4.79

See notes in Table 7.1.

Table 7.3: Predictability of excess returns on shipping investments

$$exr_t = \alpha_0 + \sum_{i=1}^p \alpha_i exr_{t-i} + \sum_{i=1}^q \beta_i \varepsilon_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim iid(0, \sigma_\varepsilon^2) \quad \text{Equation (7.7)}$$

	Capesize		Panamax		Handysize	
	1-month	3-month	1-month	3-month	1-month	3-month
α_0	0.0001 (0.006) [0.983]	0.043 (0.020) [0.029]	0.006 (0.006) [0.305]	0.034 (0.016) [0.041]	0.004 (0.006) [0.480]	0.040 (0.016) [0.010]
α_1	0.237 (0.063) [0.001]	0.265 (0.069) [0.000]	0.189 (0.060) [0.002]	0.175 (0.063) [0.006]	0.235 (0.061) [0.000]	0.227 (0.064) [0.000]
α_2	0.151 (0.068) [0.027]	0.201 (0.065) [0.002]	0.254 (0.060) [0.000]	0.259 (0.062) [0.000]	0.220 (0.060) [0.000]	0.178 (0.062) [0.005]
β_1		0.976 (0.017) [0.000]		0.975 (0.022) [0.000]		0.974 (0.020) [0.000]
β_2		0.976 (0.017) [0.000]		0.943 (0.021) [0.000]		0.959 (0.019) [0.000]
\bar{R}^2	0.092	0.77	0.12	0.79	0.13	0.80
Q(1)-statistic	0.067 [0.796]	0.921 [0.337]	0.177 [0.673]	0.182 [0.669]	0.012 [0.913]	0.140 [0.708]
Q(12)-statistic	17.51 [0.131]	17.46 [0.132]	12.90 [0.376]	13.74 [0.317]	13.24 [0.352]	13.91 [0.307]
ARCH(1)	4.939 [0.027]	4.514 [0.034]	0.269 [0.604]	0.983 [0.322]	3.202 [0.075]	3.093 [0.080]
ARCH(12)	3.339 [0.000]	2.697 [0.002]	1.550 [0.107]	1.308 [0.214]	3.156 [0.000]	2.708 [0.002]
J-B Normality	875.5 [0.000]	673.9 [0.000]	714.0 [0.000]	564.1 [0.000]	81.29 [0.000]	120.9 [0.000]
AIC	-79.50	-64.02	-79.67	-61.98	-87.52	-70.41
SBIC	-69.41	-47.21	-68.97	-44.14	-76.81	-52.57

- The sample for capesize price and profit series covers the period February 1980 to December 1998. The sample for Panamax and Handysize price and profit series cover the period January 1976 to December 1998.
- The figures in (.) and [.] are standard error and probability values, respectively.
- The lag length for each model is chosen in order to minimise the SBIC.
- Q(1) and Q(12) are Ljung-Box tests for 1st and 12th order serial correlation in the residuals.
- ARCH(1) and ARCH(12) are F tests for 1st and 12th order autoregressive conditional heteroscedasticity.
- J-B is the Jarque- Bera (1980) test for normality.

7.5.2. Cointegration tests

The existence of a long run cointegrating relationship between prices (newbuilding, second-hand and scrap values) and operating profits is investigated using the Johansen (1988) cointegration method. Results are in Table 7.4. The reported lag length for the VECM models (q) are determined alongside the deterministic parts (constant and trend) using the SBIC criterion. A lag length of 2 is selected for all unrestricted VAR models¹⁴, except for the combination of panamax newbuilding prices and operating profits, where the lag length of 3

¹⁴ This refers to the lag length of an unrestricted VAR in levels as follows; $\mathbf{X}_t = \sum_{i=1}^{q+1} \mathbf{A}_i \mathbf{X}_{t-i} + \varepsilon_t$. A VAR with q+1 lags of the dependent variable can be reparameterised in a VECM with q lags of first differences of the dependent variable plus the levels terms.

is selected for the unrestricted VAR model. The deterministic components include an intercept in the cointegrating vector in all cases.

Table 7.4: Cointegration test for prices and operational profits

$$\Delta p_t = \sum_{i=1}^q a_i \Delta p_{t-i} + \sum_{i=1}^q b_i \Delta \pi_{t-i} + \gamma_1 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{1,t}$$

$$\Delta \pi_t = \sum_{i=1}^q c_i \Delta p_{t-i} + \sum_{i=1}^q d_i \Delta \pi_{t-i} + \gamma_2 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{2,t}$$

Pair of variables	Lags	Normalised Cointegrating Vector	λ_{\max}		λ_{\max} Statistics	λ_{\max} 90% CV's	λ_{trace}		λ_{trace} Statistics	λ_{trace} 90% CV's
		[1 $-\theta$ $-\theta_0$]	H_0	H_A			H_0	H_A		
Capesize										
p^{NB} and π	q=1	[1 -0.72 -4.77]	r=0	r≥1	31.29	13.81	r=0	r=1	34.53	17.88
			r≤1	r=2	3.22	7.53	r≤1	r=2	3.22	7.53
p^{SH} and π	q=1	[1 -0.95 -4.60]	r=0	r≥1	16.69	13.81	r=0	r=1	18.51	17.88
			r≤1	r=2	1.81	7.53	r≤1	r=2	1.81	7.53
p^{SC} and π	q=1	[1 -0.61 -2.20]	r=0	r≥1	16.45	13.81	r=0	r=1	20.84	17.88
			r≤1	r=2	4.39	7.53	r≤1	r=2	4.39	7.53
Panamax										
p^{NB} and π	q=2	[1 -0.55 -4.43]	r=0	r≥1	21.11	13.81	r=0	r=1	26.28	17.88
			r≤1	r=2	5.17	7.53	r≤1	r=2	5.17	7.53
p^{SH} and π	q=1	[1 -1.03 -4.56]	r=0	r≥1	28.35	13.81	r=0	r=1	31.72	17.88
			r≤1	r=2	3.36	7.53	r≤1	r=2	3.36	7.53
p^{SC} and π	q=1	[1 -0.69 -2.01]	r=0	r≥1	19.94	13.81	r=0	r=1	24.54	17.88
			r≤1	r=2	4.60	7.53	r≤1	r=2	4.60	7.53
Handysize										
p^{NB} and π	q=1	[1 -0.76 -4.64]	r=0	r≥1	15.07	13.81	r=0	r=1	19.85	17.88
			r≤1	r=2	4.78	7.53	r≤1	r=2	4.78	7.53
p^{SH} and π	q=1	[1 -1.57 -6.00]	r=0	r≥1	9.85	13.81	r=0	r=1	12.82	17.88
			r≤1	r=2	2.97	7.53	r≤1	r=2	2.97	7.53
p^{SC} and π	q=1	[1 -0.91 -2.09]	r=0	r≥1	6.37	13.81	r=0	r=1	10.81	17.88
			r≤1	r=2	4.43	7.53	r≤1	r=2	4.44	7.53

- Johansen's reduced rank cointegration tests for each pair are estimated using a model with a constant in the cointegrating vector and no trend as selected by SBIC, calculated through $SBIC = T \log(\Sigma) + v \log(T)$, where T , Σ and v are the number of observations, the determinant of the variance-covariance matrix of the residuals and the number of parameters respectively.
- The appropriate number of lags in each case is chosen so as to minimise SBIC.
- $\lambda_{\max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1})$ tests the null hypothesis of r cointegrating vectors against the alternative of $r+1$.
- $\lambda_{\text{trace}} = -T \sum_{i=r+1}^n \log(1 - \hat{\lambda}_i)$ tests the null that there are at most r cointegrating vectors against the alternative that the number of cointegrating vectors is greater than r , where n is the number of variables in the system ($n=2$ in this case).
- Critical values are from Osterwald-Lenum (1992).

In cases where newbuilding, second-hand and scrap prices of capesize and panamax vessels are involved, λ_{\max} and λ_{trace} test statistics reject the null hypothesis of there being no cointegrating vector, against the alternative of there being one cointegrating vector between prices and operating profits at the 90% significance level. This indicates the existence of long run relationships between prices (newbuilding, second-hand and scrap) and operating profits for each size. When newbuilding prices and operating profits for handysize vessels are considered, the null hypothesis of no cointegration is rejected at the 90% significance level

against the alternative of the existence of one cointegrating vector. Test results are not very clear for second-hand and scrap prices of handysize vessels. λ_{\max} and λ_{trace} test statistics do not reject the null hypothesis of there being no cointegrating vector, against the alternative of there being one cointegrating vector at even the 90% significance level. Using the Engle-Granger two-step method, however, we could confirm that second-hand and scrap prices for handysize vessels are in fact cointegrated with operating profit series.

Table 7.5: Estimated VECM of capesize prices and operating profits

$$\Delta p_t = \sum_{i=1}^q a_i \Delta p_{t-i} + \sum_{i=1}^q b_i \Delta \pi_{t-i} + \gamma_1 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{1t}$$

$$\Delta \pi_t = \sum_{i=1}^q c_i \Delta p_{t-i} + \sum_{i=1}^q d_i \Delta \pi_{t-i} + \gamma_2 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{2t}$$

	Newbuilding-price and operating profit equations		Second-hand price and operating profit equations		Scrap-price and operating profit equations	
	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$
ECT _{t-1}	-0.027** (0.008)	0.063** (0.021)	-0.013 (0.013)	0.096** (0.025)	-0.032* (0.017)	0.105** (0.031)
$\Delta \pi_{t-1}$	-0.108** (0.039)	0.391** (0.048)	0.137** (0.027)	0.406** (0.064)	0.059* (0.032)	0.429** (0.051)
Δp_{t-1}	-0.011 (0.011)	0.279 (0.290)	0.205** (0.064)	0.183 (0.136)	0.036 (0.063)	-0.057 (0.108)
R-bar squared	0.10	0.15	0.17	0.20	0.03	0.18
LB-Q(1)	0.016 [0.898]	0.380 [0.583]	0.372 [0.542]	0.202 [0.653]	0.016 [0.900]	0.349 [0.554]
LB-Q(12)	7.35 [0.833]	24.24 [0.042]	16.27 [0.179]	20.45 [0.059]	16.26 [0.179]	26.21 [0.010]
WHITE	10.20 [0.000]	1.478 [0.224]	3.342 [0.068]	0.765 [0.382]	0.004 [0.985]	3.310 [0.069]
ARCH(12)	1.731 [0.999]	13.76 [0.316]	26.90 [0.008]	23.24 [0.026]	19.76 [0.072]	24.13 [0.019]
J-B	3332 [0.000]	6.021 [0.049]	581.18 [0.000]	19.95 [0.000]	319.9 [0.000]	25.46 [0.000]
SBIC	593.64		460.38		508.58	

- The figures in (.) and [.] are standard errors and p-values, respectively.
- * and ** indicate significance at the 10% and 5% levels, respectively.
- The standard errors are corrected for serial correlation and/or heteroscedasticity using the Newey-West method.
- The lag length for each model is chosen in order to minimise the SBIC.
- Q(1) and Q(12) are Ljung-Box tests for 1st and 12th order serial correlation in the residuals, 5% critical values for these statistics are 3.84 and 21.03, respectively.
- ARCH (12) is the Ljung-Box test for 12th order serial correlation in the squared residuals, 5% critical value for this statistic is 21.03.
- J-B is the Jarque- Bera (1980) test for normality. The 5% critical value for this statistic is $\chi^2(2)=5.99$.

Estimated VECM models along with diagnostic tests for capesize vessels are in Table 7.5. It can be seen that coefficients of error correction terms in price equations are negative and significant at the 5% level, with the exception of the second-hand market in which the coefficient is negative but not significant. Coefficients of the error correction terms in profit equations are all positive and significant. The fact that these coefficients have opposite signs

indicates that both variables respond to any disequilibrium to bring back the system to the equilibrium. Results of VECM models estimated for panamax and handysize price and profit series are in Tables 7.6 and 7.7, respectively. Coefficients of error correction terms in these models also show similar patterns as VECM models of capesize prices; i.e., indicating existence of long run relationships between prices and operating profits as well as short run adjustments to such long run relationships when the system is in disequilibrium.

Table 7.6: Estimated VECM of panamax prices and operating profits

$$\Delta p_t = \sum_{i=1}^q a_i \Delta p_{t-i} + \sum_{i=1}^q b_i \Delta \pi_{t-i} + \gamma_1 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{1,t}$$

$$\Delta \pi_t = \sum_{i=1}^q c_i \Delta p_{t-i} + \sum_{i=1}^q d_i \Delta \pi_{t-i} + \gamma_2 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{2,t}$$

	Newbuilding-price and operating profit equations		Second-hand price and operating profit equations		Scrap-price and operating profit equations	
	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$
ECT _{t-1}	-0.045** (0.011)	0.023 (0.027)	-0.023** (0.012)	0.103** (0.052)	-0.028* (0.016)	0.130** (0.053)
$\Delta \pi_{t-1}$	0.004 (0.011)	0.261** (0.111)	0.073** (0.029)	0.260** (0.117)	0.099** (0.031)	0.289** (0.059)
Δp_{t-1}	0.021 (0.048)	0.069 (0.159)	0.168** (0.082)	0.333 (0.244)	-0.043 (0.061)	0.002 (0.127)
$\Delta \pi_{t-2}$	-0.009 (0.014)	0.022 (0.039)				
Δp_{t-2}	0.067 (0.040)	-0.137 (0.252)				
R-bar squared	0.08	0.07	0.10	0.13	0.05	0.11
LB-Q(1)	0.010 [0.919]	0.003 [0.956]	0.851 [0.356]	0.034 [0.842]	0.118 [0.731]	0.0003 [0.986]
LB-Q(12)	23.50 [0.024]	19.23 [0.083]	23.29 [0.025]	18.05 [0.114]	20.93 [0.051]	18.17 [0.111]
WHITE	17.25 [0.000]	20.49 [0.000]	0.043 [0.836]	4.563 [0.033]	0.379 [0.538]	12.49 [0.000]
ARCH(12)	38.40 [0.000]	63.06 [0.000]	15.54 [0.213]	57.16 [0.000]	12.10 [0.438]	63.14 [0.000]
J-B	841.2 [0.000]	854.0 [0.000]	557.0 [0.000]	515.0 [0.000]	229.9 [0.000]	623.1 [0.000]
SBIC	637.31		565.76		506.40	

See note in Table 7.5.

The fact that ship prices and operating profits are I(1) and cointegrated also rejects the existence of rational bubbles (see discussion in section 7.2.4 and Diba and Grossman 1988). These are consistent with results of the West (1987) test for the existence of rational bubbles. Results of the West's (1987) tests (see Appendix 7.C) are 266.0, 1.636 and 3.037 for handysize, panamax and capesize newbuilding prices, respectively, and 0.419, 1.813 and 3.065 for handysize, panamax and capesize second-hand prices, respectively. With the exception of newbuilding prices for handysize vessels, these tests do not reject the null of no

rational bubble¹⁵. Therefore, the existence of rational bubbles in the formation of ship prices can be ruled out as suggested by both cointegration and West's tests. Rejecting the existence of rational bubbles in price formation is important as failure of the EMH and RVF in asset pricing (i.e. permanent deviations of actual price from the theoretical price) can be due to the existence of such bubbles.

Table 7.7: Estimated VECM of handysize prices and operating profits

$$\Delta p_t = \sum_{i=1}^q a_i \Delta p_{t-i} + \sum_{i=1}^q b_i \Delta \pi_{t-i} + \gamma_1 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{1,t}$$

$$\Delta \pi_t = \sum_{i=1}^q c_i \Delta p_{t-i} + \sum_{i=1}^q d_i \Delta \pi_{t-i} + \gamma_2 (p_{t-1} + \theta \pi_{t-1} + \theta_0) + \varepsilon_{2,t}$$

	Newbuilding-price and operating profit equations		Second-hand price and operating profit equations		Scrap -price and operating profit equations	
	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$	Δp_t	$\Delta \pi_t$
ECT _{t-1}	-0.028** (0.008)	0.020 (0.017)	-0.011* (0.077)	0.021** (0.011)	-0.022** (0.014)	0.027* (0.027)
$\Delta \pi_{t-1}$	-0.020 (0.028)	0.368** (0.059)	0.110** (0.029)	0.359** (0.062)	0.117** (0.057)	0.376** (0.000)
Δp_{t-1}	-0.002 (0.061)	0.129 (0.129)	0.210** (0.001)	0.121 (0.104)	-0.071 (0.062)	-0.021 (0.744)
R-bar	0.04	0.13	0.12	0.14	0.02	0.13
LB-Q(1)	0.012 [0.911]	0.417 [0.518]	7.00 [0.008]	0.067 [0.795]	0.780 [0.377]	0.449 [0.506]
LB-Q(12)	20.55 [0.057]	18.72 [0.097]	23.11 [0.027]	15.99 [0.192]	8.265 [0.663]	17.36 [0.137]
WHITE	2.262 [0.133]	0.229 [0.623]	0.437 [0.509]	0.070 [0.241]	0.938 [0.333]	0.166 [0.684]
ARCH(12)	9.51 [0.659]	13.31 [0.347]	36.09 [0.000]	11.80 [0.462]	16.32 [0.177]	13.77 [0.327]
J-B	304.7 [0.000]	38.72 [0.000]	58.19 [0.000]	35.63 [0.000]	104.5 [0.000]	31.02 [0.000]
SBIC	706.73		659.32		621.09	

See note in Table 7.5.

7.5.3. Restrictions on the VAR and variance ratio tests

Following Campbell and Shiller (1988), we consider $S_t^{(NB,\pi)}$ (or $S_t^{(SH,\pi)}$), π_{t-1} and $S_t^{(SC,\pi)}$ (or $S_t^{(SH,\pi)}$) to be generated by a p^{th} order trivariate VAR model of equation (7.28). The general VAR model results for the combinations of “newbuilding/second-hand”, “newbuilding/scrap” and “second-hand/scrap” prices for three different sizes of dry bulk carriers are in Tables 7.8,

¹⁵ These are Wald test statistics with 5% critical value of $\chi^2(2)=5.99$.

7.9 and 7.10, respectively¹⁶. The GMM estimation method is used, while standard errors of the estimated parameters are corrected for serial correlation and/or heteroscedasticity using the Newey-West (1987) method. A lag length of one is used in all cases, chosen by SBIC.

For each VAR model (capesize, panamax and handysize), coefficients of the lagged variables along with their respective standard errors and p-values are reported in the first block of the table. For example, the first, second and third blocks on the top LHS of Table 7.8, report coefficients of the lagged spread between newbuilding prices and operating profits, $S_{t-1}^{(NB,\pi)}$, the lagged difference between changes in log profits and log returns, πr_t , and the lagged spread between second-hand prices and operating profits, $S_{t-1}^{(SH,\pi)}$, for each of the three equations in the VAR model (for capesize, panamax and handysize vessels, respectively).

Lagged coefficients of the (first) spread series are found to be close to one, indicating a high degree of persistence in every case, except for the handysize equation when the combination of “second-hand and scrap” prices are considered (Table 7.10). Lagged values of both spread series are insignificant in determining future changes in operating profits. This is expected since operating profits are thought to be exogenous in the system because changes in ship prices do not necessarily affect operating profits.¹⁷ However, it can be seen that operating profits contain information relating to the determination of terminal values and therefore the second spread term in the VAR system, as indicated by the significance of coefficients of lagged changes in operating profits in the third equation. This can justify use of the VAR system. Also, coefficients of determination, \bar{R}^2 's, for equations explaining the spread series are high, ranging between 91% to 96%. Lagged values of changes in operating profits are found to be significant in predicting both spread series, for all sizes of vessels.

¹⁶ In the case of “newbuilding/second-hand”, the present value model implies that the newbuilding price is equal to the DPV of operating profits for the next five years plus the DPV of the second-hand price five years later. In the case of “newbuilding/scrap”, the present value model implies that the newbuilding price is equal to the DPV of operating profits for the entire economic life of the vessel (i.e. 20 years) plus the DPV of her scrap price at the end of this period. Similarly, for “second-hand/scrap” model, the present value model implies that the second-hand price of the vessel is equal to the DPV of operating profits from operating the vessel for her entire economic life (i.e. 15 years) plus the DPV of her scrap price in 15 years time.

¹⁷ This is because operating profits are related to freight rates which are determined through supply and demand for shipping services. Therefore, although ship prices may affect the supply for freight services in the long run, they do not affect the demand for shipping services and consequently freight rates at least in the short run.

Table 7.8: Results of the 3 variable VAR model; Newbuilding and Second-hand prices

$$\begin{aligned}
 S_t^{(NB,\pi)} &= \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \mu_{2,i} \pi_{t-i} + \sum_{i=1}^p \mu_{3,i} S_{t-i}^{(SH,\pi)} + \varepsilon_{1,t} \\
 \pi_t &= \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \varphi_{2,i} \pi_{t-i} + \sum_{i=1}^p \varphi_{3,i} S_{t-i}^{(SH,\pi)} + \varepsilon_{2,t} \\
 S_t^{(SH,\pi)} &= \sum_{i=1}^p \lambda_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \lambda_{2,i} \pi_{t-i} + \sum_{i=1}^p \lambda_{3,i} S_{t-i}^{(SH,\pi)} + \varepsilon_{3,t}
 \end{aligned}
 \tag{Equation (7.28)}$$

	Capesize			Panamax			Handysize		
	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SH,\pi)}$	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SH,\pi)}$	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SH,\pi)}$
$S_{t-1}^{(NB,\pi)}$	1.019 (0.035) [0.000]	-0.043 (0.032) [0.186]	0.006 (0.016) [0.714]	0.991 (0.039) [0.000]	-0.017 (0.091) [0.559]	0.026 (0.028) [0.334]	0.965 (0.022) [0.000]	0.023 (0.021) [0.263]	-0.008 (0.019) [0.680]
π_{t-1}	-0.423 (0.051) [0.000]	0.422 (0.077) [0.000]	-29.23 (6.958) [0.000]	-0.288 (0.104) [0.006]	0.303 (0.097) [0.002]	-0.207 (0.096) [0.031]	-0.395 (0.059) [0.000]	0.378 (0.061) [0.000]	-0.230 (0.057) [0.000]
$S_{t-1}^{(SH,\pi)}$	-0.141 (0.057) [0.014]	0.159 (0.046) [0.001]	0.908 (0.039) [0.000]	-0.117 (0.091) [0.199]	0.126 (0.068) [0.065]	0.838 (0.067) [0.000]	-0.010 (0.032) [0.752]	-0.001 (0.023) [0.971]	0.967 (0.023) [0.000]
R-bar squared	0.95	0.21	0.86	0.92	0.12	0.84	0.95	0.14	0.93
Q(1)	0.004 [0.949]	0.289 [0.590]	0.323 [0.570]	0.001 [0.925]	0.041 [0.838]	0.001 [0.991]	0.041 [0.839]	0.058 [0.809]	0.922 [0.337]
Q(12)	20.26 [0.062]	20.30 [0.061]	23.24 [0.026]	24.15 [0.019]	25.04 [0.014]	17.29 [0.138]	6.93 [0.862]	15.64 [0.208]	9.88 [0.627]
ARCH(12)	1.603 [0.093]	1.557 [0.107]	1.396 [0.170]	2.138 [0.015]	1.424 [0.155]	1.643 [0.080]	2.044 [0.021]	1.144 [0.325]	0.854 [0.594]
SBIC	-3600.66			-4300.64			-4459.23		
Wald tests	Statistics	p-value	DF	Statistics	p-value	DF	Statistics	p-value	DF
	6.585	[0.086]	3	9.304	[0.026]	3	5.544	[0.136]	3
Variance ratio tests	2.5%	observed	97.5%	2.5%	observed	97.5%	2.5%	observed	97.5%
VR	2.438			2.737			2.860		
95% CI	1.956 3.034			2.116 3.553			2.352 3.491		

- The figures in (.) and [.] are standard errors and probability values, respectively.
- $S_t^{(NB,\pi)}$ and $S_t^{(SH,\pi)}$ are spread series between logs of second-hand prices and logs of operating profits, and scrap prices and operating profits, respectively. $\pi_t = \Delta \pi_t - r_t$, represents the difference between changes in log profits and log returns.
- VAR models are estimated by non-linear GMM. The standard errors are corrected for serial correlation and/or heteroscedasticity using the Newey-West method.
- The lag length for each model is chosen in order to minimise the SBIC.
- Q(1) and Q(12) are Ljung-Box tests for 1st and 12th order serial correlation in the residuals.
- ARCH(12) is the F test for 12th order ARCH.
- J-B is the Jarque- Bera (1980) test for normality. The 5% critical value for this statistic is $\chi^2(2)=5.99$.
- Wald tests are nonlinear cross equation restrictions of equation (7.34), $e1 = e2A(I - \rho A)^{-1}(I - \rho^n A^n) + \rho^n e3A^n$, implied by the EHM on the VAR model. They have chi-square distributions with degrees of freedom equal to the number of restrictions. This is 3 in all cases.
- VR are variance ratio tests for actual and theoretical spread series, $\text{Var}(S_t^{(NB,\pi)})/\text{Var}(S_t^{*(NB,\pi)})$. $S_t^{(NB,\pi)}$ and $S_t^{*(NB,\pi)}$ represent the actual and the theoretical spread series, respectively.
- 95% confidence intervals are bias-corrected and adjusted bootstrap intervals for variance ratio tests. When the interval includes 1 the EMH should not be rejected.

VR tests, as explained in section 7.2.3.2, are also performed to provide additional metrics on testing the validity of the EMH on the formation of dry bulk prices. Since the distribution of VR tests are not known, their empirical distributions are constructed using bootstrap methods. For this purpose, independent samples, with replacement, are drawn from the actual and

theoretical spread series, $S_i^{(NB,\pi)}$ and $S_i^{*(NB,\pi)}$, and VR's are computed and stored. This process is repeated 10,000 times. Using the 10,000 replications of VR with replacements, bias-corrected and adjusted (BCa) 95% bootstrap confidence intervals (Efron and Tibshirani, 1993) for the empirical distributions are computed in order to allow for non-normal distributions of the VR tests. BCa bootstrap confidence intervals are more robust than the standard percentile method. The null hypothesis that the VR equals unity is rejected if the 95% confidence band does not include 1.

Results of VR tests for the model with combination of “newbuilding/second-hand” prices for different size vessels are presented at the bottom of Table 7.8. These are 2.438, 2.737 and 2.860 for capesize, panamax and handysize models, respectively. Comparing them with their 95% bootstrap confidence interval indicates that the null hypothesis of equality of variances of actual and the theoretical spreads can be rejected in all cases. This by itself can be regarded as evidence against the EMH in the formation of newbuilding prices as actual spreads (prices) show greater variance than their theoretical counterparts.

Results of nonlinear cross equation restrictions implied by the EMH and the present value model on the VAR model for newbuilding and second-hand prices, equation (7.35), are also presented at the bottom of Table 7.8. Wald test statistic values are 6.585, 9.304 and 5.544 for capesize, panamax and handysize models, respectively. They indicate that the EMH can be rejected at the 10% significance level in the capesize and the 5% level in the panamax market. In the case of the newbuilding market for handysize vessels, the Wald test can not reject the validity of the EMH at even the 10% level. However, observed variance ratios are well above unity and the 95% bootstrap confidence intervals do not include unity in all cases, therefore, rejecting the EMH in determining newbuilding prices, for all dry bulk sizes.

The results of restrictions on the VAR model for “newbuilding/scrap” price, presented at the bottom of Table 7.9, suggest that the EMH can be rejected at the 10% level in the market for newbuilding capesize panamax and handysize vessels. Variance ratios are also significantly different from one when compared with the 95% bootstrap confidence intervals. These are; 1.515 with a confidence interval of 1.190 and 1.958 for the capesize model, 1.539 with a confidence interval of 1.230 and 1.949 for the panamax model and 2.052 with a confidence

interval of 1.679 and 2.481 for the handysize model. Thus, once again the EMH is rejected in the determination of newbuilding prices for all dry bulk sizes.

Table 7.9: Results of the 3 variable VAR model; Newbuilding and Scrap prices

$$\begin{aligned}
 S_t^{(NB,\pi)} &= \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \mu_{2,i} \pi_{t-i} + \sum_{i=1}^p \mu_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{1,t} \\
 \pi_t &= \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \varphi_{2,i} \pi_{t-i} + \sum_{i=1}^p \varphi_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{2,t} \\
 S_t^{(SC,\pi)} &= \sum_{i=1}^p \lambda_{1,i} S_{t-i}^{(NB,\pi)} + \sum_{i=1}^p \lambda_{2,i} \pi_{t-i} + \sum_{i=1}^p \lambda_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{3,t}
 \end{aligned}
 \tag{7.28}$$

	Capesize			Panamax			Handysize		
	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SC,\pi)}$	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SC,\pi)}$	$S_t^{(NB,\pi)}$	π_t	$S_t^{(SC,\pi)}$
$S_{t-1}^{(NB,\pi)}$	1.005 (0.029) [0.000]	-0.042 (0.033) [0.201]	0.040 (0.038) [0.309]	0.983 (0.029) [0.000]	-0.017 (0.027) [0.534]	0.027 (0.029) [0.344]	0.959 (0.020) [0.000]	0.006 (0.057) [0.775]	0.023 (0.002) [0.429]
π_{t-1}	-0.395 (0.054) [0.000]	0.390 (0.077) [0.000]	-0.335 (0.079) [0.000]	-0.264 (0.102) [0.009]	0.277 (0.102) [0.007]	-0.172 (0.098) [0.081]	-0.392 (0.057) [0.000]	0.378 (0.060) [0.000]	-0.254 (0.075) [0.001]
$S_{t-1}^{(SC,\pi)}$	-0.085 (0.039) [0.028]	0.118 (0.042) [0.005]	0.886 (0.047) [0.000]	-0.081 (0.046) [0.078]	0.099 (0.039) [0.011]	0.883 (0.041) [0.000]	-0.001 (0.026) [0.974]	0.023 (0.022) [0.277]	0.936 (0.032) [0.000]
R-bar squared	0.95	0.20	0.91	0.92	0.13	0.88	0.95	0.15	0.92
Q(1)	0.008 [0.925]	0.266 [0.606]	1.718 [0.279]	0.000 [0.993]	0.009 [0.923]	0.260 [0.610]	0.029 [0.864]	0.052 [0.820]	0.007 [0.932]
Q(12)	21.91 [0.039]	22.15 [0.035]	17.43 [0.134]	19.90 [0.069]	18.51 [0.101]	12.05 [0.442]	6.942 [0.861]	14.72 [0.256]	7.126 [0.849]
ARCH(12)	1.535 [0.115]	1.430 [0.155]	2.141 [0.016]	3.152 [0.000]	2.292 [0.009]	1.561 [0.104]	2.050 [0.021]	1.148 [0.321]	1.024 [0.205]
SBIC	-3573.07			-4189.67			-4194.78		
Wald tests	Statistics	p-value	DF	Statistics	p-value	DF	Statistics	p-value	DF
	6.361	[0.095]	3	7.609	[0.055]	3	7.810	[0.050]	3
Variance ratio tests	2.5%	observed	97.5%	2.5%	observed	97.5%	2.5%	observed	97.5%
VR	1.515			1.539			2.052		
95% CI	1.190		1.958	1.230		1.949	1.679		2.481

- See notes in Table 7.8.
- $S_t^{(NB,\pi)}$ and $S_t^{(SC,\pi)}$ are spread between logs of newbuilding prices and logs of operating profits, and scrap prices and operating profits, respectively.
- VR are variance ratio tests for actual and theoretical spread series, $\text{Var}(S_t^{(NB,\pi)})/\text{Var}(S_t^{*(NB,\pi)})$. $S_t^{(NB,\pi)}$ and $S_t^{*(NB,\pi)}$ represent the actual and the theoretical spread series, respectively.

Finally, in the case of “second-hand/scrap” price model, Table 7.10, Wald test statistics indicate that the restrictions implied by the present value model and the EMH on the VAR model are also rejected at the 5% significance level for all dry bulk size categories. Variance ratios on the other hand, are not significantly different from one when compared with the 95% bootstrap confidence intervals, except for the handysize model, where the VR with the value of 1.697 with the 95% confidence interval of 1.371 and 2.084. For panamax and capesize models, variance ratios are 0.719 and 0.778, respectively.

Table 7.10: Results of the 3 variable VAR model; *Second-hand and Scrap prices*

$$\begin{aligned}
 S_t^{(SH,\pi)} &= \sum_{i=1}^p \mu_{1,i} S_{t-i}^{(SH,\pi)} + \sum_{i=1}^p \mu_{2,i} \pi_{t-i} + \sum_{i=1}^p \mu_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{1,t} \\
 \pi_t &= \sum_{i=1}^p \varphi_{1,i} S_{t-i}^{(SH,\pi)} + \sum_{i=1}^p \varphi_{2,i} \pi_{t-i} + \sum_{i=1}^p \varphi_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{2,t} \\
 S_t^{(SC,\pi)} &= \sum_{i=1}^p \lambda_{1,i} S_{t-i}^{(SH,\pi)} + \sum_{i=1}^p \lambda_{2,i} \pi_{t-i} + \sum_{i=1}^p \lambda_{3,i} S_{t-i}^{(SC,\pi)} + \varepsilon_{3,t}
 \end{aligned}
 \tag{Equation (7.28)}$$

	Capesize			Panamax			Handysize		
	$S_t^{(SH,\pi)}$	π_t	$S_t^{(SC,\pi)}$	$S_t^{(SH,\pi)}$	π_t	$S_t^{(SC,\pi)}$	$S_t^{(SH,\pi)}$	π_t	$S_t^{(SC,\pi)}$
$S_{t-1}^{(SH,\pi)}$	0.888 (0.047) [0.000]	0.073 (0.037) [0.046]	-0.055 (0.037) [0.142]	0.900 (0.054) [0.000]	0.057 (0.044) [0.193]	-0.058 (0.046) [0.207]	0.968 (0.017) [0.000]	0.0026 (0.019) [0.891]	0.009 (0.026) [0.720]
π_t	-0.277 (0.054) [0.000]	0.415 (0.077) [0.000]	-0.356 (0.079) [0.000]	-0.203 (0.090) [0.024]	0.298 (0.098) [0.002]	-0.195 (0.095) [0.039]	-0.229 (0.053) [0.000]	0.378 (0.061) [0.000]	-0.257 (0.075) [0.001]
$S_{t-1}^{(SC,\pi)}$	0.003 (0.037) [0.941]	0.026 (0.034) [0.438]	0.964 (0.036) [0.000]	-0.031 (0.027) [0.251]	0.053 (0.024) [0.025]	0.939 (0.026) [0.000]	-0.013 (0.015) [0.396]	0.026 (0.018) [0.128]	0.950 (0.024) [0.000]
R-bar squared	0.86	0.20	0.91	0.84	0.14	0.88	0.93	0.15	0.92
Q(1)	0.205 [0.650]	0.239 [0.625]	0.863 [0.353]	0.016 [0.899]	0.024 [0.876]	0.140 [0.708]	0.928 [0.254]	0.054 [0.816]	0.0001 [0.992]
Q(12)	26.93 [0.021]	21.55 [0.043]	16.87 [0.154]	16.49 [0.170]	22.92 [0.028]	13.99 [0.302]	9.931 [0.622]	14.56 [0.266]	7.153 [0.847]
ARCH(12)	1.296 [0.246]	1.442 [0.150]	2.089 [0.019]	1.933 [0.031]	2.012 [0.024]	1.227 [0.265]	0.847 [0.601]	1.152 [0.318]	1.199 [0.248]
SBIC	-3287.98			-4056.17			-4086.64		
Wald tests	Statistics	p-value	DF	Statistics	p-value	DF	Statistics	p-value	DF
	63.350	[0.000]	3	15.530	[0.001]	3	18.545	[0.000]	3
Variance ratio tests	2.5%	observed	97.5%	2.5%	observed	97.5%	2.5%	observed	97.5%
VR	0.719			0.778			1.697		
95% CI	0.578 0.893			0.597 1.007			1.371 2.084		

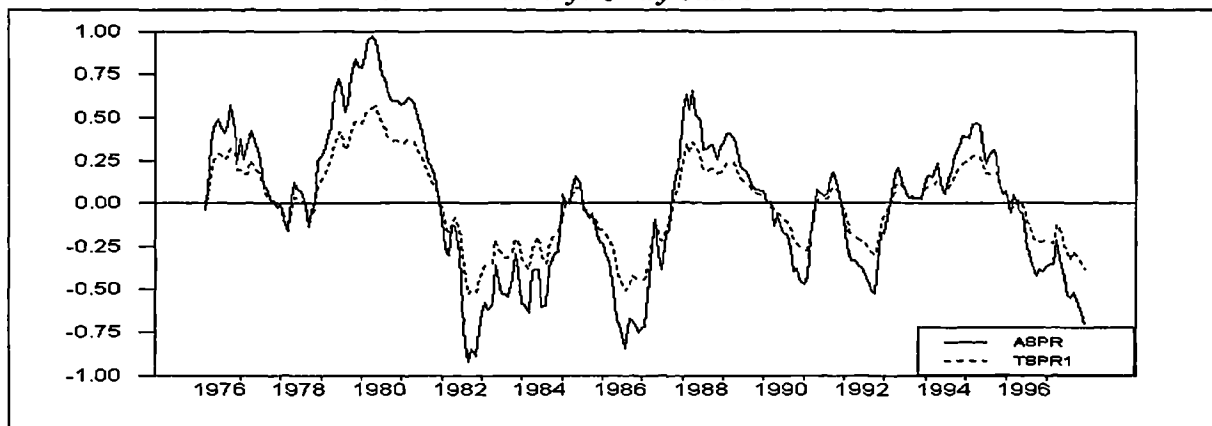
- See notes in Table 7.8.
- $S_t^{(SH,\pi)}$ and $S_t^{(SC,\pi)}$ represent spreads between logs of second-hand prices and logs of operating profits, and logs of scrap prices and logs of operating profits, respectively.
- VR are variance ratio tests for actual and theoretical spread series, $\text{Var}(S_t^{(SH,\pi)})/\text{Var}(S_t^{*(SH,\pi)})$. $S_t^{(NB,\pi)}$ and $S_t^{*(SH,\pi)}$ represent the actual and the theoretical spread series, respectively.

Panel A of Figure 7.5 illustrates the co-movements of actual and theoretical spread series for the case of “newbuilding/second-hand” price model. It can be seen that the volatility of the theoretical spread is lower than the actual spread series. Figures 7.6 and 7.7 plot the co-movements of actual and theoretical spread series for “newbuilding/scrap” price and “second-hand/scrap” price models. In both cases theoretical spread series seem to be smoother than actual spread series.

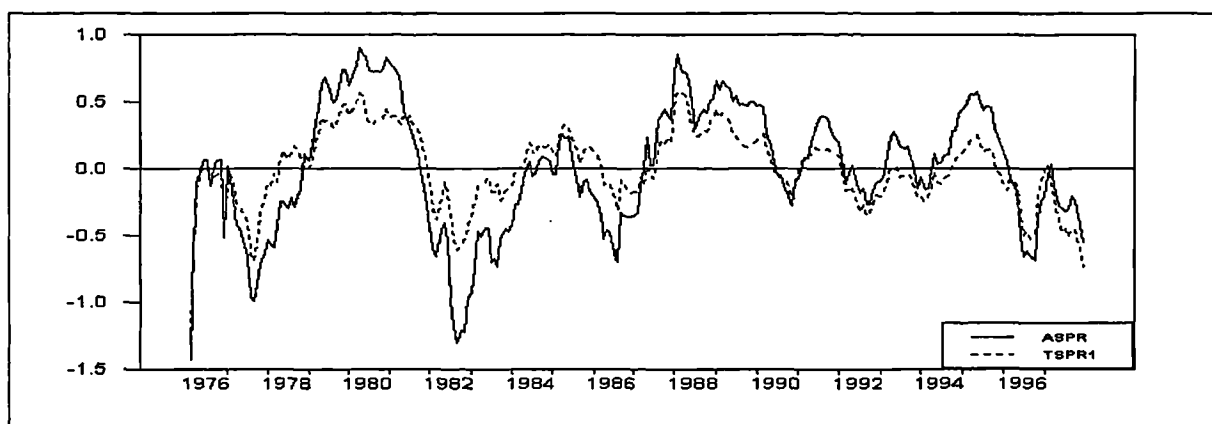
Overall, the results of VAR model and variance ratio tests reject the validity of the EMH in the formation of newbuilding and second-hand prices for different size vessels. Therefore, the aim of the next section is to investigate whether failure of the EMH is due to the existence of time-varying risk premia.

Figure 7.5: Actual (ASPR) and theoretical spread (TSPR1) series from the model for newbuilding and second-hand prices

Panel A- Handysize dry bulk carriers



Panel B- Panamax dry bulk carriers



Panel C- Capesize dry bulk carriers

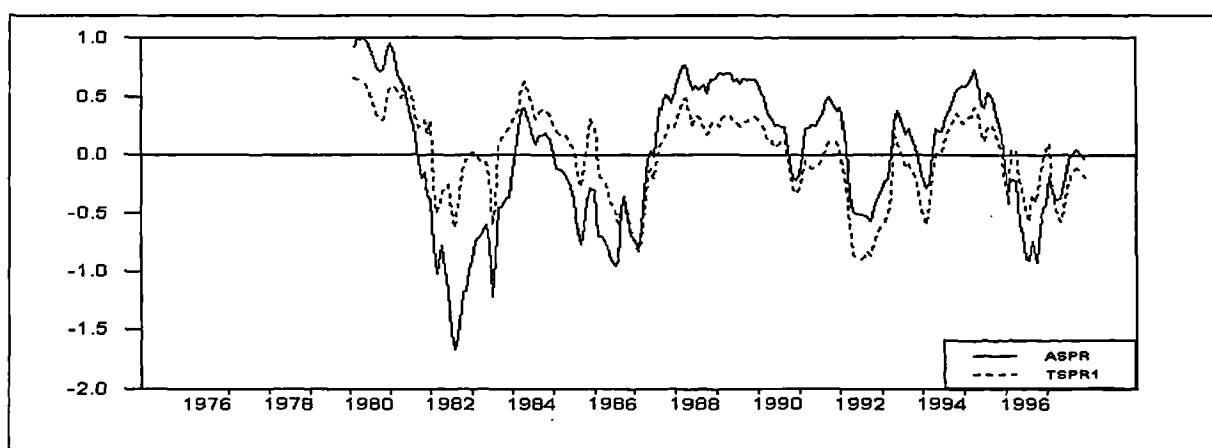
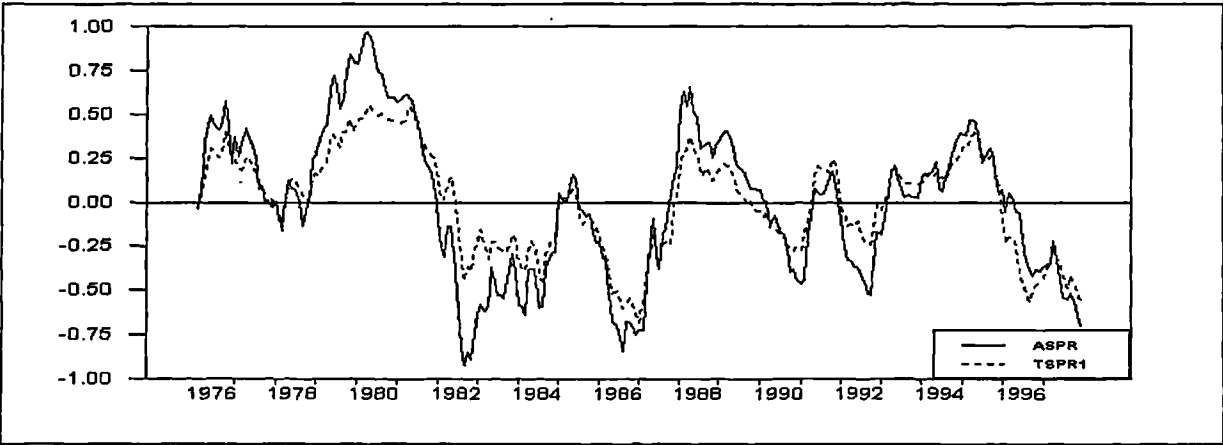
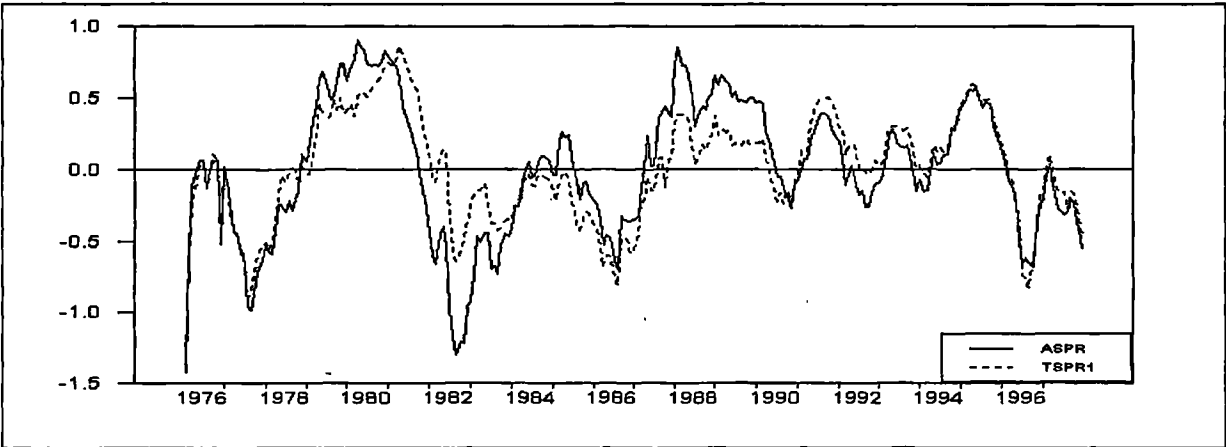


Figure 7.6: Actual (ASPR) and theoretical spread (TSPR1) series from the model for newbuilding and scrap prices

Panel A- Handysize dry bulk carriers



Panel B- Panamax dry bulk carriers



Panel C- Capesize dry bulk carriers

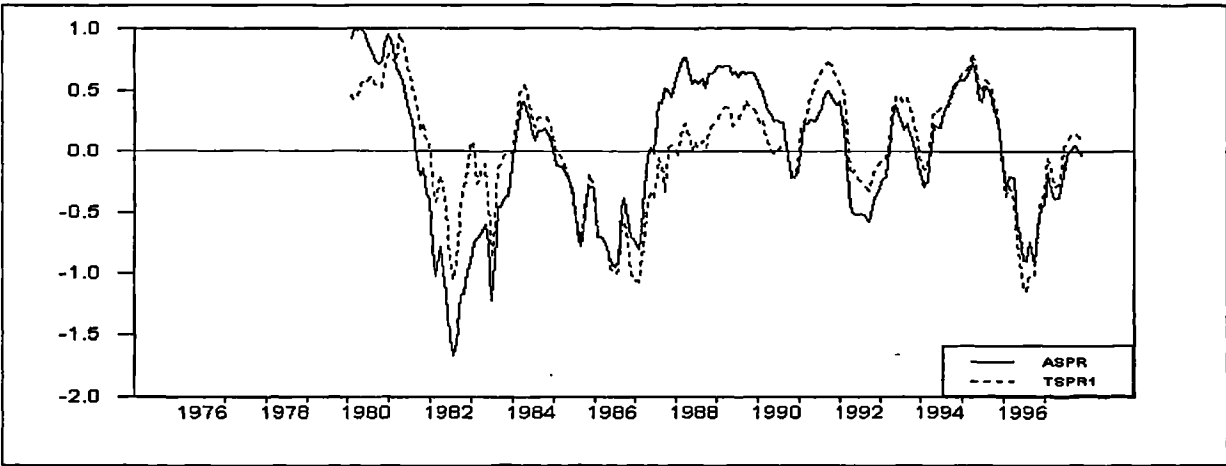
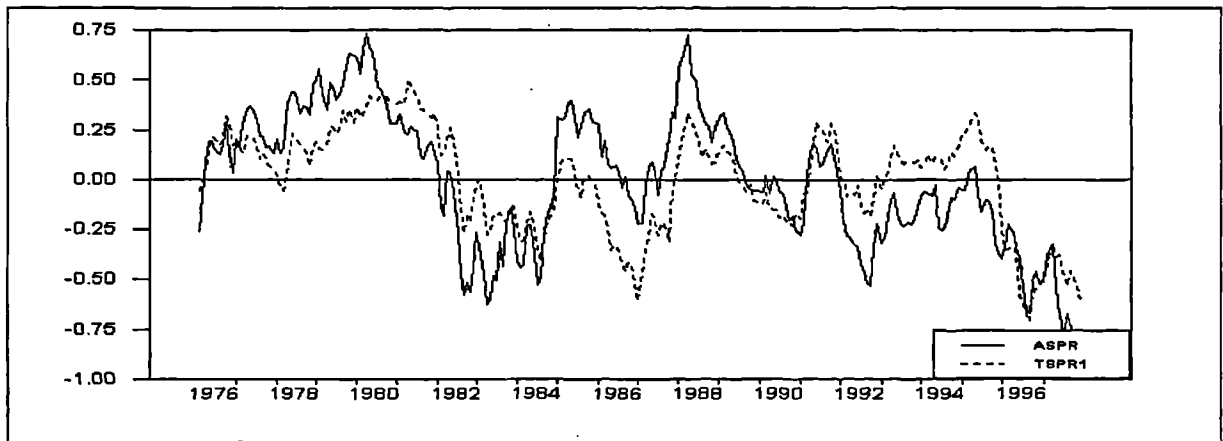
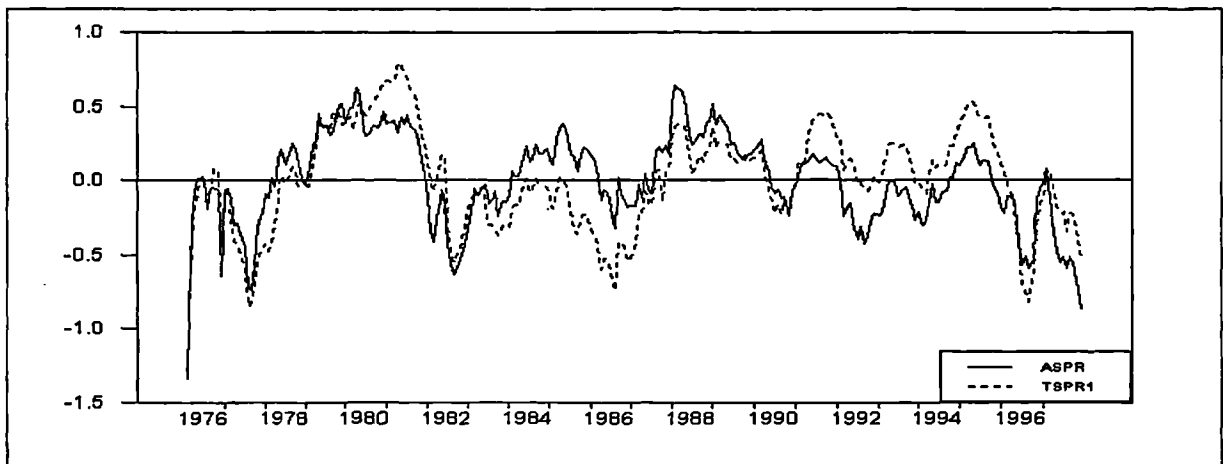


Figure 7.7: Actual (ASPR) and theoretical spread (TSPR1) series from the model for second-hand and scrap prices

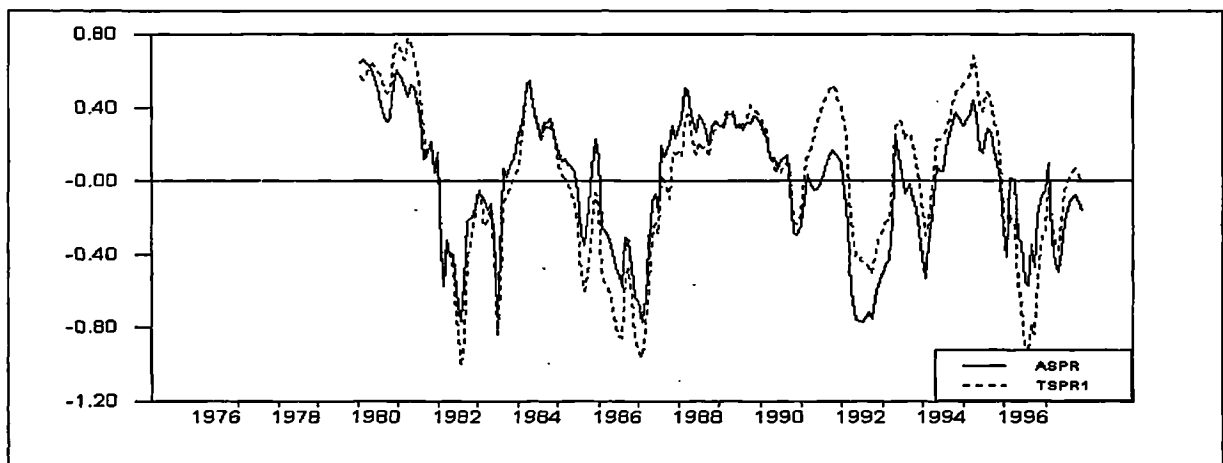
Panel A- Handysize dry bulk carriers



Panel B- Panamax dry bulk carriers



Panel C- Capesize dry bulk carriers



7.5.4. Time-varying risk premia

Overall, the results from different tests of the EMH in ship price formation reject the validity of the hypothesis. Such a rejection might be due to the existence of risk premium, which may also be time varying. In this section, we investigate the existence of time-varying risk premia in the markets for ships through the GARCH-M model of equation (7.41). To ensure convergence to a global maximum, each model is estimated using a wide range of initial values with a tight convergence criterion. Since residuals are found to be non-normal, parameters and asymptotic standard errors are estimated using the Bollerslev and Wooldridge (1992) Quasi-Maximum Likelihood (QML) method.

Results are in Table 7.11 and Table 7.12, for 1-month and 3-month excess returns, respectively. The GARCH-M(1,1) specification is found to be the appropriate specification for modelling time-varying volatilities in all cases. Diagnostic tests confirm that all models are well specified and the sign and size bias tests do not indicate any asymmetric effects of shocks on the conditional variance (see, Engle and Ng, 1993b) in the selected models. The adjusted R-square values vary from 3% for 1-month capesize rates to 77% for 3-month handysize rates. The adjusted R-square values for 3-month excess holding period return models are higher than those for 1-month excess holding period return models. This is because of the existence of MA terms in models for 3-month excess holding period returns. Diagnostic tests for 1st and 6th order serial correlation and for ARCH effects across all models, indicate that GARCH-M models are well specified and capture the ARCH effects.

In the case of 1-month excess holding period returns, positive and significant parameters of the standard deviation terms in the mean equation for all size vessels indicate the existence of time-varying risk premia. The coefficients of time-varying risk premia are 0.766, 0.361 and 0.282 for capesize, panamax and handysize vessels, respectively. These coefficients can be interpreted as the impact of forecast errors (volatility) on excess returns. The same argument also holds for 3-year charter rates. Positive and significant coefficients of lagged standard error terms of 0.106, 0.593 and 0.646 for capesize, panamax and handysize models, respectively, support the importance of risk in the excess return determination in the respective markets.

Table 7.11: Results of GARCH-M model of 1-month excess return on shipping investment over 1-month LIBOR

$$exr_{t+1} = \lambda_0 + \sum_{i=0}^m \lambda_i exr_{t-i} + \phi_1 \sigma_{t+1} + \varepsilon_{t+1}, \quad \varepsilon_{t+1} \sim iid(0, \sigma_{t+1}^2)$$

$$\sigma_{t+1}^2 = a_0 + \sum_{i=0}^p b_i \varepsilon_{t-i}^2 + \sum_{i=0}^q c_i \sigma_{t-i}^2$$

Equation (7.41)

	CAPEXSIZE			PANAMAX			HANDYSIZE		
λ_0	-0.041	(0.001)	[0.000]	-0.012	(0.007)	[0.081]	-0.011	(0.002)	[0.000]
ϕ_1	0.766	(0.084)	[0.000]	0.361	(0.161)	[0.049]	0.282	(0.037)	[0.000]
λ_1	0.273	(0.030)	[0.000]	0.207	(0.063)	[0.001]	0.243	(0.064)	[0.000]
λ_2	0.101	(0.042)	[0.016]	0.228	(0.045)	[0.000]	0.270	(0.074)	[0.000]
λ_3	0.102	(0.059)	[0.083]	—			—		
a_0	0.035	(0.004)	[0.000]	0.014	(0.003)	[0.000]	0.0002	(0.00014)	[0.113]
b_1	0.159	(0.003)	[0.000]	0.180	(0.041)	[0.000]	0.108	(0.048)	[0.027]
c_1	0.756	(0.008)	[0.000]	0.952	(0.005)	[0.000]	0.811	(0.060)	[0.000]
\bar{R}^2	0.040			0.092			0.125		
Kurtosis	10.12	[0.000]		10.81	[0.000]		3.824	[0.000]	
Q(1)-statistic	0.599	[0.439]		0.232	[0.630]		0.001	[0.935]	
Q(6)-statistic	0.669	[0.995]		9.581	[0.652]		2.046	[0.915]	
ARCH(1)	3.369	[0.068]		0.033	[0.855]		0.372	[0.546]	
ARCH(6)	0.816	[0.558]		0.142	[0.990]		0.225	[0.968]	
J-B Normality	920.7	[0.000]		1375	[0.000]		151.5	[0.000]	
SBIC	-930.23			-1102.88			-1131.9		
Volatility Persistence	0.597			0.936			0.670		
Unconditional volatility	0.087			0.218			0.0001		
Sign Bias	0.121	[0.903]		-0.438	[0.662]		-1.093	[0.275]	
Negative Size Bias	-2.686	[0.008]		-0.932	[0.352]		0.547	[0.584]	
Positive Size Bias	0.920	[0.358]		0.373	[0.709]		-0.697	[0.486]	
Joint test	3.391	[0.019]		0.636	[0.592]		1.253	[0.291]	

- Coefficients of kurtosis are centralised (Ku-3).
- Q(1) and Q(6) are Ljung-Box tests for 1st and 6th order serial correlation in the residuals.
- ARCH(1) and ARCH(6) are F tests for 1st and 6th order autoregressive conditional heteroscedasticity.
- J-B is the Jarque- Bera (1980) test for normality.
- The test statistics for the Engle and Ng (1993a) tests are the t-ratio of ψ_1 in the regressions; $e\sigma_t^2 = \psi_0 + \psi_1 S_{t-1}^- + e_t$ (sign bias test); $e\sigma_t^2 = \psi_0 + \psi_1 S_{t-1}^- \varepsilon_{t-1} + e_t$ (negative size bias test); $e\sigma_t^2 = \psi_0 + \psi_1 S_{t-1}^+ \varepsilon_{t-1} + e_t$ (positive size bias test), where $e\sigma_t^2$ are the squared standardised residuals, ε_t^2/h_t , S_{t-1}^- is a dummy variable taking the value of one when ε_{t-1} is negative and zero otherwise, and $S_{t-1}^+ = 1 - S_{t-1}^-$. The joint test is based on the regression $e\sigma_t^2 = \psi_0 + \psi_1 S_{t-1}^- + \psi_2 S_{t-1}^- \varepsilon_{t-1} + \psi_3 S_{t-1}^+ \varepsilon_{t-1} + e_t$. The joint test $H_0: \psi_1 = \psi_2 = \psi_3 = 0$, is an F test with 95% critical value of 2.60. (see chapter 3, section 3.6.3 for more details)
- Persistence of volatility in each model is calculated as $b_1^2 + c_1^2$.
- Unconditional volatility is calculated as $\sigma^2 = a^2/(1-b_1^2 - c_1^2)$.

Comparison of the coefficients of risk premia across the size of vessels indicate that the larger the vessel, the larger the impact of volatility on excess holding period returns¹⁸. However, the opposite pattern is observed when coefficients of risk premia in 3-month excess holding period returns models are compared. Therefore, there is no clear pattern as to how the impact of risk is related to the size or holding period.

Table 7.12: Results of GARCH-M model of 3-month excess return on shipping investment over 3-month LIBOR

$$exr_{t+n} = \lambda_0 + \sum_{i=0}^m \lambda_i exr_{t+n-i} + \phi_1 \sigma_{t+n} + \eta_{t+n}$$

$$\eta_{t+n} = \varepsilon_{t+n} + \sum_{i=0}^{n-1} \omega_i \varepsilon_{t+n-i} \quad \varepsilon_t \sim iid(0, \sigma_t^2) \quad \text{Equation (7.42)}$$

$$\sigma_{t+n}^2 = a_0^2 + \sum_{i=0}^q b_i^2 \varepsilon_{t+n-i}^2 + \sum_{i=0}^p c_i^2 \sigma_{t+n-i}^2$$

	CAPE SIZE			PANAMAX			HANDY SIZE		
λ_0	0.026	(0.017)	[0.142]	-0.014	(0.020)	[0.000]	-0.029	(0.021)	[0.173]
ϕ_h	0.106	(0.037)	[0.004]	0.593	(0.104)	[0.000]	0.646	(0.276)	[0.019]
λ_1	0.314	(0.081)	[0.057]	0.237	(0.061)	[0.000]	0.271	(0.057)	[0.000]
λ_2	0.112	(0.058)	[0.000]	0.216	(0.027)	[0.003]	0.285	(0.063)	[0.000]
λ_3				0.131	(0.053)	[0.015]			
ω_1	0.965	(0.034)	[0.000]	0.972	(0.027)	[0.000]	0.969	(0.021)	[0.000]
ω_2	0.946	(0.023)	[0.000]	0.931	(0.026)	[0.000]	0.972	(0.010)	[0.000]
a_0	0.014	(0.001)	[0.000]	0.017	(0.0004)	[0.000]	0.016	(0.011)	[0.155]
b_1	0.182	(0.008)	[0.000]	0.314	(0.009)	[0.000]	0.335	(0.057)	[0.000]
c_1	0.964	(0.002)	[0.000]	0.901	(0.012)	[0.000]	0.898	(0.071)	[0.000]
\bar{R}^2	0.78			0.79			0.81		
Kurtosis	8.755	[0.000]		7.293	[0.000]		4.319	[0.000]	
Q(1)-statistic	0.730	[0.392]		0.322	[0.570]		0.003	[0.958]	
Q(6)-statistic	4.482	[0.611]		4.400	[0.577]		3.147	[0.791]	
ARCH(1)	3.137	[0.078]		0.162	[0.688]		0.524	[0.469]	
ARCH(6)	0.761	[0.601]		0.315	[0.928]		0.291	[0.940]	
J-B Normality	632.3	[0.000]		568.07	[0.000]		198.9	[0.000]	
SBIC	-958.50			-1093.94			-1122.70		
Volatility Persistence	0.962			0.911			0.918		
Unconditional volatility	0.373			0.191			0.195		
Sign Bias	0.289	[0.765]		0.478	[0.631]		0.357	[0.721]	
Negative Size Bias	-2.346	[0.020]		-1.112	[0.267]		0.041	[0.968]	
Positive Size Bias	0.269	[0.788]		0.458	[0.647]		-0.884	[0.377]	
Joint test	2.115	[0.100]		0.645	[0.587]		0.293	[0.830]	

- See notes in Table 7.11.
- Sample period 1976:1 to 1997:12 for Handysize and panamax vessels and 1980:1 to 1997:12 for cape size vessels.

¹⁸ A comparison between impact of risk across size is not appropriate, as the estimation period for capesize models is different from the estimation period for panamax and handysize models. Therefore, comparisons are made between panamax and handysize models.

For 1-month excess holding period returns in the handysize market, actual and fitted values are plotted in Panel A of Figure 7.8, while Panel B of the same figure plots the time-varying volatility of 1-month excess holding period returns. It can be seen that the volatility of handysize excess returns, which is found to be a determinant of the level of excess returns, fluctuates over time. Also, periods when returns are high are associated with periods when excess returns show higher volatilities. Similarly, panels A and B of Figure 7.9 show plots of actual and fitted values of 3-month excess holding period returns, and associated time-varying volatilities, respectively. The time-varying volatilities on this figure show similar patterns as the volatility of 1-month excess returns. However, a visual inspection of the two volatilities suggests that the mean level of time-varying volatilities of 3-month excess returns is higher than the mean level of volatilities for 1-month excess returns. This is in line with estimates of unconditional volatilities reported in Tables 7.11 and 7.12, except volatilities of panamax excess returns, where unconditional volatility of 1-month returns are slightly higher than unconditional volatility of 3-month excess returns. Higher unconditional volatilities of 3-month excess returns compared to 1-month returns might be due to the higher risk involved in the asset for longer period as the risk of having unexpected changes in both prices and operating profits increase, which in turn leads to greater forecast errors.

Figure 7.8: Actual and fitted 1-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Handysize bulk carriers

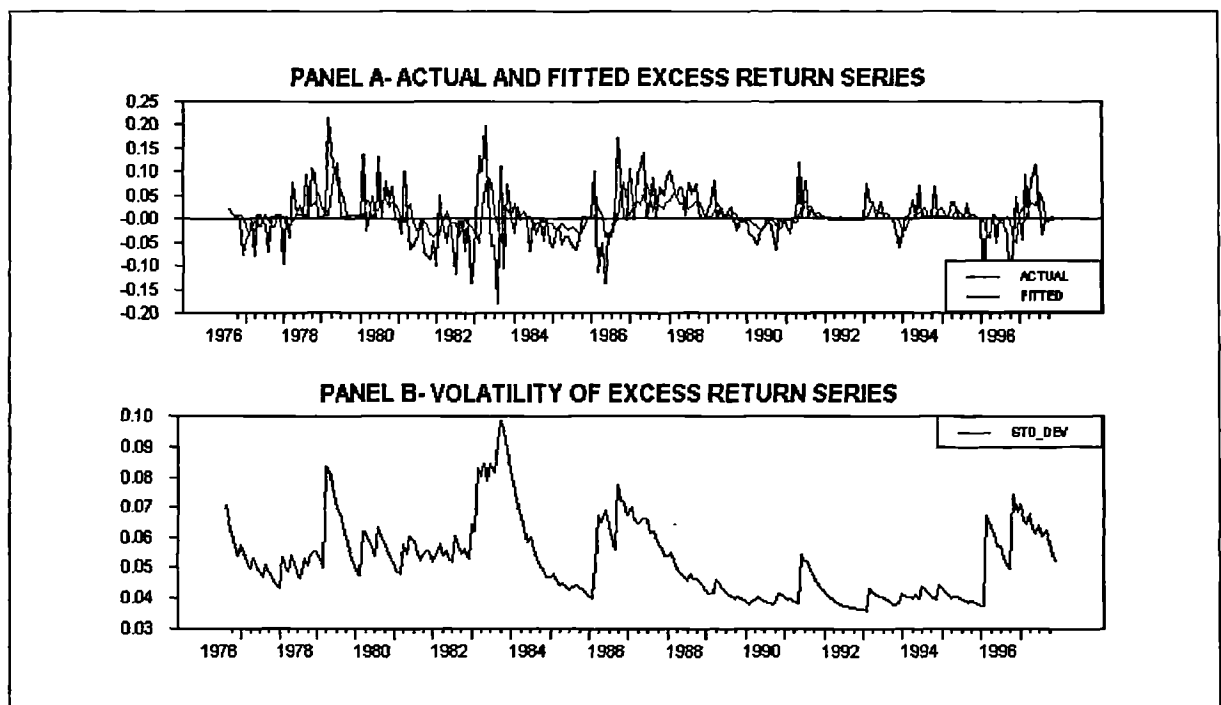
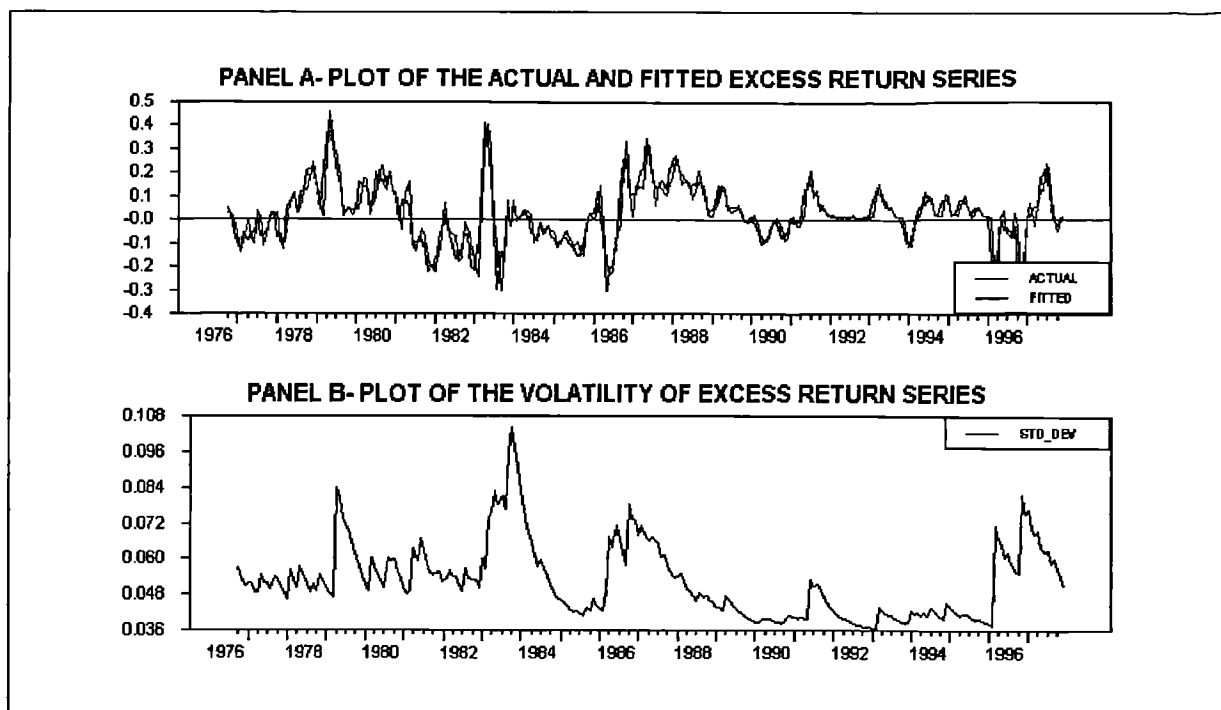


Figure 7.9: Actual and fitted 3-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Handysize bulk carriers



Panels A and B of Figures 7.10 and 7.11 plot the actual and fitted values of levels and time-varying volatilities of 1-month and 3-month excess holding period returns in the market for panamax vessels, respectively. The patterns of time-varying volatilities of both 1-month and 3-month excess returns seem to be similar with distinct peaks between 1978 to 1980 and 1996 to 1997. Volatility levels in this market are also higher for longer holding period for the reasons mentioned earlier.

Actual and fitted values of levels and time-varying volatilities of 1-month and 3-month excess holding period returns for capesize vessels are shown in panels A and B of Figures 7.12 and 7.13, respectively. Conclusions on the behaviour of excess return volatilities of 1-month and 3-month excess returns in the market for capesize vessels and their impact on levels of excess holding period returns are similar to those for the markets for handysize and panamax vessels.

Figure 7.10: Actual and fitted 1-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Panamax bulk carriers

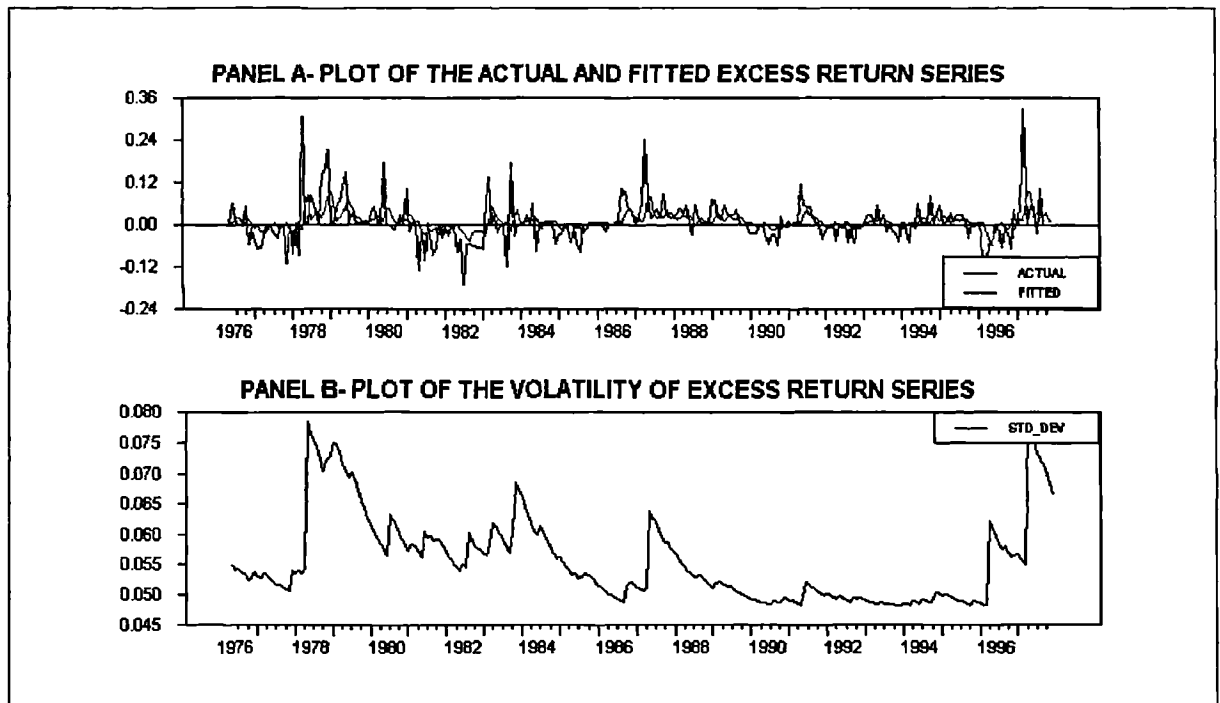


Figure 7.11: Actual and fitted 3-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Panamax bulk carriers

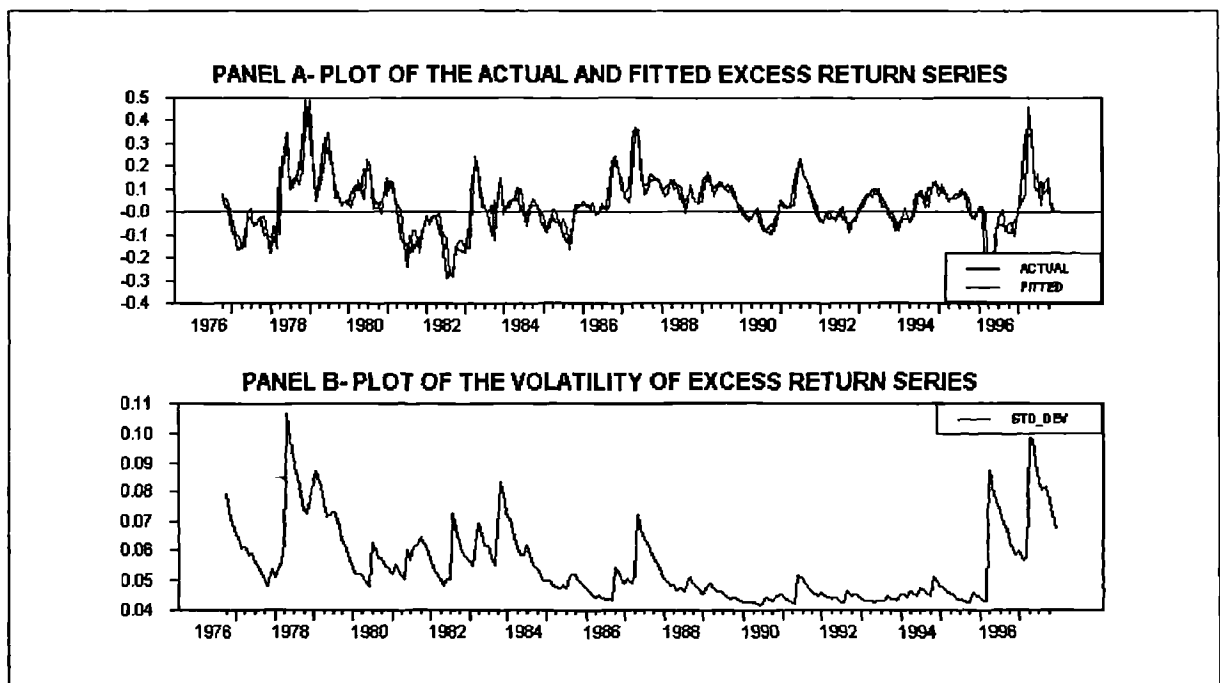


Figure 7.12: Actual and fitted 1-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Capesize bulk carriers

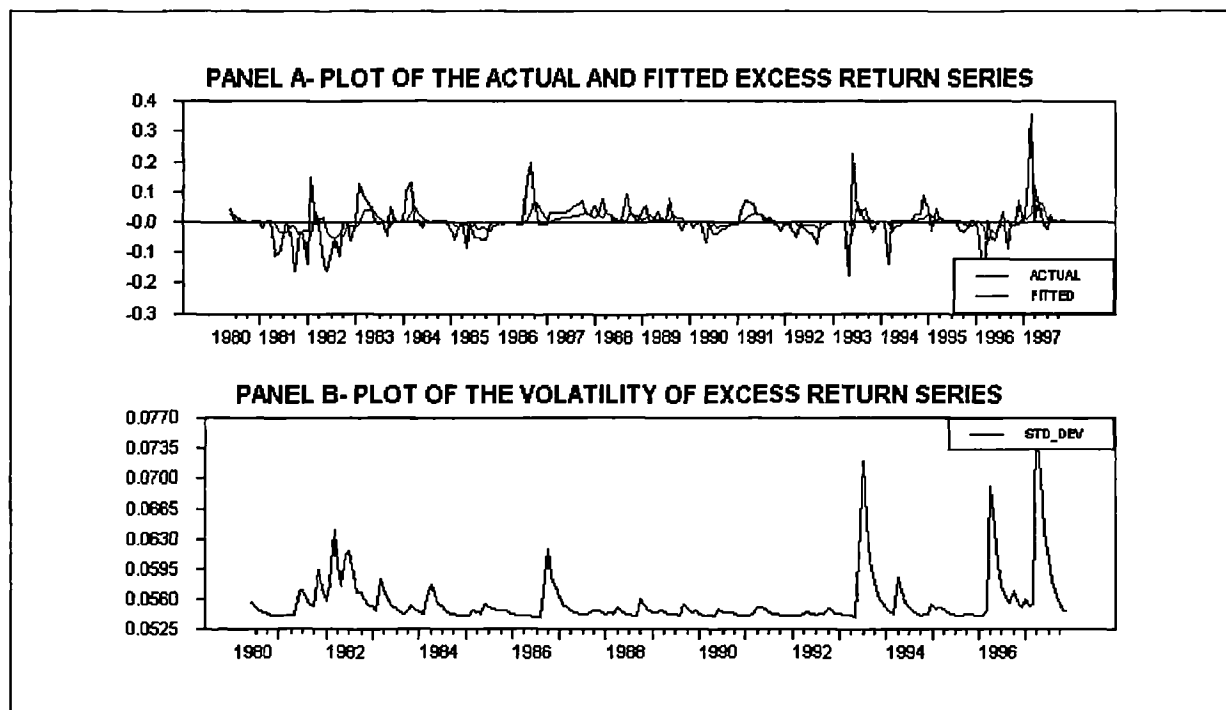
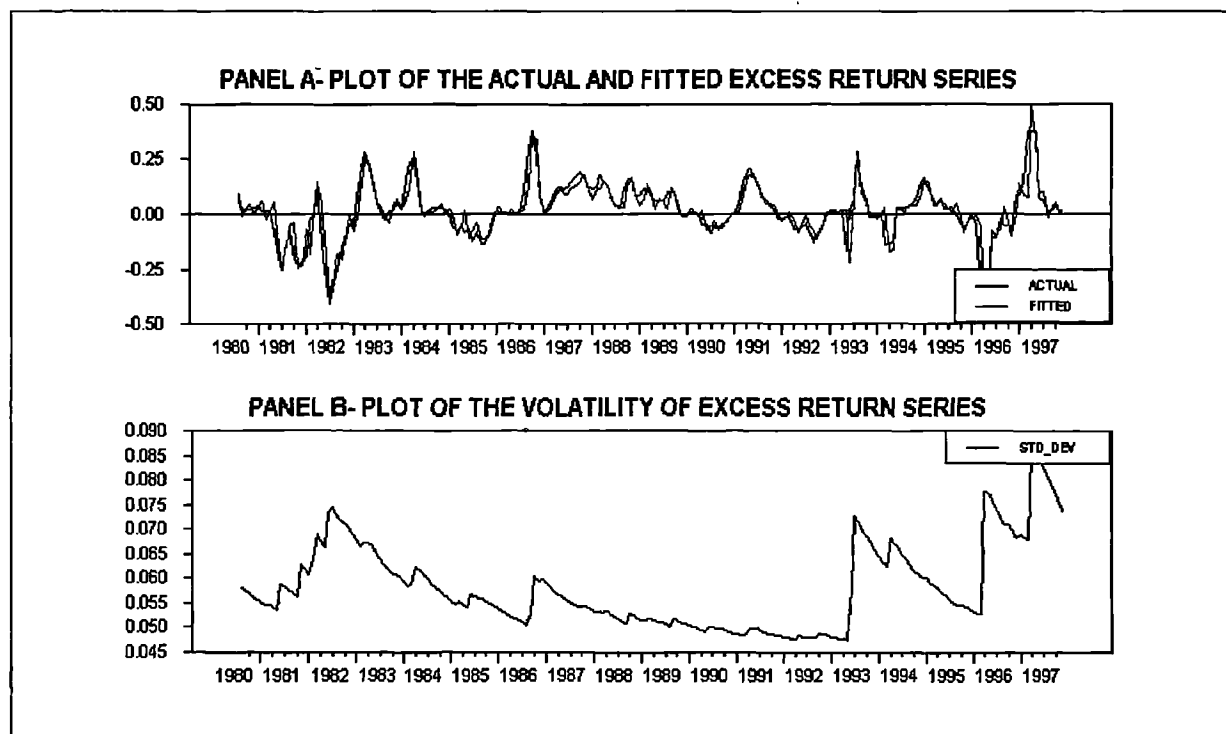


Figure 7.13: Actual and fitted 3-month excess holding period returns and time-varying volatility of excess holding period returns in the market for Capesize bulk carriers



7.6. Discussion

Several attempts have been made in recent years to explain and model the behaviour of ship prices as well as their volatilities. In general, models developed in the literature for the determination of ship prices (e.g. Beenstock 1985 and Beenstock and Vergottis 1989a and b) assume the EMH and RE. Wright (1993) investigates the validity of the RE in the formation of ship prices and finds that apart from the RE hypothesis, other hypotheses such as adaptive and static expectations are also valid. He argues that this is because agents' use different forms of expectations under different circumstances and market conditions, but he does not provide any further insight. Studies such as Hale and Vanags (1992) and Glen (1997) question the validity of the EMH and RE assumption in the formation of ship prices using disaggregated data and provide mixed evidence on the validity of the EMH and RE. For example, Hale and Vanags (1992) examine the unpredictability of price changes (returns) in the second-hand market for different size dry bulk carriers. Using cointegration techniques and error correction models, they investigate whether price changes can be predicted. Their results are mixed and inconclusive. Glen (1997) could not find support for the EMH and RE in the formation of second-hand prices for tankers and dry bulk carriers.

In this chapter we examined the EMH and RE in the formation of dry bulk carrier prices using recently developed testing techniques. In particular, we investigated the validity of the theory in the market for newbuilding vessels for the first time. Results in this chapter, based on the VAR methodology, reject the EMH in the market for newbuilding and second-hand dry bulk vessels. In addition, it is found that excess returns on shipping investments (second-hand vessels) over LIBOR are highly predictable, which is again against the notion of informational efficiency in the market for second-hand dry bulk ships. In the case of the market for second-hand ships, we attribute failure of the EMH to the existence of time-varying risk premia, which are modelled through GARCH-M specifications. The results indicate that the time-varying standard deviation of excess returns contributes to the determination of excess returns in the market. Such risk-return relationship seems to be consistent across different size bulk carriers, however, no clear pattern is observed regarding the vessel size and the impact of risk on excess returns. The following discussion is aimed to shed some light on the existence of the risk-return relationship.

Investors in the shipping industry rely not only on the profits that can be generated through shipping operations but also on capital gains from buying and selling merchant vessels. Some investors believe that the latter activity is relatively more important than the former one since correct timing of sale and purchase can be highly rewarding, whereas operating vessels may not be as profitable at times.

Authors, such as Strandenæs (1984), Beenstock (1985) and Beenstock and Vergottis (1989a and b) recognise that investors in the shipping sector are profit maximising agents and attempt to explain and model ship prices while treating ships as capital assets, which investors are willing to hold in their portfolios subject to certain rates of return. It can be argued that if investors are assumed to act as profit maximising agents, as it is assumed in the above studies, then they should also be concerned about the risk involved in holding assets in conjunction with their returns. This is because rational and risk-averse investors maximise the return on their portfolio subject to a certain level of risk, or minimise risk subject to a certain level of return. Therefore, one would expect that rational and risk-averse investors in the shipping sector foresee different types of risks involved in shipping investment and operation, and incorporate them in their decision making process, pricing formulas and portfolio adjustments.

It has been argued in the past that the risk involved in shipping can be much higher than other sectors of the economy (Stopford 1997) as investors in the shipping business experienced sharp fluctuations in both freight rates as well as ship prices. Kavussanos (1997) documents that volatility of ship prices varies over time and across vessel sizes. In fact, he finds that prices for larger vessels tend to fluctuate more than prices for smaller ones, and attributes such differences in volatility levels to the differing flexibility of vessel operation by size. Time varying volatility of ship prices in conjunction with the profit maximisation behaviour of investors implies that investors should expect different returns on their investments at different points in time.

Furthermore, it has been shown in the literature that freight rates for different size dry bulk carriers are different and show time-varying volatilities (see Kavussanos 1996). Dynamic volatilities of shipping freight rates can be due to fluctuations of different factors, which determine the supply and demand for shipping services at each point in time. Among these factors are; bunker prices which are related to the price of oil and constitute more than half of

the variable costs in shipping operations, international commodity trade, and the world economic activity. Since a proportion of return on shipping investments is realised through operations and freight services, any uncertainty in future freight revenues is considered and incorporated in investors' decisions accordingly.

Findings in this chapter are in line with those of Kavussanos (1997) regarding the time varying volatility of return on second-hand dry bulk ships in the sense that the market for larger vessels fluctuates more than the market for smaller vessels. Our results in this study indicate that returns on shipping investments are positively related to the time varying variance of forecast errors, which is consistent with the capital asset pricing literature. Such risk-return relationship seems to be consistent across different size bulk carriers, but no clear pattern exists between the vessel size and the impact of risk on return on investments.

Further insight to the failure of PV model and the EMH in the market for dry bulk vessels can be gained if we look at the differences in investors' investment strategies in this sector of the economy, a problem known as the heterogeneous behaviour of investors in the finance literature. It can be argued that investors in the shipping industry can be divided in two main groups depending upon their investment strategies and horizons. The first group of investors known as speculators or asset players are those who participate in the sale and purchase market and rely more on capital gains rather than operational profits of vessels. These are normally private investors or small shipping companies with relatively short term investment horizon. On the other hand, there are investors who acquire vessels and operate them for long periods. These types of investors are more interested in operating profits rather than capital gains and are normally larger public or state owned shipping companies with relatively long horizon investment strategies.

The fact that investors may have heterogeneous behaviour and different investment objectives and horizons may contribute to the failure of the present value model and the EMH in the market for ships since investors may use different pricing models, discount factors or weights depending on their investment objectives and horizons.

7.7. Conclusions

The EMH in the formation of newbuilding and second-hand prices in the dry bulk sector is examined using different statistical tests. We also examined the existence of rational bubbles in the formation of ship prices. Results on cointegration tests reject the existence of rational bubbles in the market for ships. Our results, based on the VAR methodology, reject the EMH in the market for newbuilding and second-hand dry bulk vessels. In addition, it is found that excess returns on shipping investments (second-hand vessels) over LIBOR are highly predictable. This is also against the notion of informational efficiency of the market for merchant ships.

In the case of the market for second-hand ships, we attribute failure of the EMH to existence of time-varying risk premia, which are modelled using GARCH-M specifications. The results suggest that there is a positive relationship between time-varying risk and return on shipping investments, which is consistent with the asset pricing theories in the financial economics literature.

It has been argued that the time-varying volatility of ship prices and freight rates in the dry bulk sector, in conjunction with the profit maximisation behaviour of investors, imply that investors expect different returns on their investment at different points in time. It is also argued that heterogeneous behaviour of investors in terms of their investment strategies and objectives might be another factor, which contributes to the failure of the EMH, since the EMH requires homogeneous investment behaviour and pricing formulas across investors.

Appendix 7.A

Transformation of the present value model

The rational valuation formula, RVF, of equation (7.8), implies that price of an asset should be equal to its theoretical price; that is, the present value of the discounted future income generated by the asset. Therefore, according to the RVF, price of an asset can be written as the discounted present value of the expected price of the asset after 1 period plus the discounted present value of the profits during the holding period.

$$P_t = \left(\frac{E_t P_{t+1} + E_t \Pi_{t+1}}{1 + E_t R_{t+1}} \right) \quad (7.A.1)$$

and leading equation (7.A.1) forward by 1, 2, ..., periods results in

$$P_{t+1} = \left(\frac{E_t P_{t+2} + E_t \Pi_{t+2}}{1 + E_t R_{t+2}} \right), \quad P_{t+2} = \left(\frac{E_t P_{t+3} + E_t \Pi_{t+3}}{1 + E_t R_{t+3}} \right), \quad \dots$$

Assuming a finite economic life for the asset, and recursively substituting values of P_{t+1} , P_{t+2} , ..., in (7.A.1), P_t can be written as the sum of present value of the future profits plus the terminal (resale) value of the asset. Mathematically

$$P_t = \frac{E_t \Pi_{t+1}}{(1 + E_t R_{t+1})} + \frac{E_t \Pi_{t+2}}{(1 + E_t R_{t+1})(1 + E_t R_{t+2})} + \dots + \frac{E_t \Pi_{t+n}}{(1 + E_t R_{t+1}) \dots (1 + E_t R_{t+n})} + \frac{P_{t+n}^{sc}}{(1 + E_t R_{t+1}) \dots (1 + E_t R_{t+n})} \quad (7.A.2)$$

or

$$P_t = \sum_{i=1}^n \left(\prod_{j=1}^i (1 + E_t R_{t+j})^{-1} \right) E_t \Pi_{t+i} + \left(\prod_{j=1}^n (1 + E_t R_{t+j})^{-1} \right) E_t P_{t+n}^{sc} \quad (7.A.3)$$

Note that, although (7.A.1) can be written in logarithmic form as

$$\ln P_t = \ln(E_t P_{t+1} + E_t \Pi_{t+1}) - \ln(1 + E_t R_{t+1}) \quad (7.A.4)$$

it is not possible to perform recursive substitutions to write the log of price ($\ln P_t$) in terms of the log of discounted expected earnings and log of discounted expected terminal value of the asset. This is because the leading equation (7.A.4) by one period results in

$$\ln P_{t+1} = \ln(E_t P_{t+2} + E_t \Pi_{t+2}) - \ln(1 + E_t R_{t+2}) \quad (7.A.5)$$

which cannot be substituted in (7.A.4) as the first term on the right hand side of (7.A.4) is the log of the sum of P_{t+1} and Π_{t+1} .

However, Campbell and Shiller (1988) solve this problem by using first order Taylor series expansion and linearising (7.A.4) in the following form

$$\ln(1 + E_t R_{t+1}) = \ln(E_t P_{t+1} + E_t \Pi_{t+1}) - \ln P_t$$

around the geometric mean of P and Π (\bar{P} and $\bar{\Pi}$) to give

$$\ln(1 + E_t R_{t+1}) = \rho \ln(E_t P_{t+1}) + (1 - \rho) \ln(E_t \Pi_{t+1}) - \ln P_t + k \quad (7.A.6)$$

Where $\rho = \bar{P}/(\bar{P} + \bar{\Pi})$, $k = -\ln(\rho) - (1 - \rho)\ln(1/\rho - 1)$, therefore, letting $E_t p_{t+1} = \ln(E_t P_{t+1})$, $E_t r_{t+1} = \ln(1 + E_t R_{t+1})$ and $E_t \pi_{t+1} = \ln(E_t \Pi_{t+1})$ equation (7.A.6) can be written as

$$p_t = \rho E_t p_{t+1} + (1 - \rho) E_t \pi_{t+1} - r_{t+1} + k \quad (7.A.7)$$

Solving (7.A.7) forward yields

$$p_t = \sum_{i=0}^{n-1} \rho^i (1 - \rho) E_t \pi_{t+i+1} - \sum_{i=0}^{n-1} \rho^i E_t r_{t+i+1} + \rho^n E_t p_{t+n}^{sc} + k(1 - \rho^n)/(1 - \rho) \quad (7.A.8)$$

It is widely known that prices and operating profit series are nonstationary, therefore, equation (7.A.8) cannot be used directly to tests the validity of the RVF and EMH. Campbell and Shiller (1987 and 1988) suggest transforming (7.A.8) in such a way so as to derive a model with stationary variables, using cointegration relationships between the original variables. They suggest using the log price-dividend ratio (price-profits in our case), which

represents the spread between the log-price and the log-dividend series, to transform (7.A.8). Therefore, subtracting π_t from both sides of (7.A.8) results in

$$p_t - \pi_t = \sum_{i=0}^{n-1} \rho^i (1-\rho) E_t \pi_{t+1+i} - \pi_t - \sum_{i=0}^{n-1} \rho^i E_t r_{t+1+i} + \rho^n E_t p_{t+n}^{sc} + k(1-\rho^n)/(1-\rho) \quad (7.A.9)$$

which can be rearranged to yield

$$p_t - \pi_t = \sum_{i=0}^{n-1} \rho^i E_t \Delta \pi_{t+1+i} - \sum_{i=0}^{n-1} \rho^i E_t r_{t+1+i} + \rho^n (E_t p_{t+n}^{sc} - E_t \pi_{t+n}) + k(1-\rho^n)/(1-\rho) \quad (7.A.10)$$

or

$$p_t - \pi_t = \sum_{i=0}^{n-1} \rho^i (E_t \Delta \pi_{t+1+i} - E_t r_{t+1+i}) + \rho^n (E_t p_{t+n}^{sc} - E_t \pi_{t+n}) + k(1-\rho^n)/(1-\rho) \quad (7.A.11)$$

Thus, since $S_t = p_t - \pi_t$ and $S_t^{sc} = p_t^{sc} - \pi_t$; that is, log price-profit ratio and log scrap-price profit ratio, respectively, we can write

$$S_t = \sum_{i=0}^{n-1} \rho^i (E_t \Delta \pi_{t+1+i} - E_t r_{t+1+i}) + \rho^n E_t S_{t+n}^{sc} + k(1-\rho^n)/(1-\rho) \quad (7.A.12)$$

or

$$S_t = \sum_{i=0}^{n-1} \rho^i E_t \pi_{t+1+i} + \rho^n E_t S_{t+n}^{sc} + c \quad (7.A.12')$$

where $E_t \pi_{t+1+i} = E_t \Delta \pi_{t+1+i} - E_t r_{t+1+i}$ and $c = k(1-\rho^n)/(1-\rho)$. Furthermore, as $n \rightarrow \infty$, i.e. when the transversality condition holds, the second term on the RHS approaches zero and (7.A.12) can be written as

$$S_t = \sum_{i=0}^{\infty} \rho^i (E_t \Delta \pi_{t+1+i} - E_t r_{t+1+i}) + k/(1-\rho) \quad (7.A.13)$$

or

$$S_t = \sum_{i=0}^{\infty} \rho^i E_t \pi_{t+1+i} + k/(1-\rho) \quad (7.A.13')$$

It can be seen that if the log of price and operating profit series are $I(1)$, then the LHS variables in (7.A.12), the log price-profit ratios, $S_t = p_t - \pi_t$ and $S_t^{sc} = p_t^{sc} - \pi_t$, might be stationary since they would be a linear combination of two nonstationary variables, p_t and d_t , which may form cointegrating relationships. Therefore, if the term on the LHS and the second term on the RHS of (7.A.12) form two cointegrating relationships, then all terms in (7.A.12) will be stationary and the model can be used to test the EMH in price formation directly.

Appendix 7.B

The PV model and EMH restrictions on the 3-variable VAR model

The following set of nonlinear cross equation restrictions on the VAR model (equation (7.35) in the text) are derived for the validity of the present value model and the EMH, when assets have finite economic life.

$$\mathbf{e1} = \mathbf{e2A}(\mathbf{I} - \rho\mathbf{A})^{-1}(\mathbf{I} - \rho^n\mathbf{A}^n) + \rho^n\mathbf{e3A}^n \quad (7.B.1)$$

where, $\mathbf{e1}$, $\mathbf{e2}$ and $\mathbf{e3}$ are selection vectors, \mathbf{A} is the companion matrix of the VAR model, ρ is the coefficient of linearisation, and n is the holding period. Assuming one period investments; i.e. $n=1$, equation (7.B.1) can be written as

$$\mathbf{e1} = \mathbf{e2A} + \rho\mathbf{e3A} \quad (7.B.2)$$

or

$$\begin{pmatrix} 1 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} + \rho \begin{pmatrix} 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \quad (7.B.3)$$

This can be simplified to yield the following restrictions

$$a_{21} + \rho a_{31} = 1, \quad a_{22} + \rho a_{32} = 0, \quad a_{23} + \rho a_{33} = 0 \quad (7.B.4)$$

On the other hand, the RVF implies that the price of an asset, P_t , with finite economic life should be equal to the discounted present value of the expected future income generated by the asset, Π_t , plus the discounted present value of its resale price (scrap price), P_t^{SC} . In the case of the market for ships, considering Campbell and Shiller's (1988) log transformation of equation (7.A.12), assuming $n=1$, we can write

$$S_t = E_t \pi r_{t+1} + \rho E_t S_{t+1}^{SC} + k \quad (7.B.5)$$

which can be expanded to result in the log linear version of the PV model for one period

$$p_t = \rho E_t p_{t+1}^{SC} + (1 - \rho) E_t \pi_{t+1} - r_{t+1} + k \quad (7.B.6)$$

Where p_t and $E_t p_{t+1}^{SC}$ are logs of second-hand prices and expected resale (scrap) values of the vessel, respectively. $E_t \pi_{t+1}$ represents the log of operational profits generated from t to $t+1$. Assuming a VAR(1) forecasting scheme, which is outlined in section 7.2.3.2, equation (7.30), one can estimate the expected values of ES_{t+1}^{SC} and $E_t \pi_{t+1}$ as follows

$$\begin{pmatrix} S_{t+1} \\ dr_{t+1} \\ S_{t+1}^{SC} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} S_t \\ dr_t \\ S_t^{SC} \end{pmatrix} \quad (7.B.7)$$

which can be written as

$$\begin{cases} S_{t+1} = a_{11}(p_t - \pi_t) + a_{12}(\pi_t) + a_{13}(p_t^{SC} - \pi_t) \\ \pi_{t+1} = a_{21}(p_t - \pi_t) + a_{22}(\pi_t) + a_{23}(p_t^{SC} - \pi_t) \\ S_{t+1}^{SC} = a_{31}(p_t - \pi_t) + a_{32}(\pi_t) + a_{33}(p_t^{SC} - \pi_t) \end{cases} \quad (7.B.8)$$

Using prediction form the above VAR, we can substitute equivalents of ES_{t+1}^{SC} and $E_t \pi_{t+1}$ in (7.B.6), ($S_t = E_t \pi_{t+1} + \rho E_t S_{t+1}^{SC} + k$), to obtain

$$S_t = a_{21}(S_t) + a_{22}(\pi_t) + a_{23}(S_t^{SC}) + \rho[a_{31}(S_t) + a_{32}(\pi_t) + a_{33}(S_t^{SC})] \quad (7.B.9)$$

and since $S_t = p_t - \pi_t$, $S_t^{SC} = p_t^{SC} - \pi_t$ and $\pi_t = \pi_t - \pi_{t-1} - r_t$, (7.B.9) can be simplified further to yield

$$\begin{aligned} p_t(1 - a_{21} - \rho a_{31}) - \pi_t((1 - a_{21} - \rho a_{31}) + (a_{22} + \rho a_{32}) - (a_{23} + \rho a_{33})) \\ - p_t^{SC}(a_{23} + \rho a_{33}) + \pi_{t-1}(a_{22} + \rho a_{32}) + r_t(a_{22} + \rho a_{32}) = 0 \end{aligned} \quad (7.B.10)$$

The above equation indicates that for the present value model and the EMH to be valid, the set of restrictions specified in (7.B.4) should hold.

Appendix 7.C

West (1987) test for Rational Bubbles

West (1987) proposes a test for the existence of rational bubbles in stock prices. This test involves estimating certain parameters in the relationship between price and dividend (operating profits) series using two alternative methods, which are shown bellow. He shows that under the null hypothesis of no bubble, parameter estimates of both methods should not be statistically different. Therefore, the test involves three steps. In the first step, an instrumental variable method is used to estimate the constant discount factor, δ , in the Euler equation (7.11), derived in section 7.2.3,

$$P_t = \delta(E_t P_{t+1} + E_t \Pi_{t+1}) \quad (7.C.1)$$

Where lagged price and profit series can be used as instruments. In the second step, assuming an AR(1) model for operating profit series (dividends), we can write

$$\Pi_t = \alpha_\Pi + \beta_\Pi \Pi_{t-1} + e_t \quad (7.C.2)$$

where $\hat{\alpha}_\Pi$ and $\hat{\beta}_\Pi$ can be estimated using OLS. If there is no bubble, then actual price (P_t) will be equal to the theoretical price (P'_t), $P_t = P'_t$, and the RVF of (7.C.1) and (7.C.2) give¹⁹

$$P_t = P'_t = \varphi + \psi \Pi_t + u_t \quad (7.C.3)$$

Where

$$\psi = \beta_\Pi / (1 + R - \beta_\Pi) = \beta_\Pi \delta / (1 - \beta_\Pi \delta) \quad (7.C.3')$$

$$\varphi = \alpha_\Pi \psi / R \delta \beta_\Pi = \alpha_\Pi \delta / (1 - \delta)(1 - \beta_\Pi \delta) \quad (7.C.3'')$$

OLS estimation of (7.C.2) and (7.C.3) provide consistent estimates of $\hat{\alpha}_\Pi$, $\hat{\beta}_\Pi$, $\hat{\varphi}$ and $\hat{\psi}$ (see West, 1987, and Mills, 1993). However, if there is a bubble, then

¹⁹ Note that (7.C.3) is derived through substituting recursive forecasts of Π_{t+h} from (7.C.2) in (7.13) or (7.C.1).

$$P_t = P'_t + B_t = \varphi + \psi \Pi_t + B_t \quad (7.C.4)$$

and, therefore, OLS estimates of (7.C.3) does not yield consistent estimates since the equation suffers from omitted variable problem. However, West argues that even when bubbles are present, a consistent estimate of δ is provided by the instrumental variable estimate of $\tilde{\delta}$ obtained from (7.C.1). Therefore, he proposes to compare the two implied estimates of φ and ψ with their counterparts calculated from (7.C.3') and (7.C.3''), in the following way

$$\begin{aligned} H_0 : \hat{\psi} &= \beta_{\Pi} \tilde{\delta} / (1 - \beta_{\Pi} \tilde{\delta}) \\ \hat{\varphi} &= \alpha_{\Pi} \tilde{\delta} / (1 - \tilde{\delta})(1 - \beta_{\Pi} \tilde{\delta}) \end{aligned} \quad (7.C.5)$$

Thus, a Wald type test can be performed on parameter estimates of (7.C.3) in order to test for the existence of rational bubbles. This has a $\chi^2(2)$ distribution. Rejection of the null implies the existence of rational bubbles. The main advantage of this approach is that the specific parameterisation of the rational bubble is not required.

West (1987) shows that this test is robust to the specification of the model selected for the determination of operating profits (dividends), equation (7.C.2). He also finds that the test is subjected to the type II error and may reject the null of no bubbles when it is true. This is because of the assumption of constant discount rates as such assumption may cause a bias in estimated values.

8. CHAPTER EIGHT

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

8.1 Introduction

This chapter summarises the thesis, including findings and main conclusions and offers suggestions for future research. The main subject of the thesis was to study the efficiency of the dry bulk shipping sector in size-disaggregated form. This is because it is believed that the dry bulk market is separated into different sectors due to the transportation requirements of the agents as well as the differentiation in commodity parcel size and trading routes over the globe. Considering such market segmentation in the analysis of the sector is important since different underlying supply and demand factors in each sub-market have different impacts on freight rate and price movements as well as their relationships.

The empirical research has been directed to cover four main areas. These areas include; univariate properties of dry bulk freight rates including seasonality issues, the relationship between spot and period charter contracts, the dynamic interrelationships between freight rates for different size dry bulk carriers, spillover effects between freight rates volatilities, and finally the efficiency of pricing in the market for second-hand and newbuilding vessels. Each area is investigated in detail and the empirical results of different sub-sectors are compared to provide further insight into the complex nature of this industry.

Throughout the analyses we have provided new evidence and insights on the behaviour of freight rates and ship prices as well as the dynamic interrelationships between freight rates for different size vessels. These areas are of interest not only to ship operators, shipowners and charterers but also to those who are involved in financing this industry. The study is also of interest to those involved in modelling and forecasting shipping variables as our results, which are derived using modern econometric and time series techniques, revealed important information (such as the seasonal behaviour of dry bulk freight rates and the importance risk in the formation of prices and freight rates) for modelling and formulating economic relationships in the industry.

The structure of this chapter is as follows. Section 8.2 offers a summary of the thesis. Section 8.3 discusses important findings and their implications. The limitations of the study and suggestions for future research are the subject of the last section.

8.2 Summary of the thesis and conclusions

In chapter one, after an introduction to the dry bulk shipping industry, we discussed recent developments in the market, including influential factors that lead to the market segmentation, dynamics of supply and demand for different size vessels, and different types of shipping contracts and their cost structures. We also discussed different conditions under which a market is thought to be perfectly competitive and argued that such conditions are a predominant feature of the freight market and the market for vessels. A section was also devoted to describing the data collection, processing and reporting in the shipping industry. Finally those areas, which needed further investigation, were identified and objectives of the thesis were highlighted.

The second chapter reviewed the relevant studies in the literature on investigating the formation and the validity of the expectations hypothesis and the EMH in determination of freight rates and ship prices. This critical review is carried out in a structured way in order to identify shortcomings in those studies and highlight the areas, which needed further investigation. The review of the literature covered early econometric studies of the shipping industry. Empirical research on the formation of long term freight rates, the expectations hypothesis and validity of the EMH in determination of ship prices were also presented and discussed. We also discussed recent studies on time series models used to investigate the dynamics of freight rate and price volatilities.

In the third chapter details of different econometric and time series techniques, which are used throughout the thesis, were discussed. Models for investigating univariate properties of time series, including stationarity and unit root tests, seasonality and seasonal unit roots were explained. Topics on multivariate analysis of time series such as VAR models, cointegration techniques and impulse response analysis were also presented. Finally, recently developed ARCH and GARCH models, which are used to estimate time-varying volatilities of time series along with some important specification and estimation issues were discussed.

Having explained the research theme in the first chapter, reviewed the relevant literature in the second chapter and discussed the econometric methodology in the third chapter, subsequent chapters are devoted to the results.

Thus, in chapter 4 we investigated the stochastic properties of spot and 1-year and 3-time-charter rates, including the existence and type of seasonality in freight rates for each type of contract. Freight rates were found to have a unit root at zero frequency, but not at seasonal frequencies for the period examined. This by itself suggests that ARIMA and VAR models (in the form of the VECM, if they are cointegrated) are appropriate when modelling the series. In addition, having rejected the existence of stochastic seasonality (that is, nonstationarity at seasonal frequencies), it was found that there is significant deterministic seasonality, i.e. regular seasonal patterns.

Careful consideration of seasonal patterns reveals that, while deterministic seasonal movements show similarities across vessel sizes and duration of contract, there are conspicuous differences too. Regular seasonal patterns are attributed to the nature and pattern of the trade in commodities transported by these ships. For example, it is argued that the increase in spot and period rates across vessel size during the spring is due to the harvest season in the Southern Hemisphere, while the decline in rates during June and July is due to the slowdown in industrial activity and the holiday season in the Northern Hemisphere.

The differences between seasonal variation in freight rates for different size vessels are thought to be emanating from factors that sub-divide the dry bulk sector, such as ship size, vessel flexibility, route and commodity parcel sizes. It was also found that, spot rates for larger vessels exhibit higher seasonal fluctuations, however, differences between sectors are eliminated as the contract duration increases. Furthermore, for each vessel size, the seasonality declines as the contract duration increases. Results also provide evidence of asymmetric seasonal behaviour of freight rates under different market conditions. It is found that seasonal fluctuations are sharper and more pronounced during market recoveries, which is in contrast to periods when the market is deteriorating. This is in line with the theory of shipping freight rate formation and is caused by the shape of the supply schedule in the market equilibrium model.

Chapter 5 examined the relationship between spot and time-charter rates across the three size vessels, capesize, panamax and handysize. The validity of the EHTS in the formation of period rates for each size vessel is examined. The EHTS asserts that the discounted earnings from a period charter contract should be equal to the discounted earnings from series of spot contracts within the life of the period charter contract. The theory stems from the EMH, which implies that rational and informed market participants (charterers and shipowners) arbitrage away, any excess earnings by switching between different types of contract; i.e. spot and time-charter.

It is important to investigate the validity of the EHTS, since its failure may signal opportunities to make excess profits by switching between shipping contracts with different duration, if there is no risk premium involved. Therefore, different testing procedures such as “perfect foresight spread”, cointegration, and non-linear restrictions on the VAR model, proposed by Campbell and Shiller (1987 and 1991), were used to test the validity of the EHTS in the formation of 1-year and 3-year time-charter rates. The methods proposed by Campbell and Shiller (1987 and 1991) take into account the univariate properties of the series and as a result provide more appropriate tests compared to other methods.

In general, it was found that the results do not support the EHTS for the period 1980 to 1997. However, this failure is attributed to shipowners’ perceptions of risk regarding their decision to operate in spot or time-charter markets. Shipowners consider the relative future uncertainty surrounding the spot market and are prepared to accept a discount in order to secure a contract with longer duration. The higher uncertainty in the spot market compared to long term time-charter contracts is thought to emanate from higher freight rate volatilities in spot markets, vessel relocation costs, risk of unemployment in spot operation, and fluctuations in voyage costs.

Time-varying risk premia have been modelled using EGARCH-M volatility models which relate the excess discounted earnings from time-charter over spot operations to the volatility of forecast errors. Consistent negative relationships between time-varying volatilities and excess earnings across different size vessels suggests that during periods of high (market) uncertainty, shipowners are willing to accept lower time-charter rates in order to secure their vessels for longer periods of time. Correspondingly, when the market seems to be stable, shipowners demand higher time-charter rates. Also, comparison of risk premia across vessel

sizes suggests that larger premia are required in the market for larger vessels to compensate the higher risks involved in operating these vessels in the spot market, as the sums involved are larger compared to smaller ships. However, no clear pattern is observed on risk premia across contracts of different duration.

Our results on risk premia in shipping markets are found to be in contrast to those found in money markets, where short term rates are thought to be more secure and investors are rewarded when taking risks in investing in long term rates. Thus, in every market, risk-averse investors price the uncertainty and are prepared to pay a premium for security. Also, from the econometric point of view, our findings suggest that modelling and forecasting shipping period rates, solely on the basis of the EHTS, is not appropriate and factors which account for agents' perception of risk and future market conditions should also be considered and incorporated in the model.

The subject matter of chapter 6 is analysis of the dynamic interrelationships between freight rates for different size carriers as well as the spillover effects between freight rate volatilities in spot and period markets. Having found that freight rates are nonstationary, we used cointegration relationships between freight rates to specify a VECM for each of the spot, 1-year and 3-year charter markets. Generalised impulse response, GIR, analysis on VECM's in each market is used to trace the effects of shocks to each variable on other series in the model. A multivariate GARCH specification (BEKK), which allows for spillover effects in the variance, was also used to model dynamics of freight rate volatilities and spillover effects in each market. Our findings can be summarised as follows.

Freight rates for different size ships in each of the spot, 1-year and 3-year charter markets are related in the long run through cointegrating relationships. GIR analyses on VECM's revealed that shocks to freight rates for one size are transmitted to freight rates for other sizes. Freight rates across the market then adjust to new levels and restore the equilibrium between rates. The adjustment of freight rates to their new levels after a shock seems to be faster in the spot market (after 5 to 10 months) compared to time-charter markets where the full impact of shocks on freight rate levels is observed after approximately 10 to 15 months. Permanent changes in freight rate levels after a shock are attributed to the fact that freight rates are nonstationary and retain the effect of shocks for long periods. Transmissions of shocks to

freight rates for one size to freight rates for other size vessels are explained by the fact freight rates are interrelated in each market through cointegrating relationships.

GIRs on cointegrating vectors also indicate that system-wide shocks are eliminated faster in the spot market in comparison to the time-charter market; that is, cointegrating vectors in the spot market return to their long run equilibrium faster than cointegrating vectors in time-charter markets. This is in line with the above observation on adjustment of freight rate levels to shocks and suggests that the interaction between different sizes is higher in the spot market compared to the time-charter market. The sluggishness in the response of cointegrating vectors to system-wide shocks in time-charter markets is attributed to the lower degree of substitution between different size vessels in time-charter markets, as opposed to the spot market. This suggests that agents are more concerned about the size of the vessel when it comes to period contracts due to the cost and time horizon involved. More precisely, since in time-charter contracts, the charterer is responsible for the voyage costs and the purpose of such contracts is to employ the vessel in certain routes or trade for a period of time, charterers choose an optimal size of vessel which meets their requirements at minimum costs. Contrary to that, in the spot market, it is only a single voyage that the vessel has to undertake with voyage costs being the shipowners' responsibility, resulting in charterers not being so concerned about the size of the vessel as long as route, and loading and discharging ports specifications allow.

Regarding the interaction between freight rate volatilities, it is found that there are volatility spillovers from capesize to panamax rates in the spot market and in the 3-year time-charter market with feedback effects from panamax to capesize volatilities in the 3-year time-charter market. Volatility spillovers in the 1-year time-charter market are found to be from capesize rates to handysize rates only. In general, results on volatility spillovers in each of the spot and period markets examined suggest that the direction of information is from larger to smaller size vessels.

In general, results on the interrelationships between freight rates for different size carriers in the spot and period markets indicate that the direction of information flow on the short run dynamics of freight rates is from the market for small vessels to the market for large vessels. However, significant volatility spillovers are found in an opposite direction; that is, from the market for capesize vessels to the market for panamax and handysize vessels.

The aim of the last empirical chapter in the thesis was to investigate the efficient pricing of second-hand and newbuilding vessel prices. The EMH postulates that prices in an efficient market fully and instantaneously incorporate all available information and therefore there are no riskless opportunities to make any profit in excess of what rational investors expect to make. It is important to investigate whether the market for ships is efficient for two reasons. First, as mentioned the failure of the EMH, if it is not due to the existence of time-varying risk premia, may suggest the existence of excess profit making opportunities in the market. Second, the validity or failure of the EMH in the market for ships has important implications when modelling and forecasting ship prices.

We employed different approaches, used in the financial economics literature, to investigate the validity of the EMH in a market where the real assets, ships with limited economic life, are priced and exchanged. Two different implications of the EMH are formulated to investigate the validity of the theory in the market for ships. The first implication asserts that under the EMH the price of a newbuilding or second-hand vessel already incorporates all relevant information and the only reason for prices to change is the arrival of new information. This in turn implies that the difference between the actual returns (or actual prices) at $t+1$ and the expected returns (expected prices) at $t+1$, i.e. forecast errors $\varepsilon_{t+1} = r_{t+1} - E_t r_{t+1}$, should be independent of the information available at time t . Thus, a direct test for the EMH is to investigate whether forecast errors, ε_{t+1} , are predictable. The EMH also implies that newbuilding or second-hand prices should reflect the fundamental value of the vessel, which is assumed to be the sum of discounted present values of expected operating profits plus the discounted present value of the expected residual value of the vessel. Therefore, a second test of the EMH is to investigate whether prices are equal to their fundamentals.

Tests related to the unpredictability of returns on ships, restrictions placed on coefficients of the VAR model, and variance ratio tests (Campbell and Shiller 1987 and 1988) fail to provide support for price efficiency and the present value model. In seeking an explanation for this failure, it is found that risk and return on shipping investment are related through GARCH-M models, where the excess holding period returns on second-hand vessels are related to the variance of the excess returns' forecast errors. Thus, in the case of second-hand ship prices,

failure of the EMH is attributed to existence of time-varying risk premia. It has been argued that time varying volatility of ship prices and freight rates in the dry bulk sector, in conjunction with the profit maximisation behaviour of investors, imply that investors expect different returns on their investments at different points in time. It is also argued that heterogeneous behaviour of investors in terms of their investment strategies and objectives might be another factor which contributes to the failure of the EMH since the EMH requires homogeneous investment behaviour and pricing formulas across investors.

8.3 Main findings and policy implications

The aim of this section is to discuss policy implications for each of the findings summarised in the previous section.

8.3.1. Seasonal patterns in dry bulk freight markets

Our results on seasonality patterns in dry bulk freight markets revealed that freight rates increase during early spring, i.e. March and April, and drop sharply in June and July. Panamax and handysize spot rates also show a rise in the autumn months. The contrast between seasonal variations in freight rates for different size carriers provides an incentive for multi-vessel companies to diversify and extend their investments to vessels of different sizes, as well as operate vessels under contracts of different duration; such strategy would reduce their exposure to seasonal fluctuations of the freight market during the year.

Other important implications of the results regarding the economic operation of ships, in the presence of seasonal fluctuations in shipping markets, are as follows. First, shipowners may use information on the seasonal movements of freight markets in order to make decisions such as sending the ship to dry-dock in seasons that freight rates are expected to fall (e.g. July and August in the dry bulk market). They can also adjust the speed to increase productivity during peak seasons (e.g. March, April and May in the dry bulk market). Second, shipowners (charterers) might be able to secure their cash flow (transportation costs) against the seasonal movements in the market using futures contracts such as the BIFFEX. Third, shipowners might be able to maximise their revenue, in the long run, by entering into the time-charter

market during peak seasons (for example, March, April and May). The results also suggest that, in the long run, for a shipowner operating in the time-charter market, renewing time-charter contracts in peak seasons (e.g. March and April and May for handysize dry bulk carriers) may increase the revenue substantially. However, to what extent these type of decisions and short run speculative strategies, based on the seasonal movements of the freight rates, can be implemented and increase the shipowners wealth is a matter of further research.

8.3.2. The expectations hypothesis and risk premia in period markets

Our results on the relationship between spot and time-charter rates for each vessel size indicate that spot and time-charter rates move together in the long run. However, due to risk factors, the relationship between the two rates is not in line with what the EHTS would lead us to expect. The fact that short term and long term rates are cointegrated suggests that at any point in time, the spread between the two charter rates contains information on future movements of at least one of them. Therefore, shipowners, operators and charterers might be able to base their chartering strategies on the spread between the short and long term rates. For example, when the spread is larger than its long run average, it means that either spot rates are too high and are likely to fall or period rates are too low and are likely to increase in to bring back the spread to its long run average. This can be used as signal to switch between contracts.

Also, comparison between the actual and the theoretical (estimated using the VAR) spread series at any point in time may be used for chartering strategies and selecting between spot or time-charter contracts. This is because the difference between the two spreads reflects the amount by which time-charter rates are miss-priced. For example, when actual spread is greater than the theoretical spread ($S_t = TC_t - FR_t > S^*_t$), it means that time-charter rates are over priced with respect to their theoretical counterparts. Thus, it is more profitable for risk neutral shipowners to fix time-charter contracts than operating in the spot market as expected earning from spot operations are lower than the earnings form time-charter operations. On the other hand, when actual spread is less than the theoretical spread ($S_t = TC_t - FR_t < S^*_t$), it means that operational earnings are higher in the spot market compared to the time-charter market. Such information may be used by risk neutral ship

operators to generate excess revenue by hiring in and out vessels under different contracts. For example, when time-charter rates are under-priced, operators may time-charter vessels and operate them in the spot market.

Furthermore, the EGARCH-M model presented in chapter 5 can be used by agents to predict the level of risk in spot market operations at any point in time. They may base their decisions on operating in either spot or time-charter markets or switch between them, on predicted time-varying risk. Also, companies with large fleets or charterers hiring several vessels may use the results to adjust their chartering portfolios (hire or employ vessels under contracts with different duration) to optimise their risk and revenues.

From the econometric point of view our results revealed that it is important to incorporate risk factors when modelling period charter rates or considering the relationship between long term and short term rates. Results in chapter 5 suggest that excluding the risk factor in the relationship between spot and time-charter rates may result in misspecified models and consequently misleading conclusions and forecasts.

8.3.3. Interrelationship between freight rates and their volatilities across vessel sizes

Our findings on the interrelationships between freight rates for different size carriers in the spot, in conjunction with the results of chapter 5, suggest that spot rates for each size vessel not only respond to developments in the period market for the same size vessel (chapter 5), but also to the developments in the spot market for other size categories. The same argument is also true for time-charter rates for each size as they respond to both spot rates for the same size vessels and time-charter rates for other size vessels. This, in conjunction with the findings in chapter 4 on stochastic properties of freight rates suggests that multivariate models such as VAR and VECM models should be used for analysis and forecasting freight rates in shipping markets.

Results of GIR on freight rates for different size vessels in VECM settings confirm the stochastic properties of freight rates as shocks to freight rates persist, but due to cointegrating property of freight rates and the existence of long run relationships between them, the system restores its equilibrium.

Regarding the direction of the information flow, it is found that the market for smaller vessels is the leading freight market. This might be due to the operational diversity of smaller vessels and the fact that they are involved in transportation of variety of commodities. This enables them to pick up signals on change in international seaborne trade before the larger vessels, as larger vessels are involved in transportation of a limited number of commodities. Therefore, operators and owners of large vessels need to monitor changes in the market for small vessels and utilise any information to improve their operations, especially chartering strategies.

It is also found that shocks to freight rates for larger vessels disseminate and affect volatility of freight rates for smaller vessels. This suggests that agents operating in the market for smaller size vessels may be able to use the information regarding the volatility of freight rate for larger vessels to predict the volatility of the market that they are operating in and base their decision on the such information. In particular, events and unexpected changes in the capesize market can be monitored and used to improve hedging. For example, as increase in volatility of freight rates for capesize vessels is expected to be transmitted to the market for panamax and handysize vessels, operators and charters practicing risk management, may foresee and measure the extent to which their financial positions will be affected and take measure accordingly.

8.3.4. The efficient market hypothesis and the markets for dry bulk vessels

The results of our investigation in chapter 7 on the efficiency of price formation for second-hand and newbuilding vessels also have important policy implications. We found that the EMH in the market for second-hand and newbuilding dry bulk vessels does not hold. Excess returns on shipping investments are directly related to the level of risk at any point in time. Therefore, for risk neutral investors, the fact that there are inefficiencies in the market suggests that there are opportunities to make excess profits. Exploiting such opportunities requires switching from owning-operating to chartering-operating and vice versa, at right times. The following explanation is aimed to provide some insight as to how the results might be used to build trading strategies in order to exploit such opportunities.

The existence of cointegrating relationships between operational earnings and ship prices suggests that the spread between prices and operational earnings (or freight rates), which

contains information on future movements of prices, may be used as an indicator for investment strategies. For example, when the spread is above its long run average, it means that prices are greater than their theoretical counterparts; that is, vessels are overvalued. Therefore, they are bound to decrease in order to restore the long run equilibrium between prices and operating profits. Hence, agents are better off chartering vessels and operating them rather than investing on vessels. On the other hand, when the spread is below its long run average, it indicates that actual prices are less than their theoretical counterparts. In other words, vessels are undervalued. Thus, investing in vessels might be profitable since prices are bound to increase while the freight market is in good condition.

In addition, comparisons between the actual spread, $S_t = p_t - \pi_t$, and the theoretical spread estimated using the VAR model, S_t^* , at any point in time, indicates that to what extent ship prices differ from their theoretical values. Thus, when the actual spread is greater than the theoretical spread, $S_t = p_t - \pi_t > S_t^*$, it means that ships are over-priced compared to their operational profitabilities. On the other hand, when the actual spread is less than the predicted theoretical spread, $S_t = p_t - \pi_t < S_t^*$, it means that vessels are undervalued compared to their future profitability. Furthermore, it should be noted that the magnitude of the difference between S_t and S_t^* can also be used as an indicator for timing such trading strategies.

8.4 Limitations of the study and suggestions for future research

Empirical investigations on different topics presented in chapters 4 to 7 of this thesis, although quite comprehensive, are subjected to certain limitations due to space constraints and availability of data. Therefore, the aim of this section is to highlight such limitations and suggest directions in which future research can be undertaken to improve and enhance our knowledge in the area of shipping economics.

The theme of the research in this thesis was to examine four main areas in the dry bulk sector. In particular; i) the univariate behaviour of freight series, including seasonality, ii) the relationship between spot and time-charter rates in each sub-sector of the dry bulk market, iii) the dynamic interrelationships between freight rates for different size carriers and spillover

effects between freight rate volatilities in each of the spot and period markets, iv) and finally the efficiency of the market for second-hand and newbuilding vessel prices.

We investigated the seasonality of freight rates and compared them over contracts with different terms to maturity. One possible extension is to perform similar analyses to freight rates over different routes. This type of analysis is interesting since one might be able to compare seasonal patterns across different trading routes and use such information to forecast freight rates in individual shipping routes. We also argued that charterers and shipowners might exploit seasonal fluctuations in freight rates. However, to what extent these type of decisions and short run speculative strategies, based on the seasonal movements of the freight rates, can be implemented and increase the shipowners wealth is also a matter of further investigation.

We restricted our investigation to testing the expectations hypothesis of the term structure and the existence of risk premia in the formation of 1-year and 3-year time-charter rates. Further analysis can be performed on period rates with different terms to maturity (e.g. 3-month, 6-month, 2-year time-charter rates) and high frequency data (e.g. weekly observations). This kind of analysis can shed more light on the relationship between spot and time-charter rates across the maturity spectrum. Furthermore, future research may be conducted to test the importance of different variables such as back-log tonnage in shipbuilding, expected lay-up rates, volatility of voyage costs, etc. in explaining time-varying risk premia in the formation of period rates in freight markets.

We examined the spill over effects between freight rate volatilities for different size vessels in each of the spot and time-charter markets in chapter 6. An interesting area for future research is to extend such study by investigating volatility spillovers between different dry bulk routes. This might be of interest for two reasons. First, there might be stronger evidence on volatility spillovers between different dry bulk routes since there are certain routes which are served by one size vessel, therefore, freight rates in those routes are expected to be closely related to each other. Second, information on volatility spillovers might be of interest to the agents operating in the dry bulk market since they may be able to use such information for hedging purposes and reduce their risk using freight futures contract.

With regard to the EMH and the market for ships, a potential area of further research is to investigate whether technical trading and switching strategies, based on criteria explained in the previous section (i.e. utilising the difference between actual and theoretical spreads or the cointegrating relationships between price and operating profits), outperforms the buy and hold strategies. Furthermore, one may extend these results and use the risk-return model developed in chapter 7 to forecast ship prices and compare those with forecasts from alternative models developed in the literature.

It is also interesting to extend the analysis performed in this thesis to other shipping sectors, e.g. the tanker market, to see whether our findings are general enough to explain the behaviour of other sectors of the shipping industry.

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